Evolution of the Landscape of Madeira Island
Long-term vegetation dynamics

DOCTORAL THESIS

Aida Maria Correia de Nóbrega Pupo Correia

DOCTORATE IN BIOLOGICAL SCIENCES

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“The further backward you look the further forward you can see”

W. Churchill

Abstract

The aim of this thesis was to evaluate historical change of the landscape of Madeira Island and to assess spatial and temporal vegetation dynamics. In current research diverse “retrospective techniques”, such as landscape repeat photography, dendrochronology, and research of historical records were used. These, combined with vegetation *relevés*, aimed to gather information about landscape change, disturbance history, and vegetation successional patterns. It was found that landscape change, throughout 125 years, was higher in the last five decades manly driven by farming abandonment, building growth and exotic vegetation coverage increase. Pristine vegetation was greatly destroyed since early settlement and by the end of the nineteenth century native vegetation was highly devastated due to recurrent antropogenic disturbances. These actions also helped to block plant succession and to modify floristical assemblages, affecting as well as species richness. In places with less hemeroby, although significant growth of vegetation of lower seral stages was detected, the vegetation of most mature stages headed towards unbalance between recovery and loss, being also very vulnerable to exotic species encroachment. Recovery by native vegetation also occurred in areas formerly occupied by exotic plants and agriculture but it was almost negligible. Vegetation recovery followed the successional model currently proposed, attesting the model itself. Yet, succession was slower than espected, due to lack of favourable conditions and to recurrent disturbances. Probable *tempus* of each seral stage was obtained by growth rates of woody taxa estimated through dendrochronology. The exotic trees which were the dominant trees in the past (*Castanea sativa* and *Pinus pinaster*) almost vanished. *Eucalyptus globulus*, the current main tree of the exotic forest is being replaced by other cover types as *Acacia mearnsii.* The latter, along with *Arundo donax, Cytisus scoparius* and *Pittosporum undulatum* are currently the exotic species with higher invasive behaviour. However, many other exotic species have also proved to be highly pervasive and came together with the ones referred above to prevent native vegetation regeneration, to diminish biological diversity, and to block early successional phases delaying native forest recovery.

Key words: Landscape, Repeat photography, Vegetation long-term dynamics, Dendrochronology, Phytosociology, Madeira Island

Resumo

O objectivo desta tese foi o de avaliar a alteração histórica da paisagem da ilha da Madeira e analisar a dinâmica espacial e temporal da vegetação. Neste trabalho recorreu-se a “técnicas retrospectivas”, como a Fotografia repetida da paisagem, dendrocronologia e pesquisa de documentação histórica a par de inventários de vegetação (relevés), de modo a obter informação não só acerca da alteração paisagem mas também sobre a história dos distúrbios e os padrões de sucessão da vegetação. Verificou-se que a alteração da paisagem durante 125 anos foi maior nos últimos cinquenta anos principalmente provocada pelo abandono agrícola, aumento da construção e aumento da cobertura com exóticas. A vegetação pristina foi sendo destruída desde o povoamento e encontrava-se praticamente devastada no final do século XIX, devido aos distúrbios recorrentes que ajudaram bloquear a recuperação e modificaram a composição florística e a riqueza de espécies. Em locais de menor hemerobia, embora tenha sido detectada uma elevada recuperação das comunidades das etapas iniciais, as etapas mais maduras mostraram um desequilíbrio entre as taxas de recuperação e perda, sendo bastante vulneráveis à invasão por exóticas. A recuperação da vegetação nativa em áreas invadidas por exóticas e de abandono agrícola foi praticamente ínfima. Embora a recuperação seguisse o modelo de vegetação actualmente proposto, apoiando o próprio modelo, essa recuperação foi muito lenta devido à falta de condições locais e aos distúrbios recorrentes. O t*empus* de algumas das etapas da sucessão foi obtido a partir das taxas de crescimento de espécies lenhosas, estimadas por dendrocronologia. As árvores exóticas que foram dominantes no passado (*Castanea sativa* e *Pinus pinaster*) quase desapareceram. *Eucalyptus globulus*, a árvore principal da floresta exótica começa a ser substituída por outro tipo de coberto, principalmente *Acacia mearnsii.* Esta última juntamente com *Arundo donax, Cytisus scoparius* e *Pittosporum undulatum* são actualmente as espécies que apresentam um comportamento mais invasor, embora muitas outras espécies exóticas tenham sido também assinaladas como invasoras e responsáveis por impedir a regeneração da vegetação, diminuindo a diversidade biológica, impedindo o desenvolvimento de etapas subseriais e atrasando a recuperação da floresta nativa.

Palavras chave: Paisagem, Fotografia repetida, dinâmica da vegetação a longo prazo, dendrocronologia, fitossociologia, Ilha da Madeira.

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List of abbreviations

a.s.l. – above sea level

ca. - from *circa*, in Latin, meaning “approximately”, “around”.

e.g. - from *exempli gratia*, in Latin, meaning “for example”.

et al. – from *et alia* or *et aliores*, in latin, meaning “and others”. It is used to shorten lists of author names in text citations or authors describing a new taxon.

i.e. – from *id est*, in latin, meaning “that is”.

GIS – Acronym of Geographic Information System, a system to capture, store, and analyse all type of spatial or geographical data.

GPS – Acronym of Global Positioning System, a space-based satellite navigation system that provides location.

M.a. – million years.

nom. superfl. – from *nomen superfluum*, in latin, meaning a superfluous name, i.e. a name that was given based on the same type, published under another name.

pp. nom. inval. – from *pro part nomen invalidum*, in Latin, meaning partly invalid name.

s.l. – from *sensu lato*, in Latin, meaning “with broad meaning”.

s.str. – from *sensu stricto*, in Latin, meaning “with tight meaning”.

sp. – used to designate a species of a particular known genus but of unknown species.

spp. – used to denote in general two ou more species within a genus.

subsp. – subspecies

TIFF – Acronym of Tagged Image File Format, a computer file format for storing raster graphics images.

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1 Introduction

It is a well-known fact that native vegetation of Madeira Island has undergone an intense damage since colonisation by Portuguese people in 1425. From the very out-set that pristine forest have been extensively devastated in spite of calls to avoid destruction and early existing legislative measures aiming forest protection (Frutuoso 1589; Silva & Menezes 1946b; Silva & Menezes 1946c, a; Pereira 1989; Andrada 1990; Menezes de Sequeira *et al.* 2007). Beside the fact that island ecosystems are ecologically fragile and more vulnerable than continental ones (MacArthur & Wilson 1967), the matter that Madeira island has suffered anthropic change over a very short time gap (600 years) and that it was not subjected to herbivory by mammals prior to settlement, makes it more important to assess vegetation change over the last 125 years. Furthermore; obtaining data about vegetation dynamics, especially the long-term one, is crucial to evaluate ecosystem resilience and to predict future course of the vegetation in order to guide management policies and restoration strategies (Egan & Howell 2001). This evaluation plays an even more important role when native ecosystems are invaded by exotic species (Pickard 2002), as it is the case of Madeira Island (Jardim & Menezes de Sequeira 2008). Strategies designed to eradicate invasive species and measures to be implemented after removal largely depend on the time length and area occupied by the exotic species. It is today widely recognised that conservation and restoration activities have frequently been misled, and the problem aggravated by the lack of knowledge of historical conditions (D'Antonio & Meyerson 2002; Henderson *et al.* 2006).

Obtaining information about the evolution of the vegetation and at the same time finding explanations to understand the changes requires close attention to space and temporal scales (Egan & Howell 2001). However, because cultural memory is short, historical documents are often scarce and earlier vegetation surveys are too recent, it is not easy to develop an accurate and reliable understanding of historical conditions. Tools that are commonly used in historical ecology can help to understand the heterogeneity of landscapes, although “historical ecology” as discipline has a rigid anthropocentric focused approach, following the perspective that natural landscapes once subjected to human influence never reestablish as such (Egan & Howell 2001; Balée & Erickson 2006b; Balée & Erickson 2006a). The sources can range from natural and social sciences deriving from distinct disciplines such as ethnohistory, history, and ethnobiology (Crumley 1998; Anderson 2001; Fogerty 2001; Balée & Erickson 2006a), intending to indirectly collect data about vegetation, to others that allow to obtain information about past vegetation, in a more direct manner, such as a palaeoecology (Hunter *et al.* 1988; Davis 2001) and dendrochronology (Kipfmuller & Swetnam 2001).

Photographs, among the historical documents, have been frequently used to get information of past state of landscapes (Reithmaier 2001; Higgs 2003; Webb *et al.* 2010a). According to Turner *et al.* (1998) historical photographs can provide insight into past conditions allowing to get data about the type of vegetation, species, size, growth rate, abundance, and their distribution in the landscape, as well as to infer the type, severity, and frequency of disturbance events. In addition, the information about landscape organisation, which is obtained from photographs, is richest in details than a written description, which is recorded as perceived by the observer and accordingly to his goals (Edmonds 2001). Repeated photography applied to those historical images has been successfully used in natural sciences to study landscape changes and to obtain information about vegetation dynamics (Debussche *et al.* 1999; Butler & DeChano 2001; Pickard 2002; Rhemtulla *et al.* 2002; Start & Handasyde 2002; Clark & Hardegree 2005; Hendrick & Copenheaver 2009a; Webb *et al.* 2010b).

However, repeating those photographs and using them to make comparisons requires substantial precaution because the quantity and quality of scientific data that can be obtained depends largely on the technical correctness. Among other issues the most crucial point to enable landscape comparison, both qualitatively and quantitatively, is to take the new photograph from the exact same point of view and the same orientation of the original photograph (Hall 2001; Munroe 2003). Although recently gaining recognition as a means to understand the landscape change through time and to develop sustainable land management strategies, some limitations have been sustained by authors that used it. In this context, it has been suggested that repeat photography should be combined with other historical techniques[1] to increase its accuracy (Bowman 2002; Pickard 2002; Dutoit *et al.* 2003; Hendrick & Copenheaver 2009a). Furthermore, through combination of diverse retrospective techniques it becomes a lot easier to overcome constraints, and increases their potential to comprehend the past and to develop more coherent explanations of the changes (Egan & Howell 2001).

The previous research done for Master Degree (Pupo-Correia 2007) supports Repeat Landscape Photography Technique (RPTL) as a useful methodology for this type of studies in Madeira Island. The research, that aimed to assess vegetated landscape change by using old and new photographic resources, used two types of approaches: a qualitative evaluation, by visual comparison of 82 photograph pairs ranging from 50 to over 100 years interval, and quantitative evaluation of landscape change over 100 years, using image processing software IDRISI32 to compare nine photograph pairs. As stated by several previous authors (Debussche *et al.* 1999; Butler & DeChano 2001; Rhemtulla *et al.* 2002; Clark & Hardegree 2005) the qualitative approach although useful it is entirely subjective and the quantitative measure is more effective to assess vegetation change. However, because the process of image analysis was extremely time-consuming the number of observations attained did not make possible to draw statistically significant conclusions. The results of this first study on the alteration of Madeiran landscape have shown that: (1) pristine vegetation destruction in south coastal areas was clear at the end of the 19th and beginning of the 20th century; (2) highly humanised areas did not changed significantly; (3) measures to prevent deforestation during five centuries of human occupancy were unsuccessful, and the reforestation led to a massive cover by exotic trees; (4) *Eucalyptus globulus* Labill[2]. and *Pinus pinaster* Aiton[3], the major trees of exotic forest, although naturalised have not shown invasive behaviour; (5) species such as *Acacia mearnsii* De Wild[4]., *Arundo donax* L[5]. have proved to be highly invasive species invading both very disturbed places and recently disrupted natural areas; (6) most of the present native vegetation occurs where it already existed or in areas without anthropic influence showing a very low regeneration in left-over spaces or areas invaded by exotic plants.

Several new questions have arisen as a result of that first approach: (1) What changes in land-use and land-management practices occurred since settlement that originated both current landscape and the one seen in the old photographs? (2) How vegetated landscapes and native plant communities were affected by changes in land-use and land-management practices? (3) What changes occurred over forsaken agricultural fields, since terraces were analysed together with other built heritage (housing, roads) preventing a separate evaluation of these areas? (4) Did

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[1] Such as dendrochronology and historical accounts of vegetation change (historic descriptions, old maps, and vegetation survey records)
[2] Commonly known by tasmanian blue gum, eucalyptus and locally by *eucalipto.*
[3] Commonly know by maritime pine and locally by *pinheiro bravo* or simply *pinheiro.*
[4] Commonly known by black wattle and locally by *acacia* or *mimosa.*
[5] Commonly known giant reed and locally by *cana-vieira.*

native vegetation recovered following a gradual and continuous process over last hundred years or otherwise suffered a cyclical effect over time, alternating between destruction and restoration at shorter intervals? (6) Did the recovery of native vegetation followed the successional model proposed by Capelo *et al*. (2004)? (4) What was the behaviour of exotic plants introduced throughout time? These issues, that were pointed out for further investigation, and the need to reinstate the evaluation performed in that first research about Madeiran landscape change, compelled the definition of aims and objectives of this project.

The aim of this thesis was to evaluate progressive change of the landscape in Madeira Island, by assessing spatial and temporal vegetation dynamics. To achieve this aim were defined the following objectives: (1) To compile further published and unpublished sources of the historical data that describe past landscape, past vegetation, changes in land-use, and land-management practices, in so far as historical documents consulted in the former research was just a starting point; (2) To get adequate number of photograph pairs to ensure a meaningful statistical sample, by increasing the number of repeated photographs as well as implementing analytical methodologies to enable answering questions set out above; (3) To extend the quantitative analysis to photos distributed over shorter time intervals (75 and 50), striving for a better understand of time patterns; (4) To conduct floristic-vegetation surveys (relevés) attempting to collect data about the *phytocoenoses* in photographed landscape and compare them to the communities proposed by Capelo *et al.* (2004) to support supervised classification of the landscape; (5) To determine tree ages using dendrochronological methods, in order to obtain information about the trees located in stands depicted in re-photographed landscape.

In addition to principal aim that was outlined above, two secondary aims emerged after the onset of the work. The first one intended to examine diversity and spatial distribution of plant assemblages[1], in relation to natural and anthropogenic factors. To accomplish this purpose the following objectives were set out: (1) To measure biological indices [Species richness, Shannon-Wiener diversity index, Equitability (evenness)] in order to evaluate diversity and species richness of the plant assemblages surveyed; (2) To determine colonisation status of taxa included in plant assemblages surveyed and compare the composition of plant assemblages surveyed intending to identify factors that influenced the development of each *phytocoenosis*. The second subsidiary goal aimed to prove dendrochronology and dendrometry as a useful tool for interpretation of native forests dynamics. With that in view the following objectives were set out: (1) To evaluate the suitability of native woody species for dendrochronological use; (2) To adjust regression models, in order to select alometric equations to estimate tree age based on variables easily measurable such as diameter and total height, and (3) To get information about growth rates of Madeiran native trees.

This thesis is structured into six chapters as follows: introductory chapter that in addition to this overall introduction (1) contains three subchapters presenting a literature review to characterise the study area (1.1), to explore landscape concept and how landscape was and still is studied (1.2.1), what ancient records are available to study Madeiran historical landscape, and what they tell us about changes in landscape since discovery and early settlement (1.2.2). The subsequent three chapters independently address key issues of the thesis. Each one of them includes introduction, methodology, results, discussion and conclusion. The introduction of *Vegetation* chapter aims to provide

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[1] Although *plant assemblage* and *plant community* are both used in same sense, in this work the first was used to designate a group of plants fortuitously aggregated to distinguish from *plant community* i.e. a recognisable and complex plant association that forms a uniform patch sharing a common environment, as communities described by Capelo *et al.* (2004).

background information on the study of landscape and vegetation from phytosociological point of view (2), on the origin and evolution of flora of Madeira (2.1.1), and on the vegetation models proposed by authors since early 19th century (2.1.2). In *Dendrochronology* chapter (3) the preliminary part addresses fundamental concepts on dendrochronological science (3.1), examines some matters related to underlying methodologies (3.1.1), and gives background information about growth rings in woody species of Madeira Island (3.1.2). The information set out in the introductory section of *Repeat photography* chapter (4) intends to give an overview of the technique (4.1), to examine methodological issues (4.1.1), and to express some considerations about advantages of the repeat photography in the context of Madeira Island landscape (4.1.2). The following points within each chapter present methods used and the output of data derived from relevés (2.2; 2.3; 2.4 and 2.5); from growth rings (3.2, 3.3, 3.4 and 3.5), and from photograph pairs (4.2, 4.3, 4.4. and 4.5) in order to meet the objectives set out above. And the two final chapters, discussion (5) and conclusion (6), link the approaches made in all previous chapters in order to answer to core problem of this thesis “How did the landscape changed and what was vegetation temporal dynamics?”. As stated by several authors (Cairns & Heckman 1996; Egan & Howell 2001; Miller & Hobbs 2007) finding the answer to this question is of utmost importance to understand the functioning of ecosystems, its resilience to disturbances, and in this way, to provide new insights for restoration projects and conservation policies.

1.1 Study area: location, geology and climate

The Island of Madeira is the biggest Island of the Portuguese archipelago of the same name (Figure 1.1) that comprises this island together with Porto Santo and Desertas (Ilhéu Chão, Deserta Grande and Bugio). This archipelago along with Selvagens, Açores, Canarias, and Cabo Verde form the Atlantic biogeographical region of Macaronesia which, not without some controversy, is generally accepted (Fernández-Palacios 2011). Madeira archipelago is located on the intraplate region of African plate (32-33º N and 16-17º W), being bounded on the northwest by the Azores, along the Mid-Atlantic Ridge, on the north by the Azores-Gibraltar fault-zone, on the east by the African coast, and on the southeast by the archipelago of the Canaries (Silveira *et al.* 2010, and references made therein).

In the context of ocean floor physiography, the island of Madeira is located on the southern edge of an extensive set of reliefs (islands, ridges, and seamounts) which are aligned along NE-SW track towards the Iberian continental platform, located at approximately 850 km. Two mountain chains are distinguished: the Madeira-Tore Rise system and the island seamount chain running towards the coast of Algarve. Even though it is still not entirely understood how all these rises were formed, there is a general agreement that the latter correspond to the Madeira Hotspot track. Being oriented NE-SW, it embodies the direction of African Plate drift to NE and it is in line with mantle plume and hotspot track model, supported by radiometric dating that shows a successive age increase from Madeira island (0-4.6 Ma), which represents the hotspot current position, passing across Porto Santo Island (11–14 Ma), several seamounts (Seine [22 Ma], Unicorn [27 Ma], Ampere [(31 Ma], Ormonde [65–67 Ma]) and reaching Serra de Monchique in southern Portugal (70–72 Ma) (Geldmacher et al. 2005). More recent radiometric dating pointed out an older age for Madeira Island, establishing 5.57 Ma as the beginning of subaerial phase.

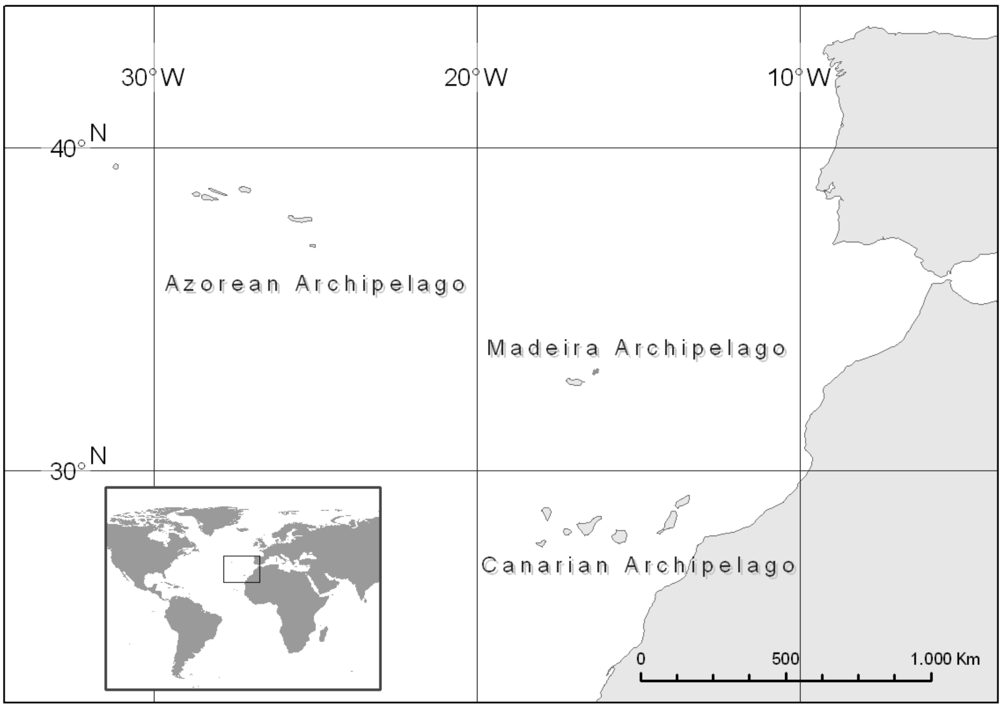


Figure 1.1 Geographical position of Madeira archipelago

The stratigraphy of the island shows three outstanding volcanic complexes indicating that the construction of the Madeiran large shield volcano followed three main phases: Lower Volcanic Complex (> 5.57 Ma) which marks the end of the volcanic structure immerse stage; Middle Volcanic Complex (5.57-1.8 Ma) resultant of subaerial eruptions and major cause for the island growth; and Upper Volcanic Complex (1.8-0.007 Ma) that gathers the events of latest volcanic activity, characterised by small volumes of lava that covered the eroded previous volcanic formations and filled valleys formed in the meantime (Silveira *et al*. 2010). The lavas occurring in these three complexes are alkaline lavas, with predominance of little differentiated lithotypes (basalts and alkali basalts), as well as less common lavas that define mildly alkaline trends (trachyte and mugearite), which are noted in a few outcrops (Mata & Munhá 2004). Alternating with the lava flows are found pyroclastic fall deposits, and occasionally pyroclastic flow deposits, which are testimony that various types of volcanic eruptions have taken place during island formation (Vulcanian, Strombolian and Hawaiian). Although the extrusive igneous rocks represent almost the total volume of the island there are also granular intrusive rocks (gabbro) that form a very small sized outcrop, and some sectors of the volcanic edifice of Madeira have become intensely intruded by dikes (basaltic and trachytic), marking the location where continued intrusions occurred during island construction process. Intercalated in the volcanic sequences, and covering the last volcanic stage, sedimentary deposits are recognised as being characterised both by terrestrial and marine facies associations, which constitute only 2 % of the emerged part of the island. In addition to sedimentary deposits associated with volcanic sequences (lahar deposits), fossiliferous limestones and calcarenites originated from calcareous reefs developed during a period of favourable climatic conditions and week volcanic activity, epiclastic conglomerates and breccias related to alluvial deposits and detrictic flows (mud and debris flow) originated in flash flood events and land-slides, glacial and periglacial deposits, and beach deposits (pebble and sand) (Galopim-de-Carvalho & Brandão 1991; Prada & Serralheiro 2000; Silveira *et al*. 2010).

Andosols are the predominant type of soil (50-60 % of total area) being distributed all over the island, excepting the central zone which is mainly occupied by escarpments. The reddish brown Andosols represent almost 50 %, being the remaining area occupied by dark brown, yellow and red Andosols, depending on the bedrock type (Ricardo *et al.* 1995). According to Madeira *et al.* (1994) Andosols distribution range from 400 m (a.s.l) in northern face, and 700 m (a.s.l) in southern face, to 1200 m (a.s.l) in both aspects, corresponding to the area occupied by forest (temperate laurel forest and exotic forest, mainly pine and eucalyptus). Other major soil types correspond to Leptosols which are more common above 1220 m (a.s.l), and Cambisols under 700 m (a.s.l) in southern face and 400 m (a.s.l) in northern face, corresponding to the area occupied by farm land. This type of soil appears combined with Phaeozems, characterised by humus rich layer, and in lower part of southern face mixed with Vertisols, with huge content in clay minerals. Regardless of the weathering stage, and related lithology, major types of soils occurring in Madeira Island are more or less homogeneous at the same height and there is a strong correlation between soils and vegetation type (Mesquita *et al.* 2007).

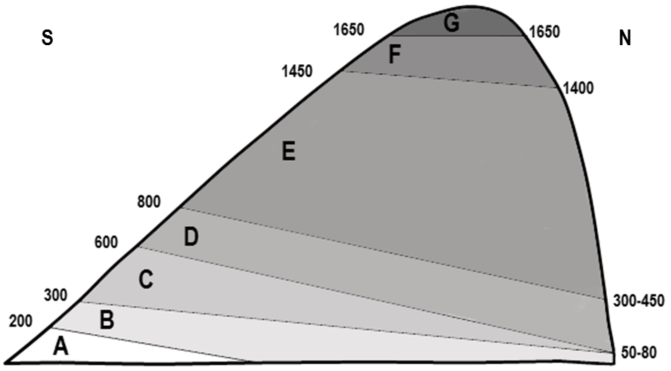
Over millions of years the general appearance of Madeira Island was modified, and current volcanic edifice has approximately 5862 meters (above ocean floor), corresponding the emerged part to 4.2 % of total volume (Prada & Serralheiro 2000). Molded by erosion Madeira Island has an irregular pentagon shape with 737 Km^2 being bounded by a coastline with 153 Km, and presenting a maximum length of 58 Km, in East-West direction, and 23 Km of maximum width in the WNW-SES direction. The 56 % mean slope reflects the very rugged terrain, which is characterised by high escarpments and deep ravines. The highest point is Pico Ruivo at 1862 m (above sea level) and average altitude is around 646 m (a.s.l.), although just 8 % of surface is situated below 100 m (a.s.l.), comprising mainly banks and beds of rivulets, as well as beaches and fajãs (talus deposits) located in coastal areas at the bottom of cliffs which are the most common landform along coastal line, especially on the north face of the island (Pereira 1989; Silveira *et al.* 2010, and references therein).

The climatic characteristics of Madeira are greatly influenced by subtropical location and the type of orography (Pereira, 1989). The geographical position places Madeira archipelago under the influence of the subtropical semi-permanent centre of high pressure, located in north Atlantic to the south of archipelago of Azores, called Azores anticyclone (or Azores High, as it is also often known) and the southern belt of the zonal flow of mid-latitudes, which determine a seasonal climatic pattern characterised by hot and dry summers, and wet and mild winters, clearly identified as Mediterranean climate. From March to October, Madeira archipelago is under direct influence of Azores High that, circulating air clockwise, transport a mass of tropical air causing a dry period. During winter, the influence of the anticyclone is lower and climate is influenced by depressions with southward and south-western trajectories, becoming exposed to cold air from north which causes rainfall, and sporadically low temperatures and frost formation overnight and hail or snow fall, at high uplands. In autumn and spring, the periods in between of higher and lesser influence of Azores anticyclone, the area is frequently affected by heavy rain (Figueiredo 2013, and references therein).

However, in addition to the annual pattern, the island is exposed to local climatic variations induced by E-W main orientation of the Island and a complex orography that foster climatic asymmetries. The maritime air with high moisture content finding the barrier formed by the relief, perpendicularly disposed to the prevailing wind direction, it is forced to rise. As gaining altitude it adiabatically cools down and forms clouds and fog that cover windward ridges. The mass of clouds originated by orographic lifting involve the mountain summits forming a cloud belt that usually ranges from 600 m (a.s.l.), up to 1600 m (a.s.l.), and remains 234.8 days per year (Prada & Silva 2001; Prada *et al.* 2009). This phenomenon results in substantial local gradients of average rainfall, being lower in coastal areas and increasing with altitude. The summits of interior uplands, above 1400 m (a.s.l.), are especially wet - about 2966.5 mm per year at Bica da Cana (1560 m a.s.l.), and slightly lower above 1600 m (a.s.l.) - near 2939 mm per year at Arieiro 1810 m (a.s.l.). Because much of the rainfall received on the island is on the windward side the leeward side, and especially near the coast, tends to be quite dry, reaching values close to 622 mm per year as in Lugar de Baixo (average altitude of 40 m) (Figueiredo 2013, and references therein). Low rainfall during summer is compensated by fog precipitation that occurs mainly on windward areas, and depends on the presence of native plant species as *Erica arborea* L.[1] and *Erica platycodon* (Webb & Berthel.) Rivas Mart., Wildpret, del Arco, O. Rodr., P. Pérez, García Gallo, Acebes, T.E. Díaz & Fern. Gonz. subsp. *maderincola* (D.C. McClint.) Rivas Mart., Capelo, J.C. Costa, Lousã, Fontinha, R. Jardim & M. Seq.[2] (Prada & Silva 2001; Prada *et al.* 2009, 2010).

The precipitation asymmetry observed is also a trend recorded for air temperature values. Thus, both atmospheric and physiographic factors are also responsible for temperature fluctuations all year around and in north-south faces and low-high altitudes. Despite showing annual low range the spatial variation of temperature triggers hot summers in south coastal areas (although rarely rising above 25 ºC), and slightly cooler temperatures in slopes facing north due to a cloud belt. During winter the temperatures in coastal areas are frequently around 16-18 ºC (e.g. in Funchal) while in mountainous areas, above 1500 m (a.s.l.), the average temperature ranges 5-6 ºC (e.g. Arieiro, and Bica da Cana) (Figueiredo 2013, and references therein).

Because climatic factors influence each other and collectively influence the vegetation, bioclimatic variables are more biologically meaningful than temperature and rainfall values when considered separately. Bioclimate of Madeira refers to *Bioclimatic Classification of the Earth* of Rivas-Martinez (Rivas-Martínez *et al.* 1999; Rivas-Martinez 2002) which was modeled by Mesquita *et al.* (2004). According to this typology, Madeiran bioclimate crosses two macrobioclimates: Mediterranean in southern face under 800 m (a.s.l.) and in northern face under 300 m (a.s.l.), and temperate in slopes, above those altitudes. Within these two units the variations in thermic and ombrotermic values enabled to recognise different bioclimatic gradients (Figure 1.2): ten thermothypes and eight ombrotypes; ranging from *inframediterranean* to *supratemperate*, and from *upper dry* to *ultrahyperhumid* within the bioclimatic belts (Mesquita *et al.* 2004; Mesquita *et al.* 2007). As consequence of the high correlation between bioclimate and vegetation, it was possible to predict the type of natural



A – Mediterranean: *inframediterranean*; *upper dry*
B – Mediterranean: *inframediterranean*; *lower subhumid*
C – Mediterranean: *upper inframediterranean and thermomediterranean*; *upper subhumid*
D – Mediterranean: *thermomediterranean; lower humid*
E – Temperate: *infra, thermo and mesotemperate*; *humid and lower hyperhumid*
F – Temperate: *upper mesotemperate*; *upper hyperhumid and ultrahyperhumid*
G – Temperate: *lower supratemperate; ultrahyperhumid*

Figure 1.2 Bioclimatic belts (thermotypes and ombrotypes). Modified from Menezes de Sequeira *et al.* (2000) based on Mesquita *et al.* (2004).

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[1] Commonly known by besom heath and locally by *urze durázia, urze-das-vassouras*.

[2] Commonly know by tree-heath and locally by *betouro, urze molar*.

vegetation that should occur at any point based on bioclimatic data, as well as the reverse, to produce a bioclimatic characterisation from the vegetation on the ground (Rivas-Martínez *et al.* 1999). Six Climatophyllous vegetation series were found (see chapter two) and were mapped (Figure 1.3) based on aforementioned bioclimatic indices. Although being a simplification, which does not cover biotopes located in atypical conditions, it proved to be very close to the vegetation belts that actually exist, being therefore very informative (Mesquita *et al.* 2004; Mesquita *et al.* 2007).

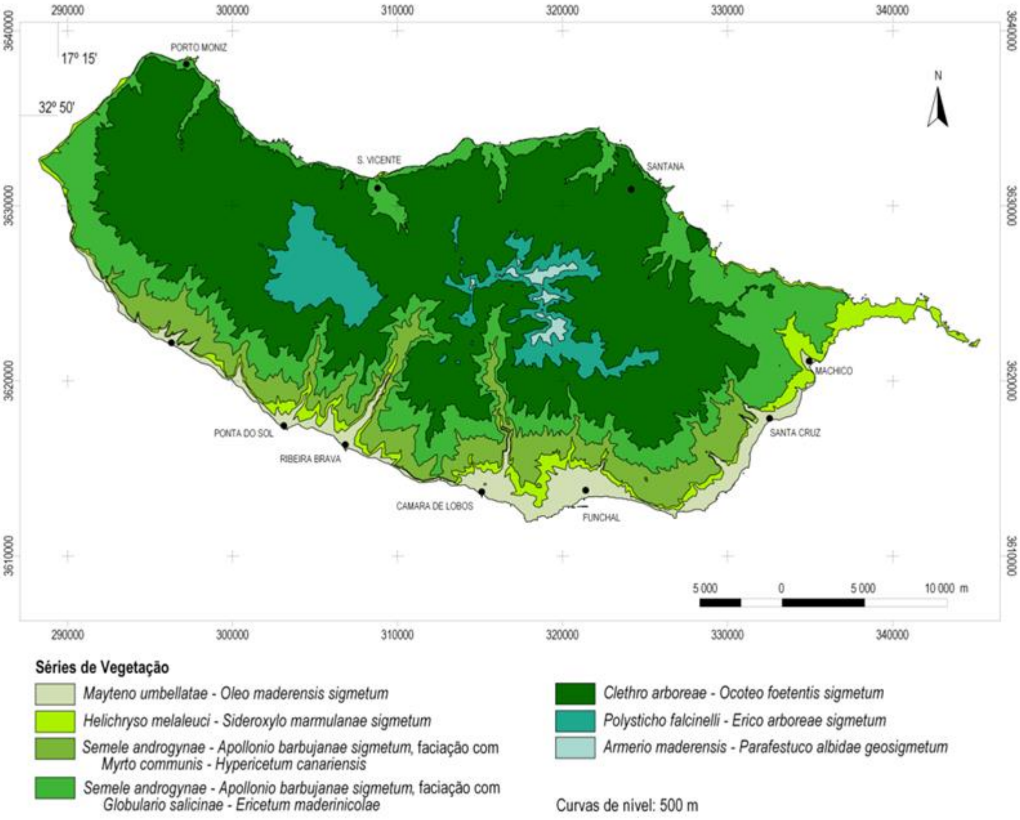

Figure 1.3 Map of potential natural vegetation - Climatophyllous vegetation series (Mesquita *et al.* 2004)

1.2 Landscape

The word *landscape* has become commonplace, an everyday term, which each person freely uses in their own way, even in metaphorical sense (Bertrand 1968; Jackson 1984; Makhzoumi & Pungetti 2005). It is a polysemous term which is used in different disciplines within natural sciences (e.g. landscape ecology), human sciences (e.g. historical geography) or applied sciences (e.g. landscape architecture) with different approaches and aims (Antrop 2005; Vieira 2006).

1.2.1 Landscape: Concept and Study

The etymological components of the word *landscape* have roots in Indo-European languages that became the basis of European idioms. In the Germanic languages, the words forming the old term *lantscap* (land [an area of ground] plus the suffix *schap* [exhibiting a constitution or a quality] became *landscape* and *landschaft* (or similar, in Germanic languages of Northern Europe). The Portuguese word *paisagem* derived from the French word *paysage* (Casteleiro

2001) which in turn came from *pagus* (a rural district) plus *age* (the result of an action) (Jackson 1984; Makhzoumi & Pungetti 2005). However, apart from the exception of German language in which the word *landschaft* can also mean an administrative division (Jackson 1984), in all other languages the term is commonly used according to two general conceptions: *landscape* as an area of the earth surface or *landscape* as the view that is seen by the observer. Other terms are also used to refer the visible features of an area as: *environment*, which has gained wide usage in last decades, and *scenery*. However, as stated by Bourassa (1991) none of the terms should be used as a synonym for *landscape*. The first because it regards a more comprehensive approach embracing the total components of an area and the second, although interchangeable, refers to the general appearance being, therefore, less profound. But, although *scenery* is currently less common, it was often used in 19th century both to refer the view ["… the scenery is probably the first in sublimity, and perhaps in beauty, in all world." (Picken 1840, p. 58)], and a space on the surface of the earth ["One of the most striking features of the Madeira scenery are the numerous ravines…" (Picken 1840, p. 81)].

The connotation of the word *landscape* relating to scenery appeared in the 16th century, introduced by Dutch painters to refer paintings of natural or rural scenes to distinguish from a sea picture or a portrait (Jackson 1984; Makhzoumi & Pungetti 2005). The association of the term to a picture of a view persisted all over the 16th and 17th centuries, referring sometimes not the view itself but the artist interpretation, not being used for physical landscapes before the early 18th century. This concept spread into landscape design, giving rise to parks and gardens that were designed by artistic inspiration, applying the same compositional rules as seen in landscape paintings. But, these two disciplines that once had the exclusivity of the word *landscape* no longer use it in the same sense (Jackson 1984). In the 18th century the word evolved from being a picture of a view to the view itself: "a prospect of natural inland scenery, such as can be taken in at glance from one point of view", and in the 19th century the word began to be used to mean "a tract of land" (Makhzoumi & Pungetti 2005, p. 3).The use of the term to refer to a space, still not very common by the 1800s, started to be used (Kwa 2005) and is evident in some descriptions written in the 19th century [e.g. "...those features have been prominent in the landscape around Funchal" (Picken 1840, p. 69)].

The term preserves a range of meanings and associations (Meinig 1976). However, according to Makhzoumi & Pungetti (2005) it is possible to establish four major perspectives: (1) landscape as *scenery*, that is used to describe characteristics of an area and its view i.e. the characterisation of "a portion of the earth´s surface that can be comprehended at a glance" (Jackson 1984, p. 3); (2) landscape as a *specific geographical place*, which has roots in the European school of *landschatsgeographie*, in the 19th century; (3) landscape as *an expression of culture* that is related to the idea of landscape as man-made environment; and (4) landscape as *a holistic entity* where the notion of landscape combines different aspects (physical, ecological, social and cultural).

First landscape record goes back to the Neolithic period, in spite of the fact that those earliest forms of representation depicted the landscape with little sense of perspective (Schmitt *et al.* 2014). Landscapes copied from real views (i.e. topographical view), become rather common in ancient Chinese art, especially ink painting (Sullivan 1980), and also in Greek and Roman *frescos.* Those paintings dating from 2300 years B.P. are evidence that a rough scaling system was already used to represent real landscape with some accuracy (Clark 1949; Büttner 2006). Also in literature, landscape descriptions are found in the oldest extant literary works, such as the Old Testament lyrical poems, written three thousand B.P. (Metzger 2001), or the Odyssey, that is believed to have been composed near the 2700 B.P. (Haller 2007). Even if very little written material have survived tales and poems recorded in oral tradition, and later on written, are currently used to trace back the historical landscape, especially from the Middle Ages (Graves 2004), when Western painting has lost interest in Landscape art (Clark 1949; Büttner 2006). The pictorial record of the landscape was revived by the 14th century becoming an established painting style during 15th and 16th centuries. Supported by the development of an effective system of graphical perspective, and exceptional skills of renaissance painters, especially Italian and Flemish, landscape paintings become more realistic (Clark 1949). Indeed, it was by this time that recording landscapes with some degree of precision also became an important issue. With the beginning of the great voyages and the discovery of new territories came the need of describing those lands, not only for navigation or military reasons, but particularly on account of economic interests (Carita 1982; Capelo 2003). Regrettably, a significant number of paintings did not depict the real landscape, but instead a fantasy scene, an idealised landscape, especially in the 17th century when a dramatic growth of landscape art occurred due to its commercial success (Clark 1949). However, the increase of scientific expeditions, especially by the end of 18th century and in the early 19th century (Carita 1982; Capelo 2003), and the emergence of Romantic and Realist movements led landscapists to a truthful representation of the landscape (Murray 2004). With the invention of photography in mid-19th century landscape photography became a form of art, and a source of inspiration for artists that used the medium to capture landscape views (Anderson 1914; Giovanzana 1999). Photography also become a popular medium to document scientific expeditions, survey activities, tourist trips, family outings, and therefore a way to record landscape elements by depicting landscape either as main subject or as background (Pupo-Correia *et al.* 2011a). The first aerial photography was taken in the middle of the 19th century, but only after the First World War had it become an effective method for surveys and cartography. Only after 1940 was the coverage of the territory of the most developed countries carried out, it was from then that it became widespread as a tool in vegetation land-use surveys (Debussche *et al.* 1999; Read & Graham 2002).

Throughout time scientists felt compelled to observe and explain the spatial heterogeneity of landscape. Amongst many others it's worth emphasising some Greek philosophers such as Aristotle[1] and Theophrastus[2], Roman naturalists as Pliny, the Elder[3] and Dioscorides[4], the Greek physician serving Roman legions, Portuguese and Spanish naturalists of the 16th century such as Garcia da Orta[5] and Gonzalo Fernández de Oviedo[6], Carl Linnaeus[7] in the 18th

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[1] Aristotle (2384-2322 BP) the Greek philosopher and scientist whose studies between many subjects also covered 'natural philosophy' (physics and biology). Even though focusing on animals, also stated that plants have mechanisms to control reproduction and growth ('vegetative soul'), and left a legacy of accurate descriptions, a system classification of living things (Aristotele 2350BP; "Aristotle" 2015).

[2] Theophrastus (2372-2287 B.P.) the Greek scholar considered the "father of botany" who produced the botanical treatises that constitute the first systemisation of plants knowledge. Although he also wrote about several other issues (e.g. ethics, logic, mathematics, and astronomy) were in fact *De historia plantarum* (Enquiry into plants) and *De causis plantarum* (On the causes of plants) his best known and handful works ("Theophrastus" Complete Dictionary of Scientific Biography 2008).

[3] Gaius Plinius Secundus, known as Pliny the Elder (23-79AD) the Roman naval commander who spent his life, writing and investigating natural and geographic phenomena. One of his most known works it was *Naturalis Historiae,* the first encyclopedia covering all knowledge of that time, not being restricted to natural sciences (Smith 1813-1893).

[4] Pedanius Dioscorides (40-90) the Greek surgeon serving Roman legions, who was also pharmacologist and botanist. He was the author of *De material medica*, an encyclopedia and pharmacopoeia that still was the core of European pharmaceutical guide in the nineteenth century, and was the precursor of modern pharmacopoeias (Smith 1813-1893).

[5] Garcia da Orta (1501-1568) the Portuguese Sephardi Jewish who was the pioneer of tropical medicine, pharmacognosy and ethnobotany. After his studies at Spanish universities he spent some years as Professor at the University of Coimbra, and fearing the inquisition he sailed for Goa, then a Portuguese colony, where he worked as physician, herbalist and also naturalist at the end of his life (D'Cruz 1991).

[6] Gonzalo Fernández de Oviedo e Valdez (1478-1557) the Spanish historian and writer appointed as historiographer of the Indies (America) where he went for six times. Through his writings and drawings Europeans get to know about animals, plants, and habits of Native Americans (Chisholm 1911).

[7] Carl Linnaeus (1707-1778), the Sweedish doctor that established the binomial system of biological nomenclature, and use it consistently, becoming known as "father of taxonomy". His most productive time in botanical field was during the three years between receiving medical degree at the University of Harderwijk (1735), and to become professionally established practicing medice in Stockolm. During that time that he was

century, and also some great naturalists-explorers as Joseph Banks[1] and Charles Darwin[2] by the end of 18th and 19th centuries. Although for most of them landscape did not constitute the primary object of study the incipient approach aiming to understand the relationships between living beings and their environment were crucial to future works within this area (Basalla 1967; Capelo 2003). However, the real emergence of *landscape* as an object of scientific study is, in some way, connected to Alexander Von Humboldt[3], who in the early nineteenth century started the accurate approach of landscape and laid the foundation of physical geography and biogeography. Describing, from a scientific point of view, what he saw in his extensive travels, especially in South America, he changed the concept of landscape. Humboldt viewed nature holistically and tried to explain earth surface as a result of the interrelation of all elements which should be measured and evaluated to enable a clear understanding. Since then, landscape was no longer seen as just an aesthetic concept and become an entity that could be scientifically documented and quantified (Nicolson 1987; Capelo 2003; Kwa 2005).

In the last century, studies on landscape have been separated in cultural landscape and natural landscape. The former was highly encouraged in early 20th century by Carl Sauer[4], an American geographer linked to human geography. He regarded the study of landscape as a description of the transformations into *cultural landscape*, i.e. the humanised landscape resultant of human direct intervention over nature (agricultural land, infrastructures and settlements). The latter, the physical landscape that exists without man (land forms, water, soil, vegetation) was the subject of study of physical geography, especially British school (Makhzoumi & Pungetti 2005; Howe 2011). The concept of *natural landscape* was highly questioned, especially by Hartshorne (1939) who argued that no place on earth is free of man actions. However, because cultural landscapes once abandoned can return to wilderness and be recovered with native vegetation, being pristine is not mandatory for natural landscape designation. On the other hand an altered landscape by afforestation, which can be confused with natural landscape, is no more than a cultural disruption (Rolston 1998). Hence, because it is difficult to define the line that separates cultural landscape and natural landscape (Vale 2002) and being the majority of landscapes a product of physical origins and cultural overlay, some authors agreed that it does not make sense to separate the landscape study in these two lines, as were promoted by human geography and physical geography in the past (Vale 2002; Shier 2003; Makhzoumi & Pungetti 2005). Accordingly to Capelo (2003) currently landscape is seen as an entity formed by natural and cultural elements, tightly interconnected and interdependent, that can be categorised into natural landscape (dominance of natural ecosystems); rural landscape (co-dominance between natural ecosystems and agroecosystems) and urban-industrial landscape.

Despite this, the idea of landscape as a cultural construction (i.e. not a material 'object') still prevails within the social sciences, particularly in human geography. The cultural perspective on landscape was adopt and developed by

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enrolled in the University of Leiden for further studies he published a large number of works, among which the *Systema Naturae* focusing his classification of living things ("Carl Linnaeus." Encyclopedia of World Biography 2004)

[1] Sir Joseph Banks, 1st Baronet (1743-1820) the English naturalist and botanist, patron of natural history who sent explorers and botanists to collect and study plants to far-off lands. He, himself travelled extensively participating in scientific expeditions, as the great voyage of Captain James Cook, in which he collected plants and described many species new to the science (PlantExplorers.com 2015)

[2] Charles Robert Darwin (1809-1882) the English naturalist whose studies of specimens seen during his travel around the world led him to develop the theory of evolution (Charles Darwin 2015).

[3] Alexander Von Humboldt (1769-1859) the German explorer and naturalist, the symbolic figure of physical geography and biogeography, and the first to use the term 'association' to refer a plant community (Kellner 2014)

[4] Carl Ortwin Sauer (1889-1975) the American geographer and Professor of geography at the University of California. Mainly interested in cultural landscapes he created the human-environment geography school and laid the foundation of cultural ecology, political ecology and historical ecology (Williams 2014).

Cosgrove (1984) who advocated that landscape is the result of cultural and socio-economic context. Although criticised for placing too much emphasis on landscape as a form of visualisation, forgetting the relationship with the material world, this point of view became a steady influence mainly in cultural geography, and also in social sciences in general (Macpherson & Minca 2006).

On contrast with the previous line of thought the perspective accepted across physical geography and natural sciences started to see landscape as a territorial unit, an object real and quantifiable (Macpherson & Minca 2006). It was within those two sciences that emerged *landscape ecology,* a discipline that combines the approaches of physical geography (spatial) and ecology (functional) (Forman & Godron 1981; Turner *et al.* 2001; Capelo 2003; Honrado *et al.* 2012). *Landscape ecology* is rooted in European tradition of regional geography and was launched by the German biogeographer Carl Troll[1] in middle 20th century driven by the possibilities of aerial photography and the emergence of new concepts from ecology as the *ecosystem* from Tansley[2], *biogeocoenosis* from Sukachev[3] and *succession* and *climax* from Clements[4] (Sanderson & Harris 2000; Bastian 2001; Capelo 2003; Turner 2005a; Trueba 2012). *Landscape ecology* essentially aims to investigate how the abundance of organisms, at the landscape level, is affected by the spatial structure i.e. it intends to quantify two landscape dimensions: (1) composition (what and how much there is of each landscape element); (2) configuration (spatial arrangement across a landscape) (Turner *et al.* 2001; Capelo 2003). Contrarily to other ecology sub-fields, it usually focuses on large extents, although the scale depends on the level on which an event is observed and small spatial scales are also accepted [*e.g.* a 4 m^2 grass cover microlandscape (Turner *et al.* 2001; Wu 2013)].

Landscape ecology became broadly accepted and intensely used by German and Dutch scholars throughout the 50s and 60s and stood out as an established branch within ecology in the 80s, especially in North America (Turner *et al.* 2001; Wu & Hobbs 2007a). During this time several authors (e.g. Bertrand 1968; Forman & Godron 1981; Urban *et al.* 1987; Turner & Gardner 1991; Wu & Hobbs 2007b) developed different tools and concepts that contribute to the theoretical advance of *landscape ecology*. Two disciplines were crucial precursors to *landscape ecology* key concepts: phytosociology and biogeography (Turner *et al.* 2001). The first, also known as plant synecology is a branch of geobotany and started in Europe in late 19th and early 20th century, associated to names such as Flahault[5], Schröter[6]

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[1] Carl Theodor Troll (1899-1975) the German geographer, pioneer of aerial photography utilisation for research in ecology and geography of mountainous lands, and author of many early terms and concepts of landscape ecology (geographie-studieren.de 2015)

[2] Sir Arthur George Tansley (1871-1955) the English botanist, Sherardian Professor of Botany in Oxford, and one of the earliest ecologists. His interest in Vegetation drove to the foundation of the journal *New Phytologist*, of which he was editor for almost thirty years. Also served as first president of British Ecological Society and was first editor of the Journal of Ecology (Ayre 2012).

[3] Vladimir Nikolayevich Sukachev (1880-1967) the Russian geobotanist and forest ecologist with interests in dendrology, plant systematics and paleobotany. Pionner of ecosystems studies and the author of terms like biocoenosis, phytocoenosis, phytocoenology, and phytogeocoenology (Smith 2005).

[4] Frederic Eduard Clements (1874-1945) the American botanist and plant ecologist, after being Professor in the Universities of Nebraska and of Minnesota, become ecologist at full time in Carnegie Institution of Washington. He developed the theory of ecological succession converging into a climax community considering units of vegetation as individual organisms. This was heavily criticised by other ecologists and largely abandoned in 1950s, but re-emerged in last decades of the last century (Garraty 1973).

[5] Charles Henri Marie Flahault (1852-1935) the French botanist who was one of the pioneers of phytogeography, phytosociology, and forest ecology. Its school, established in Montpellier become later the strong Zurich-Montpellier school of phytosociology, after some differences with Schröter (Zurich school) were resolved in 1910 (Sharma 2009).

[6] Carl Joseph Schröter (1855-1939) the Swiss botanist who was one of the pioneers of phytogeography and phytosociology, and author of terms and concepts as 'autecology' and 'synecology'. Its school, established in Zurich become later Zurich-Montpellier, as already seen, with large acceptance in southern Europe (Sharma 2009).

Braun-Blanquet[1] and Du Rietz[2], followed by different generations of phytosociologists in Europe as Tüxen[3], and Rivas-Goday[4] (Capelo 2003) and also in the United States, in latter following slightly different methods (Barkman 1950; Whittaker 1956). Aiming to study plant communities and their relationships with the environment, it has long-established the link between vegetation patterns and topographic gradients, i.e. time and spatial heterogeneity (Capelo 2003; Rivas-Martinez 2005). The second, and specially island biogeography theory (MacArthur & Wilson 1967) through the analogy between isolated patches and oceanic islands was important to understand populations response to fragmented landscapes (Turner *et al.* 2001).

The recent growth of *landscape ecology* has mostly happened due to the development of remote sensing, GIS, spatial statistics, and neutral modeling (Turner *et al.* 2001; Lomba *et al.* 2004; Turner 2005a; Mackey *et al.* 2007; Wu & Hobbs 2007a; Honrado *et al.* 2012; Wu 2013). But, *landscape ecology* is still passing through a process of definition and it does not exist, yet, as an unified theory (Bastian 2001; Wu & Hobbs 2007a). Although the common position is focused on interactions between spatial heterogeneity and ecological processes, there are too much different conceptions what leads to a blur scope. Nevertheless, it is possible to trace two main lines of approach: one aiming the study of large areas, addressing land-use issues and very close to landplaning, and another where landscape is defined, regardless the scale, by the spatial patterns and influence of ecological processes, being the organisms and the processes the main focus (Turner 2005a). Methods and concepts developed in *landscape ecology* context are nowadays incorporated in a variety of branches of ecology (*e. g.* historical ecology, restoration ecology, sinecology) and it has important links to application-oriented disciplines such as land management, conservation, and restoration (Lomba *et al.* 2004; Turner 2005a; Honrado *et al.* 2012).

Following a parallel conceptual framework, the *integrated landscape research* school approaches the study of landscape, however, not as a new discipline but rather as an integration of methods and concepts from other disciplines such as phytosociology, biogeography, physical geography or even applied sciences like forestry (Ingegnoli 2002; Capelo 2003). Because vegetation is a defining element of landscape and is the one that better integrates the biological response to different factors (physical, biological and anthropic), its study has great value in the diagnosis and organisation of landscape information. In the context of the *integrated landscape research* the study of vegetation follows the botany and phytosociology tradition without any type of conflict with *landscape ecology* (Capelo 2003; Santos 2010). Theory and practice of phytosociology are described in further detail in chapter two.

1.2.2 Madeiran historical landscape

Understanding how landscape features were organised in the past helps to develop more adequate strategies to landscape management. To access historical information about past landscape can be done by using complementary

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[1] Josias Braun-Blanquet (1884-1980), the Swiss botanist and phytosociologist that developed a floristic-sociological approach to plant communities, by establishing analytical method based on tables and the syntaxonomic hierarchy of nomenclature. He developed an independent group emerged within the Zürich-Montpellier school of plant sociology which spread rapidly and became the dominant European approach to phytosociology (Haber 1980, Sharma 2009).

[2] Gustaf Einar Du Reitz (1895–1967) the Swedish Professor of plant ecology at the University of Uppsala, leader of the 'Uppsala School of Phytosociology'. Some differences between this school, with larger tradition in northern Europe, and Zurich-Montpellier were resolved in 1910, among which the acceptance of sub-associations or facies (Smith 2005; Sharma 2009).

[3] Reinhold Tüxen (1899-1980) the German botanist and phytosociologist, who founded in 1927 the "Floristisch-soziologische Arbeitsgemeinschaft", and one of the strongest drivers of phytosociology (Haber 1980).

[4] Rivas-Goday (1905-1981) the Spanish pharmacist, botanist and phytosociologist, Professor of Botany in Faculty of Pharmacy of University of Granada and later on in the University of Madrid.

approaches. Field work to prospect clues can help to realise how landscape was like long ago, however because landscapes undergo on uninterrupted modification it might be less informative than expected. That is why documentary research to find useful references to landscape features it is absolutely crucial to get the perspective of time (Crumley 1998).

1.2.2.1 Sources of information

It has long been recognised that the Portuguese travel literature from the 15th and 16th centuries was one of the great contributions to a new type of literature that, contrary to medieval chronicles, become strongly oriented to transmit the information collected by direct observation. Those reports from the time of sea discoveries such as nautical guides, navigation regulations, and geography books also held a systematic description about the regions visited, beyond the navigation technical information (Carita 1982). Madeira archipelago was the first place out of geographic boundaries of the old-world to be settled and since colonisation, around 1425, it has become a privileged place to try out new crops, to engage in important business operations and, being the last port of call before great voyages, an obligatory stop-off point. Such overriding reasons justified the inclusion of narrative descriptions of the islands in early writings (Carita 1982; Melo & Farrow 1983). First record was made by Gonçalo Ayres Ferreira[1], one of the companions of Zargo[2], who wrote a rudimentary description of what he saw when exploring the coastline of the new land (Frutuoso 1589; Silva & Menezes 1946a; Visconde do Porto da Cruz 1949). Much that is currently known it is based on that early record and also on the chronicles of Azurara[3] (1434-1448), on the journeys memoirs of Cadamosto[4] (1445-1455), and on the accounts of first Portuguese historians João de Barros[5] and Damião de Góis[6] in early and mid-16th century (Silva & Menezes 1946b).

At the same time, in Portuguese literature of that period can be found, more or less, detailed descriptions. From the love poems and narrative accounts, that were mostly transmitted by oral tradition (Visconde do Porto da Cruz 1949), to the major literary works as the Portuguese epic poem *Os Lusíadas* by Camões[7] (1572), and the historic novel *Epanophora* by Francisco Manuel de Mello[8] (1660) all have contributed to record landscape elements of those times.

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[1] Gonçalo Aires Ferreira (139?-14??) the most educated and wealthiest companions of Zargo. It was him that recorded the first impressions of the new land and led the first expedition on land going through a rivulet that received his name. His children were the first to be born in the island, a twin couple that were called Adão e Eva (Adam and Eve) (Silva & Menezes 1946a).

[2] João Gonçalves Zargo (Zarco) [1390(5)-1470(1)] the Portuguese captain who commanded the maritime voyage to the (re)discovery of the Madeiran archipelago in 1425. He was the *Capitão donatário* placed in charge to start the colonisation of one of the two Captaincies in which the island was divided (Silva & Menezes 1946c)

[3] Gomes Eannes de Azurara (Zurara) (ca. 1410-1474) the Portuguese chronicler who wrote about early Portuguese voyages and conquests along the African coast (Silva & Menezes 1946a).

[4] Luiz (Alvise) Cadamosto (ca. 1432-1483) the Italian explorer at service of the Principe Henrique (Prince Henry) of Portugal. In his first journey (1455) he spent a few days in the archipelago during which he delighted in observing and writing details about the country (Silva & Menezes 1946a)

[5] João de Barros (1496-1570) the Portuguese writer and historian who wrote some works about morality, pedagogy and Portuguese grammar, and greatly about the historical accounts of Portuguese discoveries and conquests, especially in the Orient. He also wrote about the history of Madeira archipelago (Silva & Menezes 1946a; Abdullah 2015).

[6] Damião de Góis (1502-1574) the Portuguese historian and humanist philosopher. It was as *Guarda-mor* (High Guardian) of the Royal archives (*Torre do Tombo*) that he wrote the chronicle of the reign of D. Manuel I (Silva & Menezes 1946b; Abdullah 2015).

[7] Luís Vaz de Camões (1524(25)-1580) the Portuguese poet, author of the epic poem *Os Lusiadas* (The Lusiads), which focuses on the Portuguese voyages in the 15th and 16th centuries (Abdullah 2015).

[8] Francisco Manuel de Mello (1608-1666) the Portuguese leading poet and prose writer of the 17th century. He started writing at the age of fourteen (poetry and mathematics) but it was during the time that he was in prison and exile that wrote most of its work. What he wrote about Madeira archipelago is found in *Epanaphoras de vária História portugueza* (Abdullah 2015).

From the late sixteenth to early seventeenth centuries Madeira Island, although subject to decrease in sugar trade, was gradually increasing wine production and exportation, and become a valuable centre for commercial and military routes connecting Europe to other continents (Melo & Farrow 1983; Sousa 1994; Vieira 2014a). Because Portuguese colonisation was accompanied by catholic envangelisation another travel literature emerged. The written texts with descriptions produced by Jesuit missionaries become important historical resources (Silva & Menezes 1946a; Carita 1982). Of high relevance in this context, there is the work *Saudades da Terra* by Gaspar Frutuoso[1] (1589) that covers the history of the Atlantic archipelagoes, which still stands out today as a wide repository of historical data about the discovery and early settlement (Silva & Menezes 1946a).

Throughout the 18th century economic needs required a more detailed description, not only to provide information concerning exploitation of wealth but also to locate strategic places. At the outset of the century many of these descriptions were still made by Jesuit priests, as members of the Military Religious Order *Companhia de Jesus,* such as *História Insulana Lusitana* by António Cordeiro[2] (1717) in which third book Madeira archipelago is described in detail. However, after that, reports started to be made by military and army engineers that as well as including very precise descriptions also attached accurate maps (Carita 1982), as for instance *Descrição da ilha da Madeira* by Paulo Dias de Almeida[3] (1817). In addition, petitions and claims to the competent authorities and also Royal licenses and Regulations aiming to protect the vegetation are also a useful source of information, which are wholly or partially transcribed in more recent works as e.g. Silva & Menezes (1946b).

Up until this time, all descriptions were associated to colonialism, economic interests and strategic location (Carita 1982; Melo & Farrow 1983). Yet, the visit to Madeira Island, in 1768, by Banks[4] and Solander[5], naturalists that accompanied the Captain James Cook's in his first great voyage, contributed to draw attention to Madeira Island on another perspective: the scientific interest. Although, already in the 17th century, the flora of the Macaronesian archipelagoes has become a matter of interest, as shown by the record of Madeiran flora made by Sloane[6] in 1687, in his way to Jamaica, it was indeed after the publications upon Cook's first voyage that Madeira Island becomes a pole of attraction. During late 18th century and throughout entire 19th century, year after year, prominent scholars[7] came to Madeira archipelago to study its peculiar flora and fauna, as well as the geology. Their collections, notes, illustrations,

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[1] Gaspar Frutuoso (1522-1591) the Portuguese priest, historian, and humanist from the archipelago of Azores who wrote a six-volume work about the history, and traditions, geography, flora, fauna, of Portuguese archipelagos of Madeira, Azores and also Cape Verde and Canaries that were Portuguese at the time. Descriptions of Madeiran archipelago constitute the Book II (Silva & Menezes 1946a).

[2] António Cordeiro (1641-1722) the Portuguese Jesuit priest born in the archipelago of Azores. He was the author of *Historia Insulana*, firstly published in 1717, mainly dedicated to the history of Azores (nine volumes) which also addressed the other Portuguese archipelagos. The volume referring to Madeira it is a summary of the manuscript of Gaspar Frutuoso (written in 1589) which was not yet published and was in possession of *Companhia de Jesus* (Silva & Menezes 1946a, b).

[3] Paulo Dias de Almeida [1778-1832(36)] the Portuguese military engineer, working with Brigadier Outinot to reconstruct the town of Funchal after the huge flood in 1803. Being in charge of mapping he included in his work several floor plans, and enriched it with drawings and descriptions (Almeida 1817; Carita 1982).

[4] A short biographical note was presented on p. 11.

[5] Daniel Carlsson Solander (1733-1782) the Swedish botanist and naturalist pupil of Linnaeus in the university of Upssala, who sent him to England to Promote the Linnean system. He was one of the companions of Banks on the Cook's voyage. He work all his life in the British Museum, but he was also in charge of Banks collections (Tingbrand 2011).

[6] Sir Hans Sloane, Baronet (1660-1753) the British physician and naturalist, with particular interest in plants. Being an enthusiastic collector he gathered a legacy that gave rise to the British Museum in 1759 (The British Museum, 2015). It was in his voyage to Jamaica, during the short stoppage in Madeira Island that he collected some plants (Menezes de Sequeira *et al* 2010).

[7] Among many notable naturalists that visited Madeira Island a few should be highlighted such as: Leopold Von Buch (1774-1853), Christen Smith (1785-1816), Philip von Martius (1794-1868), Giuseppe Raddi (1770-1829), Heinrich Kuhl (1796-1829), Thomas Bowdich (1791-1824), Philip Barker Webb (1793-1854), Charles Bunburry (1809-1886), Charles Lemman (1806-1852), Christian Lippold (1788-1852), Richard Thomas Lowe (1802-1874), Carl Lindman (1856-1828), Theodore Vogel (1812-1841), Oswald Heer (1809-1883), Friedrich Welwitsch (1806-1872), Charles Lyell (1797- 1875), Gilbert Mandon (1799-1866), Herman Schacht (1814-1864), William Trelease (1857-1945), Joseph Dalton Hooker (1817-1911), Thomas Vernon Wollaston (1822-1878) (Conceição & Menezes de Sequeira, 2007 pp. 190-191).

publications, and also the letters that they wrote to each other, are a remarkable source of data about species-occurrence (Harcourt 1851; Conceição & Menezes de Sequeira 2007; Menezes de Sequeira *et al.* 2010; Vieira 2014a) and therefore an important record about composition and structure of vegetation of that time. Several of those naturalists happened to stay more than a short time, such as Lowe[1], who in the course of his career as Anglican minister lived in Madeira from 1827 to 1852, or as Heer[2], who spent several months (1850 to 1851) in Madeira to treat pulmonary tuberculosis (Marques 2013 and the references made therein).

In fact, pulmonary illness was the reason why Madeira Island became a popular destination throughout the 19th century, attracting diseased and convalescent from all Europe, where air pollution resulting from industrialisation prevented a speed healing. Since the end of the previous century that therapeutic qualities of Madeira Island's climate in curing stubborn respiratory diseases were stressed by medical community but its development as health resort has been enhanced by Napoleonic Wars that have blocked terrestrial and maritime access to more renowned treatment centres located in South France and Italy. However, even after 1815, when the conflict was brought to an end, tourism activity did not break down vis-à-vis its competitors and Madeira Island grew as a tourist area increasing the number of visitors both on account of their state of health and just to spend the winter in a milder weather (Wells 1880; Melo & Farrow 1983; Silva *et al.* 1985; Vieira 2014a). Amongst those who lived in the island, for more or less time, some ventured to visit difficult-access locations (Figure 1.4) and left a legacy of landscape drawings, sketches, watercolors and paintings [e.g. Isabella de França[3] (1853-1854), *inter alios*]. According to Sousa (2008) even though some landscapists were Portuguese as e.g. Tomás José da Anunciação[4] (in 1865) most of them were English, and all together carried out an important historical record of 19th landscape. Whilst being

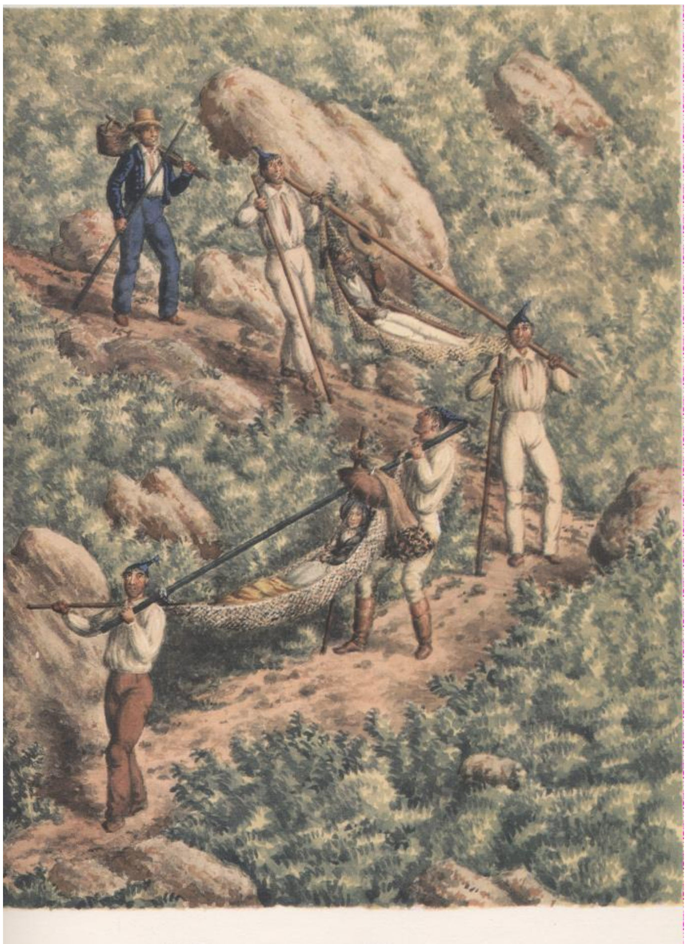

Figure 1.4 Illustration accompanying the description of the excursion to Rabaçal ["(...) cut through a forest of laurel, myrtle and other evergreens, growing so thickly together, that the whole forest seems one tangle mass of leaves."(De França 1854, pp. 104-105)].

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[1] Rev. Richard Thomas Lowe (1802–1874) was the English chaplain who lived in Madeira for more than twenty years who extensively studied the local flora and fauna describing many species new to the science (Silva & Menezes 1946a).

[2] Oswald Heer (1809-1883) the Swiss Professor of botany, geologist, and one of the pioneers in paleobotany. During his stay in Madeira Island made paleontological study of the Pliocene-Pleistocene deposit of São Jorge and phenological observations in exotic plants (Silva & Menezes 1946a, c).

[3] Lady Isabella de França (1795-1880) the English wife of José de França, also born in England but Portuguese on his father's side and landowner (*morgado*) in Madeira Island. She lived in Madeira for seven months and wrote a diary that remains one of the most detailed descriptions of landscape, uses, costumes, social life, fauna, and flora of nineteenth century (Santos Simões 1969).

[4] Tomás José da Anunciação (1818-1879) the Portuguese painter, who enjoyed fame painting landscape and animalistic themes. He came to Madeira at the invitation of Count of Carvalhal and left three paintings depicting views of the island (Sousa 2008).

difficult to apply photogrammetric techniques, because frequently Romantic artists did not depict the views with great accuracy and often modify the features in the landscape, those images can still be helpful to reconstruct past environments and have been widely used for that purpose (Clement 1999; Farag-Miller *et al.* 2013). However, in Madeira landscapes the vegetation portrayed shows more often agricultural species [e.g. banana tree seen in Ackermann (1821)] than native trees. The latter were sometimes depicted in engravings and prints but its identification is difficult and normally achievable for those with a very peculiar shape [e.g. *Dracaena drago* (L) L: subsp. *drago*][1] (Vieira 2014a).

Despite the controversy about the benign nature of Madeiran climate, which emerged among medical experts, therapeutic tourism continued throughout early twentieth century bringing people from all over the world looking for the cure for a broad array of diseases, mainly pulmonary problems (Vieira 2014b). Aiming to inform the medical community, and those suffering from consumption, books were published (e.g. Pitta 1889) which apart from medical opinion also included meteorological data, lists of plants and animals, and a guide with helpful information for visitors.

Also, because Madeira was a convenient stopover port of ships traveling to the South and West Indies, it developed into an active cosmopolitan region, published by a multitude of albums sold as souvenir (e.g. Wagner 1885 *ca.*), tourist guidebooks (e.g. Jardim 1914), as well as articles and reports in magazines, journals and newspapers (e.g. Santos 1905; Fairchild 1907). Many of those guides were travelogues that were published containing engravings (e.g. Ackermann 1821; Picken 1840), and lithographs (e.g. Harcourt 1851), copied from landscape paintings and drawings made during their stay, descriptions of the island and useful information, as other typical guidebook. Those texts often included information on local flora merely as part of landscape description (e.g. Picken 1840) or supported by a list either made by the author himself (Ackermann 1821; Soares 1882) or deriving from scientific publications (Harcourt 1851). Although varying in scientific objectivity they are an important historical record (Garcia 2000) which can be used to get information on species occurrence, its distribution and abundance.

The invention of photography in the first half of the nineteenth century and its rapid evolution allowed to capture more detailed information, making it the ideal means to record memories. Madeira landscape was early documented by those tourists, whose interest in photography was to such a point that some hotels provided a dark room as a way to attract clients (Melo & Farrow 1983). Also among locals, photography had become very popular, especially among the wealthier families who photographed tours around the island, holidays and family events. Also important for that record was the activity started by local photographers as Vicente Gomes da Silva (since before 1856) and Manuel Olim Perestrello (since 1879) that were followed by generations of photographers. Since then, Madeiran landscape is being photographed both as main subject, just due to artistic flair or for business to sell photographs to tourists as souvenir, and as background when recording a variety of events in the foreground (Melo 1978; Araújo 1990; Abreu *et al.* 2004; Pupo-Correia *et al.* 2011a). Because the earliest aerial photography of Madeira territory was taken in 1960s, those ground based pictures are the unique photographic record of landscape prior to that date (Pupo-Correia 2007).

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[1] Commonly know as dragon tree, and locally by *dragoeiro.*

1.2.2.2 From pre-settlement to present: a brief historical overview

Many authors pointed out the fact that Madeira Island is so called because being the land clothed by a dense forest with very large trees, as no longer existed in overexploited forests all over mainland (Corrêa 1927), they named it with the Portuguese noun "madeira", meaning wood, timber. In fact all descriptions reporting the arrival and early journeys that were made to explore the new land refer a thick forest with big trees and canopy density so high that the sun light hardly penetrated the crown. The understory was so pretty dense and the accumulation of stumps, branches, and leaves was so great, which disguising steep slopes and deep gorges made that it was not only difficult to walk but also very dangerous (Cadamosto 1445-1455; Camões 1572; Frutuoso 1589; Mello 1660; Cordeiro 1717). It is very important the early account of forest structure describing a climax forest with very old trees, and crowns, as they were seen from the sea, reaching the same height[1], occasionally with a single tree[2] standing above the general canopy level, and with very few clearings formed by fallen trees of old age[3] (Frutuoso 1589; Cordeiro 1717). The best narrative of pristine vegetation belongs to Frutuoso (1589), that besides being the most comprehensive one it is known to be based on Gonçalo Ayres Ferreira early description (Silva & Menezes 1946a). Below is a transcript of the of such descriptiont:

> *" (…)Toda esta ilha fragosíssima e povoada de alto e fresco arvoredo, que, por ser tal, se perdem alguns caminhantes nos caminhos, e aconteceu já alguns perdidos, neles morrerem. E não, tão somente, há pelo meio e lombo da terra grandes e alevantadas serranias, mas também grotas e altas funduras, cobertas de matos e grossos paus e arvoredo de til (…), vinhático (…) aderno, (…) folhados (…), cedro (...), azevinho (…) louro (…) barbuzano, (…) e nas faldras da serra, da banda do sul muita giesta (…) e não faltam muitas urzes (…)"* (Frutuoso 1589 p.55).[4]

This accout not only characterises the pre-settlement vegetation but amply demonstrates the great difficulty that must have been to disembark as well as to settle down. In such circumstances, Zargo (Zarco) ordered to set the forest on fire. This event that would have consumed the forest during seven years was reported by several historians, and transmitted by oral tradition as well. Given the accumulation of great quantity of biomass the fire severity must have really been huge. In fact, several accounts refer that people were forced to seek refuge in the sea due to the enormous heat whenever the wind was blowing from land (Cadamosto 1445-1455; Frutuoso 1589). However, although all authors

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[1] "(…) *toda coberta de formoso arvoredo, tão igual, por cima, que parecia feita à mão, sem haver árvore mais alta que outra*, (...)" (Frutuoso 1589, p.20); meaning: "all covered with fine woods, so equal on the top as if it was handmade, without one tree higher than the others".

[2] "(...) *Antre este arvoredo igual e espaçoso iam entremeados alguns cedros, tão altos que se divisavam por cima das outras árvores,* (...)*"* (Frutuoso *1589*, p.20), meaning: "They saw some cedars interspersed among the trees of a spacious and equal wood, which were so high that were viewed above the canopy of the other trees".

[3] *"(…) acharam um formoso e deleitoso vale coberto de arvoredo por sua ordem composto, onde acharam em terra uns cepos velhos derribados do tempo, (…)"* (Frutuoso *1589*, p.20), meaning:"they found a beautiful and delightful valley all covered with trees, with some old stumps that were thrown down by time".

[4] "The island, with steep slopes, is covered with high trees, and because of that several walkers got lost in the way, and some of those that were lost have died. In the middle there are not only high rugged mountains but also deep gorges and steep cliffs, covered with scrub, trunks and trees like stink-laurel (*Ocotea foetens* (Aiton) Baill.) (…) Madeira mahogany (*Persea indica (L.) Spreng.*) (…) aderno-tree (*Heberdenia excelsa (*Aiton) Banks ex DC.) (…) lily of the valley tree (*Clethra arborea* Aiton) (…), juniper (*Juniperus cedrus* Webb & Berthel. subsp. *maderensis* (Menezes) Rivas Mart., Capelo, J.C. Costa, Lousã, Fontinha, R. Jardim & M. Seq. and *J. turbinata* Guss. subsp. *canariensis* (Guyot) Rivas Mart., Wildpret & P. Pérez) (…), holly (*Ilex canariensis* Poir. and *I. perado* Aiton subsp. *perado*) (…) laurel (*Laurus novocanariensis* Rivas Mart., Lousã, Fern. Prieto, E. Dias, J.C. Costa & C. Aguiar) (…) *barbusano-tree* (*Apollonias barbujana* (Cav.) Bornm. subsp.*barbujana*) (…) and in the base of the mountain, facing south, there is a lot of broom (*Genista tenera* (Jacq. ex Murray) Kuntze) (…), and likewise many heath (*Erica platycodn* subsp. *maderincola* and *Erica arborea*) (…)".

agreed that the fire had in fact occurred, there is a large divergence about the extension and duration of the fire. Two facts have allowed for some belief in the fact that the event may not have been continuous in time nor the island was entirely burned down. First, being the region prone to torrential rainfall the amount of water should be strong enough to put out the fire during part of the year, and second, the massive forest exploitation that took place over succeeding centuries indicates that a huge part of the forest did survived (Cadamosto 1445-1455; Mello 1660; Pereira 1989). Anyway, several descriptions stressed that the fire was not limited to Funchal valley where it was kindled. It spread consuming from low-lying vegetation to tree canopies, and also as subsurface fire by slowly burning roots[1] and igniting fires in the open air in unexpected areas away from the place that was set on fire[2] (Frutuoso 1589; Cordeiro 1717). The destruction of the vegetation that was started by this great fire was enhanced by others. Some were small-scale fires aiming agricultural land reclamation and to create space for pasturing or to speed up regrowth of grasses, a practice that has prevented the full recovery of primeval forest. Others, caused either by carelessness or malice, have also reached catastrophic proportions causing forest devastation and considerable ecological and economic damages, as for instance the huge fire in 1919 that was kindled in retaliation for the Pastures Act of 1913 (Sequeira 1913; Silva & Menezes 1946b; Azevedo 1950; Andrada 1990).

Agriculture and grazing, which were indirectly responsible for deforestation by fire, also had a direct bearing on forest damaging (Sousa 1994). Although no large extensions for pastures were available it has always existed a high number of stock breeders that reared mainly sheep, goats, and cows, but also some pigs and horses. Whether by putting them to graze unsupervised in the hills (Figure 1.5) or by pruning native trees as e.g. *Clethra arborea*, *Myrica faya* Aiton, and *Ocotea foetens* as fodder for stabled animals, burning down scrub to create pastures, they were one of the primary causes that largely prevented natural regeneration (Corrêa 1927; Sousa 1946; Boesser 1951; Natividade 1953; Pereira 1989; Andrada 1990; Vieira 1992). Agricultural growth, both for feeding the expanding population and to establish cultures which were the mainstays of island economy during centuries, as sugar cane and vines, led to the destruction of native vegetation that covered desired fields. In addition, because sometimes they attempted to grow in less suitable soils, and often by using inadequate farming practices, it led to soil degradation and committed native vegetation renewal after abandonment[3].

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[1] “(…) *a arder no vale o fogo, e não só pelas árvores de cima, e muito mais por baixo d’ellas em infinita corrida, e seca lenha, mas também por baixo da mesma terra andava lavrando cruel fogo pelos subterraneos troncos sem se poder apagar* (...)” (Cordeiro 1717 p. 103), meaning: “in the valley the fire was burning not only above the trees but also much more beneath them, consuming dry wood in an endless race. Also, under the same land through the underground stems, the cruel fire was ploughing without being possible to put it out”.

[2] “(...) *apegou o fogo de maneira neste vale do Funchal* (...) *que andou sete anos apegado pelas árvores e troncos e raizes, debaixo do chão, que não se podia apagar e fez grande destruição, assim no Funchal como em o mais da ilha, ao longo do mar, na costa sul* (...) *e além* [para lá da Ribeira Brava], *acharam ainda o fogo que mandou pôr pela costa, pela razão que não puderam passar* (...)” (Frutuoso 1589 pp. 34, 36), meaning: “Funchal valley had caught on fire with great intensity (...) and the fire prevailed for seven years burning trees, trunks and roots below ground, and because it was not possible to extinguish it, the destruction was very huge, not only in Funchal but also along south coast (…) and farther away [beyond Ribeira Brava, that was near where they stop in first exploration tour] they had found the fire, slightly far from the coast, and couldn’t pass through it”.

[3] *“É uma mania introduzida na ilha, que semeada a giesta e ocupada a terra por 5 ou 6 anos, largando-lhe o fogo produz melhor pão. (…) Enfraquecem a terra com o fogo e depois a abandonam. Eis aqui de onde procedem as quebradas, porque a ilha é toda cortada de ribeiras e ribeiros, muito próximos uns dos outros, formando altos lombos, e nas encostas deles é onde fazem as roçadas, (…) apenas tem 1 e ½ palmos de terra que estas chuvas levam à ribeira, ficando a pedra solta e alguma agarrada ao salão e por consequência cai.”* (Almeida 1817, p. 83) meaning: “It is a fad introduced in the Island. It is believed that sowing broom [*Cytisus scoparius*], and setting it on fire after five or six years the wheat production increases. (…) but because of this the soil becomes thin and poor, and land is abandoned. This is the main cause of the frequent landslides, because the slopes, were these clearings happen, have a lot of streams and rivulets that carry away the soil removed by rain, remaining only stones that fall down sooner or later.”

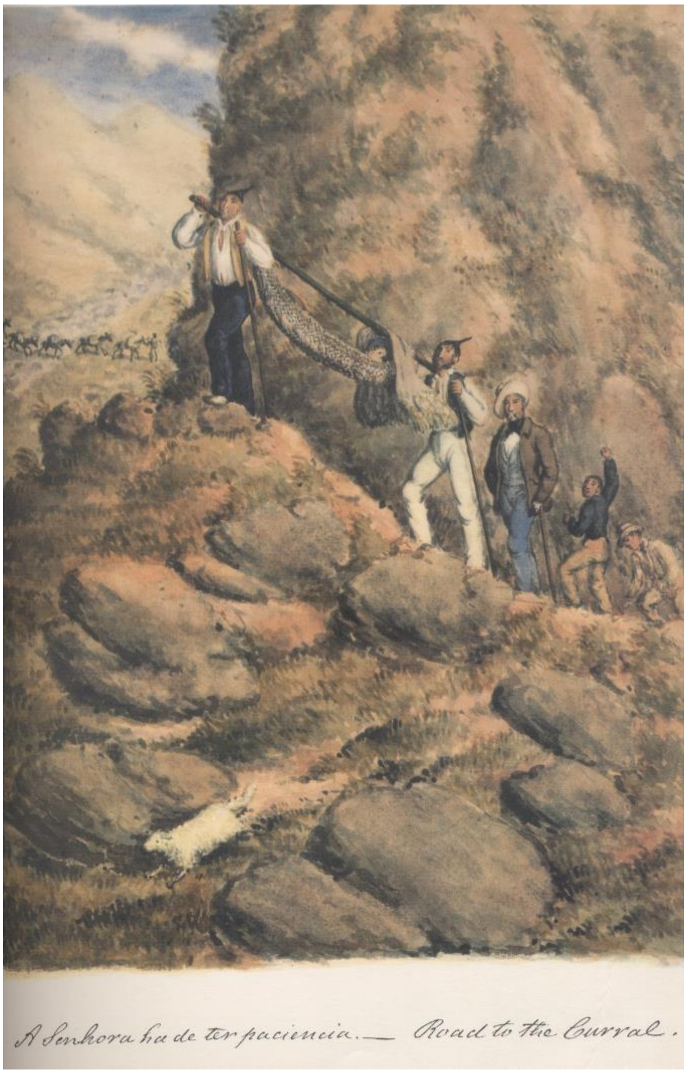

Figure 1.5 Illustration accompanying the description of a tour in the mountains "Here were wild goats, cows, and ponies enjoying their mountain liberty uncontrolled by man, in places where it appear as if no animal unsupplied with wings could have attained to, (…) (De França 1854, p.140).

Thus, it is clear that agriculture was a crucial factor for the disappearance of native vegetation, and species that today are rare or extinct could have been very abundant before the settlement. Agriculture was also responsible for exotic species introduction that becoming naturalised have brought about a dramatic change of local flora and guided vegetation landscape far from its original state (Silva & Menezes 1946b; Andrada 1990). Many of these species were not cultivated for food production, as sumach[1] (*Rhus coriaria* L.) (Frutuoso 1589), and prickly pear[2] (*Opuntia tuna* Mill.) (Figure 1.6), but as an attempt to produce raw materials to supply different industries, or as the giant reed (*Arundo donax*) planted in limits of agricultural parcels as windbreaks or to protect them from erosion, and to provide trellis for grapevines grow (Forster 1777; Bowdich 1825; Silva & Menezes 1946b; Silva & Menezes 1946a; Vieira 2002). Because exploitation ceased and traditional uses were abandoned some of those plants spread over native species habitat preventing them to regenerate (Jardim & Francisco 2005; Jardim & Menezes de Sequeira 2008)

Another cause for pristine vegetation depletion was the exploitation of wood products[3]. Timber harvesting of native trees not only provided the material for local building but, given its abundances, it was also highly exported to the mainland and to other European countries, where they were greatly praised (Visconde do Porto da Cruz 1950). According to Azurara (1434-1448) immediately after the settlement so much wood was exported from the island, that a change was produced in the house building in Lisbon with the construction of loftier edifices with a new architectonic style. At that time, all over Portugal there was furniture made of fine wood from Madeira Island (Cadamosto 1445-1455). Another change brought about by the

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[1] "(...) *muito sumagre, que serve para curtir couro (...) colhe-se cada ano, cortando-se rente com a terra para não secar a soca dele e poder tornar a rebentar, por ser planta que dura muitos anos na terra. É novidade de muito proveito porque multiplica tanto, que se enchem os campos dele* (...)" (Frutuoso 1589 p. 56), meaning: "large production of sumach, used for tanning, which is cut each year leaving stools in the ground to produce new shoots, because it can live for many years. This is a novelty product with a great added value because it multiplies so much that the fields become quite full of it".

[2] Locally known as *tabaibos* ou *tabaibas*, a species that was introduced in eighteenth century and intensively cultivated during all nineteenth century for cochineal carmine (Silva & Menezes 1946c).

[3] As shown in the following excerpt of "Timber Rules of Procedure", enacted in1562: "(…) cortavam as ditas madeiras e lenhas em muito mais quantidade da que lhe era necessária e muito levavam para fora da dita ilha e outras se perdiam sem aproveitarem delas as pessoas, que as cortavam" meaning: "timber was logged in larger quantities than it was needed. In part it was exported but other part was lost not being used by people who had cut them down" (Camacho 1920).

abundance and size of the trees that existed on the island, which was much more important than the former, was the improvement in ship design and construction that occurred throughout this period which allowed the Portuguese maritime discoveries that followed (Frutuoso 1589; Silva & Menezes 1946c; Pereira 1989). The most appreciated wood species was *Persea indica* that was mainly used to make boxes to transport sugar, and also to make robust house chests to keep belongings. It was highly exported to England, particularly during the eighteenth century, where it was known by the name of Madeira mahogany (Bowdich 1825; Macaulay 1841). Among the main wood species used for furniture and construction were referred: (1) *Ocotea foetens* that was primarily used for building and flooring, but was also used to make furniture after *vinhático* wood started to become scarce (2) *Juniperus cedrus* subsp. *maderensis* that was very exploited especially for roof beams, and clothe chests due to its scented wood; (3) *Heberdenia excelsa* often used to make barrels, especially for honey; (4) *Clethra arborea,* which was very employed for farming and everyday household utensils; (5) *Taxus baccata* L. that was much appreciated for bow fabrication (6) *Apollonias barbujana* subsp. *barbujana* that having a very hard and compact wood was used for structures in contact with ground and water as bearing structures of buildings and poles for trellised vines; and (7) *Picconia excelsa* (Aiton) DC, also with extremely hard wood, which was used to make press spindles and keelboats. In addition, these native tree species were also exploited for some applications other than woodwork such as the production of lighting oil with berries (*Ocotea foetens*, *Heberdenia excelsa*, *Persea indica* and *Laurus novocanariensis*), medicinal oil (*L. novocanariensis*), and tannery (*H. excelsa*, *Myrica faya* and *P. indica*) (Cadamosto 1445-1455; Frutuoso 1589; Silva & Menezes 1946c; Pereira 1989; Andrada 1990; Vieira 1992).

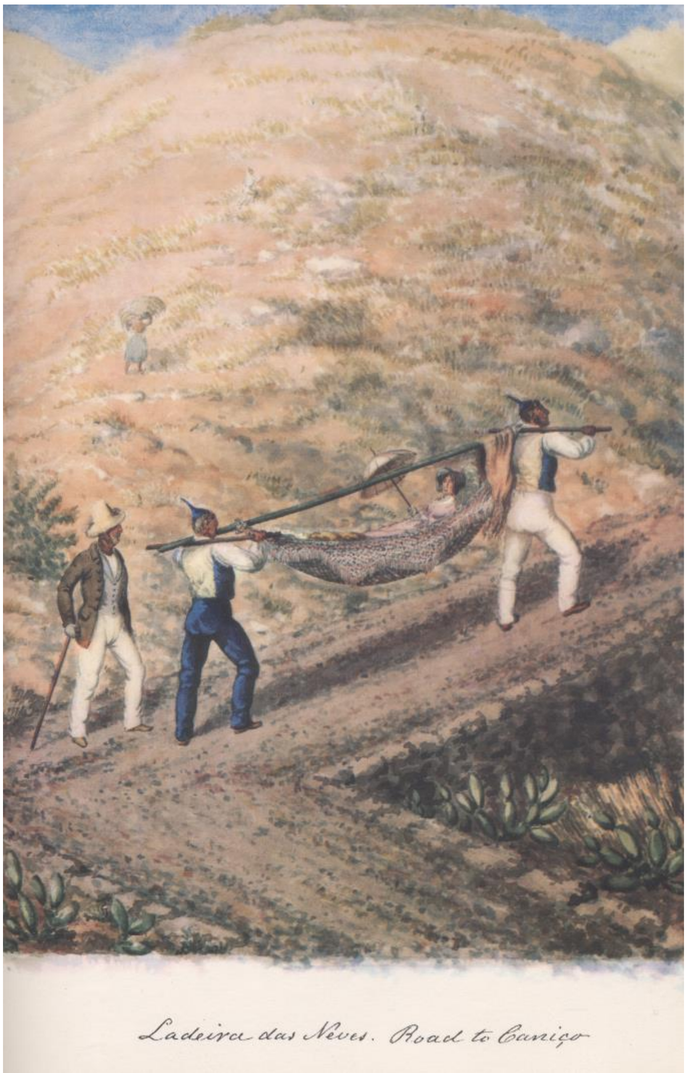

Figure 1.6 Princly pear, one of the exotic plants more often depicted in illustrations made by travellers, principally the ones showing southern coastal areas, in a landscape dominated by herbaceous vegetation. Illustration accompanying the description of the “expedition to Caniço” (De França 1854, pp. 152-153).

Another major cause of remnant vegetation destruction, as well as the one that was recovering, was its use as fuel and to produce charcoal (Sequeira 1913). Some species were highly used as burning firewood in sugar cane mills, like *Ocotea foetens*, and for this reason were very exploited (Andrada 1990). Although the amount of laboring engines had varied over time it required cutting wood in such a quantity that forced logging throughout the year and storing the timber until sugar cane harvest time (Frutuoso 1589; Silva & Menezes 1946b; Vieira 1999). Some other species as *Myrica faya*, *Genista tenera,* and *Teline madeirensis* Webb & Berthel were also quite employed, both for domestic and industrial use. For the charcoal production heath (*Erica arborea* and *E. platycodon* subsp. *maderincola*) was prefered, although some other species have also been widely used as *Ocotea foetens*, *Myrica faya*, *Vaccinium padifolium* Sm., *Clethra arborea* and *Laurus novocanariensis*. Timber from these species was often used in illegal charcoal production which used a rudimentary process of burning piles of wooden logs. This process, consuming more timber when compared to the sealed metal container method, led to further destruction of native woody flora (Dionísio 1950; Visconde do Porto da Cruz 1950; Pereira 1989; Andrada 1990). The description made by Paulo Dias de Almeida (1817) gives an account of the rate at which forests were destroyed both by firewood cutting and the activity of charcoal producers, referring that during his stay on the island (around 10 years) an entire mountain was completely deforested, and only very few trees, located in inaccessible scarps, were not cut down. Although sugarcane mills activity had decreased after sugar production stopped, in the eighteenth century, alcohol production and steamboats which call at the port of Funchal still demanded great quantity of fuel. Despite the activity having decreased due to reduction in demand and, after the 1950s only allowed on certain conditions, it continued to be practiced until early 1980s by using native woody flora and impacting on the forest recovery (CFF 1952-1980; Andrada 1990)

From almost the outset there was a clear perception of deforestation problem. Since less than one hundred years after the settlement several attempts started to be made to protect the forest. Some of those legislative acts and administrative arrangements strived to eliminate the causes of forest destruction and others aimed afforestation of bare areas. Because it was found from early on that grazing had a very serious adverse effect, assorted attempts were made to control this issue. In the fifteenth century, a Royal Warrant decreed open hunting to goats and pigs in a specific locality (Ribeira dos Socorridos) which was already showing serious damage in vegetation. During the sixteenth century, a compulsory measure imposed by the governor João António Sá Pereira had attempted to regulate unrestrained grazing (Pereira 1989). But neither these measures nor the Pastures Act of 1913 managed to put an end to the pernicious habit of letting the cattle loose to graze completely unsupervised (Pereira 1989; Andrada 1990). This is why when the Forest Service (Circunscrição Florestal do Funchal) was established in 1952 faced a great resistance from cattle breeders that hamper the deployment of forestry and pastoral regime, a measure that was urgent to laid down in order to solve the deforestation problem (Neves 1950; Pereira 1950; Andrada 1965, 1990).

Yet, the first diploma that clearly aimed to halt forest cover loss was the Royal Warrant by D. João II, in 1493, which despite comprising provisions concerning regulation for water use and to protect fresh water springs, also prohibited felling tree species which had become very rare, such as the cedar (Frutuoso 1589). Subsequently, in 1515, King D. Manuel I promulgated a law which forbade timber harvesting without legal authorisation, which should not be granted if trees were close to fresh water springs and streams. In 1562, the Queen D. Catarina has given royal assent to *Regimento das Madeiras* (Timber Rules of Procedure) launching a vigorous campaign against the forest destroyers by imposing drastic measures in attempt to save the remaining woods. This very first Forestry code implemented penalties such as fines, lashing in public squares and deportation to Africa, to be applied against someone found cutting or carrying timber or firewood without proper permission. However, even this very strict regulation was able to solve the problem (Andrada 1990; Menezes de Sequeira *et al.* 2007).

Because deforestation had got to such a state it was not enough to prevent forest loss. In view of this situation, governments and local authorities, such as municipal councils, began to legislate on measures to recover the areas without vegetation, especially those showing signs of soil erosion. After the legislation promulgated by the King D.

Manuel that, in addition to logging restrictions, already issued orders for planting, several other Regulations and Royal Charters were enacted to force landowners and tenants to plant trees. The tree species that were ordered to plant were always exotic species, and until the eighteenth century the species most frequently imposed were the pines (*Pinus pinea* L. or *Pinus sylvestris* L.)[1], chestnut tree (*Castanea sativa* Mill.)[2], and walnut tree (*Juglans regia* L.), whereas other were also targeted,such as the mulberries (*Morus nigra* L. and *M. alba* L.) [3].

In the eighteen century some plant nurseries were constructed, meant primarily to be used as acclimatisation gardens for tropical plants to be carried to European gardens. These nurseries, however, also ended up assisting local afforestation insofar thousands of exotic plants were taken to cover the bare ground (Silva & Menezes 1946c; Pereira 1989; Menezes de Sequeira *et al.* 2007). After that, in the nineteenth century, and particularly during José Silvestre Ribeiro governance (1846-1852), the maritime pine (*Pinus pinaster*) was widely cultivated and forest stands formed by this species spread all over the island (Silva & Menezes 1946a, c; Pereira 1989).

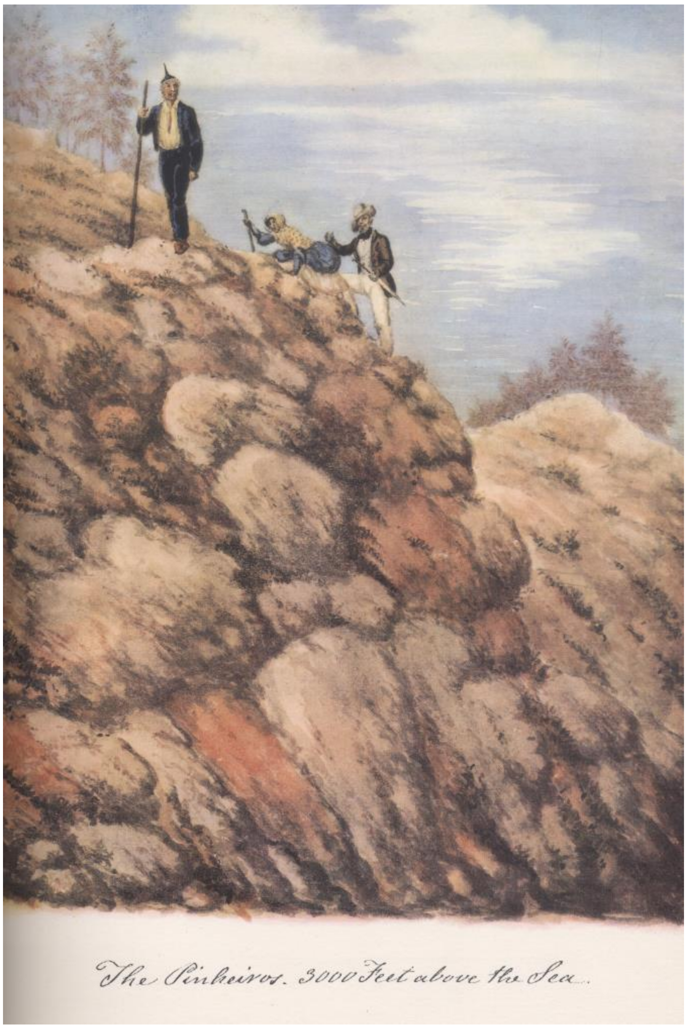

Figure 1.7 Young pine trees which have been recently planted at an altitude of about 900 metres. "Higher in the mountains immense quantities of pines have been planted, mostly within the last twenty years (…)" (De França 1854 p. 62).

Several other exotic trees[4] were also used to afforest non-agricultural land, but the pine tree (Figure 1.7) was the one more often mentioned in landscape descriptions of that time (Ackermann 1821; Picken 1840; Harcourt 1851; De França 1854; Soares 1882). Until the twentieth century only exotic tree species were used to create forest resources (Camacho 1920). There is no reference that native trees were used for reforestation prior to that date, although, over the centuries several measures were taken to protect them, mainly *Apollonias barbujana* subsp. *barbujana, Heberdenia excelsa, Juniperus cedrus* subsp. *madeirensis, Laurus novocanariensis, Ocotea foetens*, *Persea indica*, *Picconia*

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[1] There is no indication of the pine species; however Silva & Menezes (1946a) mentioned stone pine (*Pinus pinea*) as the pine tree that was firstly grown in the island, and Bowdich (1825) refers *Pinus sylvestris* as the species widely cultivated in lower parts of the island.

[2] The chestnut was until the first half of 19th century the most outstanding tree on the lower parts of inland mountains and also on the north coast (Macaulay, 1841).

[3] Accordingly to Pereira (1989) mulberry trees were introduced in early 16th century, but this first effort failed as well as when it was re-introduced in the 19th century aiming silkworm rearing.

[4] *Quercus robur* L., Q. *ilex* L., Q. *suber* L., *Anacordium occidentale* L., which cultivation was highly encouraged throughout this period and *Eucalyptus globulus* that was used in a forest stand located near Funchal which became a sort of nursery providing plants to whole island (Silva & Menezes 1946a; Pereira 1989).

excelsa and *Taxus baccata*). On this matter Silva & Menezes (1946b) called for the use of native plants for mountains reforestation in contrast to what was currently followed. They drew attention to the fact that despite the existence of exotic species able to adapt to Madeiran climate, there was no need to use them having local flora thirty two spontaneous trees and shrubs much better adjusted to the soil and relief of the island. According to these authors this fact alone should have been enough to choose them, although the core issue should always be the priority to conserve and protect indigenous flora.

Despite the fact that from early on it has always been suggested the planting of indigenous tree species, only at the beginning of the 20th century had it become a clearer reference (Sequeira 1913; Silva 1946; Menezes de Sequeira *et al.* 2007). However, although the idea of using native species for reforestation was mooted it did not take place at that time. For example, in the plan for afforestation of the mountain commonage land around Funchal, in 1913, in spite of the fact that was recognised the importance of native species due to the quality of their wood they were brushed aside by the exotic species. To justify the fact of not using native trees, the report on this work pointed out the fact that they were thought to be slow-growing species, and foremost because little was known about their cultivation under the harsh conditions found in eroded areas. In contrast, the plan appended a list with about 250 exotic tree species, including several wattle species (e.g. *Acacia melanoxilon* R. Br. and *A. dealbata* Link.), sweet pittosporum (*Pittosporum undulatum* Vent.[1]) and some eucalyptus species, mainly Tasmanian blue gum (*Eucalyptus globulus*) (Sousa 1946).

During the initial phase of the settlement, forest matters were supervised by the Captain-major (*Capitães donatários*) of the two Capitaincies in which the colony was divided (Camacho 1920; Corrêa 1927). After 1562, forestry matters fall under Municipal Councils supervision up to 1911, when it was established the Agricultural Division of Madeira (Junta Agrícola) that was in charge of technical assistance and administrative management of forests. This body was superseded, after 1919, by Forest Regency (*Regência Florestal*), that until 1946 held a massive afforestation, with plants and seeds brought from main land, Canary Islands, France and Germany (Silva 1946; Pereira 1989). By a Decree-law of 22 February 1951 it was created a local Division of National Forest Service (Circunscrição Florestal do Funchal), which was responsible for following-up the activities related to afforestation, conservation of native forest, and for controlling the utilisation of forest resources. A key work of the Forest Services was the placement of the mountain commonage land under the forestry regime, the management of forest perimeters and the regulation of pastoralism in upland areas. In addition, nine plant nurseries were established to provide plants for afforestation. They grew exotic tree species[2], from seeds acquired overseas, as well as native trees[3] both from seeds collected locally, and from Azores[4],

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[1] Known locally by *incenso* or *incenseiro.*

[2] Among the nearly 50 species that were most frequently used between 1952-1973, the following were introduced in greater quantity (around tens or hundreds of thousands in each forest stand): *Pinus radiata* D. Don., *Pinus sylvestris* Lour., *Pinus insignis* Douglas, *Pinus halepensis* M.Bieb, *Pinus canariensis* C.Sm., *Pinus patula* Schltdl. & Cham, *Pinus nigra* Aiton, *Picea excelsa* Link, *Pseudotsuga menziesii* (Mirb) Franco, *Cryptomeria japonica* D.Don, *Cupressus macrocarpa* Hartw., *Chamaecyparis lawsoniana* (A.Murray bis) Parl., *Quercus rubra* L., *Quercus robur*, *Quercus borealis* F.Michx., *Quercus ilex* L., *Fagus sylvatica* L., *Castanea sativa*, *Cedrus deodara* Loudon, *Eucalyptus globulus*, *Fraxinus excelsior* Bové ex A.DC., *Populus italica* Du Roi (CFF 1952-1973, 1953-1968-1953-1969).

[3] *Ocotea foetens*, *Persea indica*, *Ilex perado* Aiton subsp. *perado, Ilex canariensis*, *Juniperus cedrus* subsp *maderensis*, *Picconia excelsa*, *Apolonias barbujana* subsp, *barbujana* and *Heberdenia excelsa* (CFF 1952-1973, 1953-1968-1953-1969).

[4] At that time was current the exchange of seeds between different Forest Divisions. For instance, seeds of species that were regarded as the same [e.g. *Picconia excelsa* and *Picconia azorica* (Tutin) Knobl] were sent from Azores to Madeira, as well others that were known as being endemic species of Madeiran Flora were send to Azores (e.g. *Clethra arborea*) (CFF 1953-1968).

whose species were thought to be the same (CFF 1952-1973, 1953-1968, 1953-1969b; Pereira 1989; Andrada 1990; Menezes de Sequeira *et al.* 2007).

After the Portuguese Revolution, in April 25th 1974, Madeira archipelago has embarked on a process of regionalisation and local autonomy. Since then forestry policy measures drawn up by the government of Madeira fall in the competence of the Regional Directorate of Forests (Gonçalves & Nunes 1990). This body has been responsible for afforestation with a significant investment in native plants propagation, forest surveillance, and it was also responsible for the removal of cattle (goats and sheep) from the hills, a complicated process that was finally resolved in 2003, and which contributed positively towards natural vegetation recuperation (Menezes de Sequeira *et al.* 2007).

Despite several calls for the creation of an entity more geared towards conservation and management of natural heritage, that have happened almost since the beginning of the 20th century (Sequeira 1913; Neves 1950; Malato-Beliz 1977; Pessoa 1977; Andrada 1990), it was only in 1982 that the Natural Park of Madeira was created. The Park has an area of 56,000 ha, i.e. almost 60% of the total area of Madeira Island, including parts with distinct conservation status, and demanding specific conservation measures. It is also responsible for managing several nature reserves not included in the park area. In addition to watching over the protected areas, they are responsible for the scientific monitoring of habitats, and environmental education. The Botanical garden, also included in those early appeals, was created in 1960s and plays an important role in conservation of native species, especially the threatened ones (Gonçalves & Nunes 1990; Menezes de Sequeira *et al.* 2007).

Since Portugal accessed to the EEC, in 1985, it has been implemented several policy instruments and also financial support aiming environmental protection. There are several Directives that until now have made up protected areas based on Community legislation on this matter, as: (1) The Natura 2000 network whose sites comprises a large proportion of the laurel forests and the high-altitude tree-heath forest, although not covering the oleaster[1] tree microforest; and other coastal plant communities (2) Berne Convention that protects 40 plant *taxa*, due to their high rarity degree; (3) Habitats Directive that defined 49 priority species and five Forest Habitats, out of which three are priority for conservation (laurel, high-altitude heath, and *Juniperus* spp. forests), and also coastal habitats, even though regarded as less important (oleaster tree microforest and madeiran tree-spurge[2] community). Since the launch of the Life programme several projects have been financed (e.g. Life$_{99}$ NAT/P/6431 targeting conservation of rare plant species of Madeira Island, and Life$_{97}$ NAT/P/4082 supporting management measures to ensure appropriate conservation of laurel forest of Madeira Island), which have contributed to the conservation of some plant species and recovery of habitats. In addition, the laurisilva of Madeira Island (mostly stink-laurel forest) was classified by UNESCO as "Unesco Heritage site" which also contributed to the conservation of the largest area of natural forest of Macaronesia region (Menezes de Sequeira *et al.* 2007).

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[1] *Olea maderensis* (Lowe) Rivas Mart. & del Arco

[2] *Euphorbia piscatoria* Aiton

2 Vegetation

> *"A vegetação é um elemento estruturante fundamental das paisagens. Não só domina, pela sua biomassa, a maioria dos ecosssitemas terrestres, como constitui o habitat das populações animais e a sede da maioria das actividades produtivas e culturais humanas. É também o elemento que melhor integra a resposta biológica de uma paisagem aos factores do meio (físicos, biológicos e antrópicos). Possui também neste sentido, um enorme valor diagnóstico e sistematizador da paisagem."*[1] (Capelo 2003 p. 46)

The interest in landscape by phytosociologysts is not new. Braun-Blanquet[2] himself, although not devising any method of landscape inventory, introduced terms and concepts (e.g. association complex, association mosaic) and paved the way for later developments of *landscape phytosociology* (Capelo 2003). It was Bertrand[3] (1968) who firstly advocated landscape systematisation based on the study of plant communities. This author, whose ideas also have been central to modern *landscape ecology school*, set forth that phytosociological method is the one that better allows delimitating homogeneous landscape units. He has set up a spacio-temporal taxonomic system defining landscape units in which the elementary unit (geosystem) is defined as a homogeneous spatial category resulting from interaction between ecological potential, biological exploitation and anthropic actions (Pissinati & Archela 2009). Accordingly to Capelo (2003), several other distinguish connoisseurs of phytosociological methodology and landscape studies enthusiasts contributed to launch methodological bases of *landscape phytosociology s.l.* as vegetation landscape sciences. It is worth emphasising (1) Schmithüsen[4] who proposed the inductive analysis of landscape, in 1968; (2) Tüxen[5] who applied the Braun-Blanquet scale to vegetation associations which occur in the landscape, in 1973, and introduced, later on, the terms *sigmetum* and *geosigmetum*; (3) Rivas-Martinez[6] who established a hierarchy within the *synphytosociologic* units, in 1976; and finally (4) Géhu[7] and Rivas-Martinez that settled methodological bases for *synphytosociology* (dynamic phytosociology) and *geosynphytosociology* (dynamic-catenal phytosociology), in 1981; (Capelo 2003, and references therein).

During *landscape phytosociology* development it come out a variety of definitions and concepts with little consensus among phytosociologists [see Aguiar (2000) for details]. However, three levels of study are recognised within the integrated phytosociology (phystosociology *s.l.*): (1) *classical physociology s. str.* that focuses on *phytocenoses* (object) and *association* or *association* (fundamental abstract unit); (2) *dynamic* or *successional*

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[1] Meaning: "Vegetation is a defining element of landscape. It dominates most of the ecosystems due to its huge biomass, and constitutes the habitat for animals and location for human activities. Thus, it is the component that better integrates the biological response to different factors (physical, biological and anthropic), and its study has great value in the diagnosis and organisation of landscape information (Capelo 2003)

[2] A short biographical note was presented on p. 13.

[3] George Bertrand (1932–) the French Bio-geographer, who developed the GTP model to describe and analyse the geographical space.

[4] Josef Schmithsüsen (1909-1984) the German geographer Professor in the University of Saarland, in Saarbruecken, where he investigated and taught since World War II up to its retirement in 1977. He was one of the founders of modern geography and greatly contributed to current knowledge on vegetation science and landscape ecology (Hengesch 1985).

[5] A short biographical note was presented on p. 13.

[6] Salvador Rivas-Martinez (1935-) the Spanish pharmacist and botanist, Professor of Botany in Faculty of Pharmacy of Complutense University, in Madrid. Beyond intense phytosociological research all over the world he is responsible for the Worldwide Bioclimatic Classification System (Real Academia de Ciências Exactas Fisicas y Naturales 2015).

[7] Jean-Marie Géhu (1930-2014) the French botanist, Professor in Faculty of Pharmacy of Lille, who become known for his research on phytosociology and vegetation works applied to conservation (Taffin, 2014).

phytosociology that focuses on *series* (object) and *sigmetum* (fundamental abstract unit); (3) *catenal phytosociology* or *landscape phytosociology s. str.* that aims to study *geoseries* (object) and *geosigmetum* (fundamental abstract unit). These two last levels that evolved over last decades are gathered in a more comprehensive approach: dynamic-catenal, integrated or landscape phytosociology *s.l.* (Aguiar 2000; Capelo 2003; Rivas-Martinez 2005). Contrarily to classical phytosociology where concepts and methodology are more consensual, within *landscape phytosociology* were developed different methodological approaches to study vegetation complexes (Aguiar 2000). Accordingly to same author the methodology proposed by Géhu & Rivas-Martinez (1981), that defines *vegetation series* and *geoseries* by using sigmarelevés and geosigmarelevés (applying Braun-Blanquet scale) similarly to classic phytosociological method, is the most suitable to construct robust landscape hierarchical systems and having, additionally, a great value for territorial management.

Throughout time *phytosociology* has been criticised, largely based on groundless prejudice and detachment of progress made by vegetation science in last decades (Mucina 2010). One of the main issues was triggered by the old debate on Gleasonian[1] and Clementsian[2] succession theories about if vegetation occurs accordingly to a coherent community where individuals react similarly and succession process results from facilitation between species (the community-unit concept), or whether, on contrary, species respond individualistically to environmental factors, being the role of competition between species recognised, but not facilitation (the individualistic-continuum concept) (Capelo 2003; Santos 2010; Vellend 2014). But, being phytosociological approach focused in the existence of vegetation communities and the pattern explanation surge as a subsequent investigation, this is a pointless discussion that is beyond the objective pursued by phytosociology (Santos 2010).

In any case, because both schools have pros and cons, Austin & Smith (1989) looking for a unified theory developed a new hypothesis situated between the two concepts. Those authors re-defined the concepts by accepting the importance of the facilitation role together with competition in succession process and developed a model that enables to describe vegetation both continuously (continuous variation of composition along altitude gradient related to temperature gradient), and noncontinuously (co-occurrence of groups of species due to rugged terrain). Another model which has proven to be inadequate to explain real situations is the Clementsian concept of *mono-climax.* However, this does not mean that is not recognised the operational usefulness of the succession theory proposed by Clements. Conversely, the successional model is the most suitable to explain the replacement of subseral communities within a *Vegetation series* in the context of *sigmatistic phytosociology*. However, it was necessary to assimilate several objections made to Clementsian paradigm in order to explain situations, as for instance different vegetation types in areas with same mesoclimate (Aguiar 2000).

Thus, it is currently accepted the *phytocoenosis* as a result of species assembly driven by environmental selection, facilitation and competition. It shows specific spatial organisation and vertical stratification, and evolves to a metastable state. The time that takes to reach that state depends on the dominant species (e.g. stabilisation of grassland takes a couple of months whereas a forest develops very slowly). It is important to distinguish this stable community from temporarily communities which although important as pioneer assemblage, merely result from

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[1] Developed by Henry Allan Gleason (1882-1875) the American ecologist and taxonomist who started to work largely based on Clement's concept, but later developed "species-individualistic models" which were largely ignored until the 1950s, being the reason why he abandoned ecology and focus his work on taxonomy (McIntosh 1975).

[2] Developed by Frederic Eduard Clements. A short biographical note was presented on p. 12.

environmental selection and tend to disappear (Keddy 1992; Capelo 2003; Sänger & Jetschke 2004). The succession that begins in newly exposed surface (primary succession) is always a progressive succession, and plant communities replace each other tending to a stable end-stage (*Climax*) that it will persist in equilibrium, barring large scale disturbances (Rivas-Martinez 2002; White & Jentsch 2004). The replacement of vegetation stages within the *tesela*, after a disturbance in a pre-existing community, can be both progressive and regressive succession, and do not follow necessarily same stages. Identical *vegetation series* (*sigmetum*) can show subseral sequences with floristic and dynamic variations (*facies*) as consequence of differences in ecological factors. Presently two concepts are related to successional dynamics the concept of *sigmetum s. str.* (composed of more than one perennial stage) and *permasigmetum* (with few perennial stages and a poorly stratified climax community) (Capelo 2003; Rivas-Martinez 2005; Santos 2010). Although those two concepts cover the majority of successional dynamics some types of successional dynamics (e.g. ephemeral plant communities of wetlands) are not included (Santos *op. cit*). Attempting to achieve a more comprehensive approach this last author suggests to expand into three types of succession, based on disturbance/stress regimens: (1) *Edaphosigmetum*, corresponding to *sigmetum s. str.;* (2) *permasigmetum*; (3) *ephemerosigmetum.*

There is a general rejection of *monoclimax* concept advanced by Clements, however debates still continue regarding equilibrium vs. non-equilibrium processes, the latter related to alternative stable states theory (Laska 2001). However several studies suggest that while in a small area the processes are stochastic in larger areas there is a deterministic effect that directs succession upwards to one possible composition (White & Jentsch 2004; Prach & Řehounková 2006). This, however, does not imply the existence of a unique climax community within the *climatic dominion:* different stable communities can exist within a region under similar climatic conditions, and not every *seral communities* shift towards the *climatic climax* (Rivas-Martinez 1976, 2002, 2005).

The alternative idea of a variety of climaxes driven by topography, soil moisture and soil nutrients is not new, it was advanced in the early 1930s by Du Rietz[1], and it was upheld by phytosociologists as Tüxen, Géhu and Rivas-Martinez (Capelo 2003). Three different climaxes can be found, as a mature stage (head series) of a *Synassociantion* (*Vegetation series or Sigmetum*), within a similar teselar place: (1) *climatic climax*, the mature stage of the *climatophilous series,* which develops where pedological factors do not disturb the mesoclimatic conditions, normally located in smoother terrain that holds soil and rain water at field capacity. (2) *edaphoxerophilous climax*, the mature stage of *edaphoxerophilous series*, with plants resilient to dryness, which is found in xeric soils or rocky scarps, where even receiving same amount of rain it is not available because it percolates immediately and flows down; (3) *edaphohygrophylous climax*, as mature stage of *edaphohygrophylous series*, located at the bottom of the valleys where the rain water is supplemented by groundwater and water outflow. Each *vegetation series* has its own dynamics and different stages of succession can occur. The vegetation modification (*zonation*) that occurs under an ecological gradient (*e.g.* moisture) is, in this way, responsible for the occurrence of contiguous plant communities (*catena*) whose presence goes beyond climatic influence. The group of contiguous *sigmeta* along the ecological gradient is called *geosigmetum* (*geosigmassociation* or *geoseries*). This basic unit of *landscape phytosociology s. str* is the one located

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[1] A short biographical note was presented on p. 13.

in a certain *bioclimatic belt* within a biogeographical territory, and correspond to the *topographical geosigmetum.* The number of *geosigmeta* that can be found in a certain geographical area depends on relief, climate and geographical context. In complex terrains the occurrence of unusual edaphic features within the *tesela* are responsible for ecological niches, in which can be found a single non-stratified permanent community, with very few seral stages (*microgeosigmetum*). A different type of *geosigmetum* (*cliseral geosigmetum*) can be found above tree line where altitudinal *catenas* have fewer *geoseries* or even just the *edaphoxerophylous* one as result of inhospitable climate (Rivas-Martinez 1976; Costa *et al.* 1998; Aguiar 2000; Rivas-Martinez 2002; Capelo 2003; Rivas-Martinez 2005*).*

The *climax stage* is commonly accepted as being a mature forest where individuals are replaced overtime by others of the same type, and it typically happens when physical environmental conditions are favorable. However, on account of geographical or topographical reasons sometimes succession cannot reach the theoretical climax. It stops at a preclimax stage and the *subseral community* becomes a permanent community: i.e. a *paraclimax or topographical climax* (Capelo 2003; Capelo *et al.* 2005). Another type of climax can be found in little disturbed old-growth forests. Due to old trees senescence or minor disturbances related to natural disturbance regime gaps are formed in the forest canopy. In such conditions climax community vegetation does not regenerate, being the *synusiae* spontaneously fulfilled by xerophytic and heliophytic species of subseral communities. If the forest is big enough to maintain a seed bank succession will continue until reach the mature state and all forest will remain in a state of dynamic mosaic (*post-climax, cyclical climax*) (Capelo 2003).

Present vegetated landscape embraces both natural vegetation, *i.e.* the several *climax* and *subserial communities*, and the one of anthropogenic origin, *i.e*. agro-systems, afforested lands and altered natural ecosystems. However, vegetation complexes within territories under human influence are characterised separately (Capelo 2003). Normally *phytosociology* focuses on natural and semi-natural vegetation, but there are some examples of its application in urban environment (*e.g*. Pyšek *et al.* 2004)

Modern vegetation is in opposition to *pristine vegetation* which identification is only possible by using palaeoecological techniques which is not always feasible or practical. Tüxen in mid 50s, introduced the concept of *potential natural vegetation* (PNV), aiming to make an hypothetical assumption of what vegetation could be expected if human activity stops, under current environmental conditions. It was recognised since the beginning that sometimes the present climax vegetation does not match with the pristine climax vegetation (old climax) (Capelo 2003; Loidi *et al.* 2010; Mucina 2010). Because is not possible to exclude human influence (exotic species introduction, soil alteration, pollution) other concepts surged as *e.g.* PRV (potential replacement vegetation) specially to be applied in environments with certain hemeroby level (Chytrý 1998). Both concepts have been fiercely contested by using arguments based on palaeopalynology data to show PNV inability to reconstruct “pre-human” vegetation patterns (Carrión & Fernández 2009; Chiarucci *et al.* 2010). However, neither PRV nor PNV ever aimed to reconstruct vegetation patterns from geological times and it has never meant to foretell the vegetation that would establish after removal of human pressure. In fact, PNV is a tool that demands in-depth knowledge of the local flora, vegetation and environmental factors. It is based on present vegetation interpretation which is helped by information from other disciplines, namely paleobotany, and taking in account natural and anthropogenic changes. Potential natural vegetation cartography, which today is also supported by GIS technology, and predictive modeling, represents a useful tool for land management and planning (Capelo 2003; Rivas-Martinez 2005; Loidi *et al.* 2010; Mucina 2010; Pedrotti 2013).

2.1 Vegetation of Madeira Island

Since the eighteen century that the flora of Madeira Island attracted keen interest from botanists, especially because of the degree of endemism and the large number of plants that were likely new species to science. Thus, most of the endemic *taxa* that are presently known were described before the twentieth century, and can be found in early publications as *Species Plantarum* by Carl Linnaeus[1] in 1753 and *Manual Flora of Madeira and the adjacent Islands of Porto Santo and the Desertas* by Richard Thomas Lowe[2] in the end of nineteenth century (Lowe 1857, 1872), among several others. The first complete Flora was published by Carlos Azevedo Menezes[3] in early twentieth century (Menezes 1914) and it was the most updated source until the *Flora of Madeira* by Press & Short, published in 1994. Several cheklists scoped to list the *taxa* occurring in Madeira being the most recent and complete the *Ckecklist on Madeira and Selvagens* by Jardim & Menezes de Sequeira (2008). Accordingly to this publication the flora of Madeira Island comprises 1,204 species and subspecies (94.4% of the total *taxa* of vascular plants of the archipelago). Of these, 401 *taxa* are plants that were introduced and become naturalised, 95 have dubious *status*, 480 are native species, and 228 are endemic *taxa*. Within the latter group, 74 are Macaronesian endemics that are shared with Canary Islands (65), Azores (16), and Cape Verde (9). In what concerns the 154 *taxa* that are exclusive endemics of the two Portuguese archipelagos of Madeira and Selvagens, Madeira Island comprises 89.6% of the endemic vascular plants (136 species and 21 subspecies). The floristic richness of Madeira is clearly reflected by the fact that although being such a small island it comprises five endemic genera (*Chamaemeles* Lindl., *Melanoselinum* Hoffm., *Monizia* Lowe, *Musschia* Dumort, and *Sinapidendron* Lowe). Unfortunately it is also higly endangered: a few *taxa* are already extinct in Madeira Island (*Ruppia maritima* L., *Osmunda regalis* L., *Dracunculus canariensis* Kunth, and *Frangula azorica* Grubov), and most probably some others have disappeared before being described (Jardim & Menezes de Sequeira 2008; Menezes de Sequeira *et al.* 2011a).

2.1.1 Origin and evolution of the flora

Early on it was perceived that there were similarities between Madeiran, Canarian and Azorian plants, as well as in plants from some continental areas (Webb & Berthelot 1840). There were attempts to explain those resemblances. Some authors conjectured that these islands may have been part of the mainland in the past (Heer 1857). Others, such as Bowdich[4] (1825) and Macaulay[5] (1841), considered that the similarities in flora to be connected to seeds dispersal by wind, birds, marine currents and as well as adventitious introduction by ships, especially plants akin to American *taxa*. It was, however, in the twentieth century that the origin and phytogeographic affinities of Madeiran flora received deepest attention. The important role of geographical location of Madeira Island in relation to other islands,

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[1] A short biographical note was presented on p. 10.

[2] A short biographical note was presented on p. 16.

[3] Carlos Azevedo de Menezes (Meneses) (1863-1928) the Portuguese Botanist born in Madeira Island, Director of Biblioteca Municipal do Funchal until his retirement. Its nonacademic formation in botanical field was due to João Maria Moniz, the Madeiran reputable botanist (1822-1898). Author of Flora da Madeira, published 1914 (Silva 2012).

[4] Thomas Eduard Bowdich (1790-1824) the English traveler and writer who work for several years as writership at service of African Company of Merchants. He lived for several months in Madeira in his way to Gambia where he died of malaria. The account of this last journey was published by his widow, under the title "Excursions in Madeira and Porto Santo" (Chisholm, 1911)

[5] James Macaulay (1817-1902) the Scottish author, and journalist, graduated both on Arts and Medicine at the age of 21: After graduation he spent several months in Madeira contributing to the record of geography, geology, climate, flora and vegetation, that were published in different works. Later on he abandoned medical activity and focused on his career as periodical editor (Norgate 1912).

other Macaronesian archipelagos, and continents, from which diaspores could have come from, was recognised (Cockerell 1928; Boesser 1951; Sjögren 2000; Capelo *et al.* 2004; Capelo *et al.* 2005; Capelo *et al.* 2007; Fernández-Palacios *et al.* 2011). In spite of the controversy surrounding the definition of the geographic boundaries of the Macaronesian biogeographical region, it is currently accepted Macaronesia as a distinguished province formed by five volcanic archipelagos (Azores, Madeira, Selvagens, Canaries and Cape Verde). The archipelagos of Madeira, Selvagens and Canary Islands form the Macaronesian core and are greatly related to the Mediterranean domain. They share with each other the highest number of endemic *taxa* when compared with Azores and Cape Verde. However, although the distance between the former and the latter group, and the fact that their biogeographical affinities belong to different realms, they still share some endemic *t*axa and similar biotic elements. The sub-desert succulent coastal scrub and the thermophilous woodland in Cape Verde and the laurel forest in Azorean archipelago are related to analogous ecosystems of Macaronesian Central archipelagos demonstrating that they are united by a common biogeographic history (Fernández-Palacios 2011; Menezes de Sequeira *et al.* 2011a). Further support emerged by the advance in the knowledge of Atlantic bathymetry, and the acquisition of geo-chronological data, that permitted to follow the islands ontogeny and to reconstruct the *Paleomacaronesia.* Further support came from recent phylogeographic molecular analyses allowed a better understanding of colonisation, dispersion, and speciation events that were responsible for the origin of Macaronesian flora (Caujapé-Castells 2011; Fernández-Palacios *et al.* 2011, and the references made therein).

The strong affinity between present vegetation of Macaronesian islands and the extinct Tertiary flora of Europe was originally proposed by Heer[1] (1857), and highlighted by Darwin[2] (1859). Since then, it was traditionally considered a relic of the Palaeotropical geoflora that occurred over the margins of Tethys Sea until late Miocene (Cockerell 1928; Bramwell 1972; Bramwell & Bramwell 1974; Axelrod 1975; Sunding 1979; Mai 1989). This assumption was sustained by the fossil record showing genera, that formed the forests that covered the Southern Europe and Northern Africa, which become extinct from late Miocene onwards due to climatic changes (cooling and dryness), and are currently represented in the natural vegetation of those archipelagos (Axelrod 1975; Mai 1987; Capelo *et al.* 2007; Fernández-Palacios 2009; Barrón *et al.* 2010). Further arguments used by early authors in their time were: (1) the existence of several other relics of Tethyan-Tertiary flora found in small-discontinued areas of Asia and America (Axelrod 1975; Mai 1989); (2) the occurrence of low level of polyploidy of several *taxa*; and (3) the richness of floral elements with woody habit, which are in general small herbaceous plants in the continental areas. Some of those happen to be related to very rare woody *taxa*, also considered relicts, that are nowadays restricted to very small areas in the mainland (Bramwell 1972; Bramwell & Bramwell 2001).

However, relict theory started to be rebutted by the evidence that part of Macaronesian endemisms cannot be regarded as relicts and must be interpreted as having a neo-endemic character. The most conspicuous example is the woody flora, which belongs to genera usually comprising herbaceous plants. Those plants exhibiting woody habit represent a common evolutionary tendency within the oceanic islands that was firstly denoted by Darwin (1859) who, in those early times, expressed the assumption that some bushes and trees on the islands would have evolved from

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[1] A short biographical note was presented on p. 16.

[2] A short biographical note was presented on p. 11

herbaceous colonisers. It was, however, Carlquist[1] (1974) who enlightened *island woodiness* as a common phenomenon to islands all over the world, and assumed this occurrence as the result of adaptive radiation undergone by herbaceous ancestors that reached the islands. This approach is supported by several facts, namely (1) those woody plants have specific (paedomorphic) wood features congruous with evolutionary patterns (Carlquist 1962, 1966, 1970b, a, c); (2) the greater dispersal capacity of herbaceous plants (Carlquist 1983); (3) the molecular systematic studies performed in past years which provided a large amount of information about directional timing of colonisations and patterns of plant radiation. The latter enabled the confirmation of some putative herbaceous ancestors, the rapid radiation of monophyletic groups, the rather young age of several woody groups, and to verify that some of the woody relatives, considered relics living in some refugial areas in mainland seem to be, on the contrary, as resulting from back-colonisation (Carine *et al.* 2004; Kim *et al.* 2008; Caujapé-Castells 2011). However, the clarification of the evolutionary mechanism responsible for island woodiness still is subject of ongoing research, and so far, it was difficult to find a unique answer. Several hypotheses have been carried out based on competition [advantage by growing taller (Darwin 1859)], longevity [living longer and having greater reproductive success (Wallace 1878)], herbivory (absence of large herbivores), climatic (insular mild climate allowing plants to grow all year around) (Carlquist 1974), and drought resistance [wood formation triggered by drought (Lens *et al.* 2013)] but none has provided a satisfactory explanation to cover all situations. For instance, the woodiness habit as a physiognomical characteristic favouring when competing with trees fits well for forest woody plants [e.g. *Isoplexis sceptrum* (L.F.) Loudon] but is no longer suited to explain the evolution of non-forest groups (e.g. *Aeonium* Webb& Berthel.) (Capelo *et al.* 2005). Furthermore, the neo-endemic character of some woody taxa, formerly regarded as relict, still remains a controversial issue. Several conflicting aspects related to woodiness as an island evolutionary phenomenon were pointed out by Lens *et al.* (2013) and in addition, even molecular phylogenies and molecular clocks that could invalidate relict theory sometimes fail to explain some relationships between islands endemics and continental relatives, that still remain unresolved, and have gaps in data that mislead interpretation of phylogenetic history (Bramwell & Caujapé-Castells 2011). On the other hand, several studies have suggested that many of the woody Macaronesian endemics could be *de facto* an ancient lineage, which diverged from a now-extinct common ancestor during the Terciary period, and whose arrival, setting up and evolution occurred before the Quaternary period, and therefore a relict lineage (Vargas 2007).

Anyway, the neo-endemic character [in the sense that they suffered phylogenetic radiation *in situ*, as noted by Fernández-Palacios (2011)] of several genera [e.g. *Sonchus* L., *Euphorbia* L., *Isoplexis* (Lindl.) Benth., *Echium* L., *inter alia*) is broadly agreed. These woody frutescent or arborescent taxa, showing frequently long woody caulirosetted stems, are regarded as deriving from a single or very few founder events (depending on colonisation-window opportunities) that happened in late Tertiary or at the very outset of Quaternary period, and were followed by adaptative radiation, or also vicariance. Despite largest radiation events were confined within each archipelago there are some examples of radiation inter-archipelagos and also retro-colonisation to Africa and Iberian Peninsula (Carine *et al.* 2004; Capelo *et al.* 2005; Kim *et al.* 2008; Fernández-Palacios 2011). Reconstruction of geographic origin of those successful colonisers revealed a predominance of herbaceous ancestors from Mediterranean region (e.g. *Echium*, *Aeonium,* and

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[1] Sherwin Carlquist (1930-) the American botanist who in addition to his work in taxonomy studied anatomy of woody plants and developed the theories to explain paedomorphosis in the secondary xylem and insular woodiness (Plant Discoveries Sherwin Carlquist 2015).

Euphorbia), but some have affinities with Euro-Siberian *taxa* (e.g. *Silene* L. and *Saxifraga* L.), and American *taxa* (e.g. *Pericallis* D. Don, *Sedum* L., and *Bystropogon* L Hér.) (Capelo *et al.* 2004; Capelo *et al.* 2007, and references therein).

Several recent studies also aimed to verify the relict nature of Macaronesian laurel forest elements such as trees and ferns that were, and still are viewed as palaeoendemics remnants of the Thetyan Tertial flora. Phylogeographic analyses of bryophyte and pteridophyte floras have shown that several taxa are more recent than originally thought, some others have taxonomical ancestors in other archipelagos, and others evolved from ancestors with affinities with American taxa. On the other hand, same studies have evidenced that for some taxa divergence has happened circa 40 million years ago and that since then no evolution occurred being, in fact, remnants of those which became extinct in Europe (Vanderpoorten *et al*. 2007; Aigoin *et al*. 2009). Although these results give support to the idea of endemic cryptogamic flora as a mix of palaeoendemics and neoendemics resulting from a dynamic interchange between islands and mainland, they are also a quite vivid proof that Macaronesia archipelagos acted as refugium for Tertiary flora (Fernández-Palacios *et al*. 2011).

Similarly, the relict nature of the trees of laurisilva forest is currently being questioned by using phylogeographic analyses (Kondraskov *et al.* 2012). But, while being recognised that current laurel forest is a depleted variant of the original Tethian Tertiary forest it is accepted the some elements remained very close to their ancestors without suffering significant evolutionary change (i.e. palaeoendemics) that. In fact, same arguments used in the past still militate in favour of laurel forest trees as remnants of laurel forests of the Palaeotropial geoflora: (1) European fossil record allowing reliable determination of genera that became extinct in continental areas and are still extant in Macaronesian region (e.g. *Visnea* L. f.*, Picconia* DC.) (2) some genera persisting as relicts in Iberian refugia, with water availability throughout the year, which are found in the islands (e.g. *Laurus* L., *Diplazium* Sw., *Woodwardia Sm.*) (3) geographic palaeoendemics that belong to some genera of trees occurring in Macaronesian laurel forests (e.g. *Clethra* L., *Ocotea* Aubl., *Persea* Mill.); (4) the Pliocene-Pleistocene deposit of São Jorge in Madeira providing a clear indication that several species were already present in Madeira 2 Ma ago (Heer 1857; Axelrod 1975; Mai 1989; Sjögren 2000; Fernández-Palacios 2009; Marques 2013).

More recently geological data and morphological analysis of Madeiran and Canarian volcanic provinces allowed to speculate about the existence of the Palaeo-Macaronesia in which current seamounts might have been emerged islands. Although the oldest of all emerged islands of Macaronesian archipelagos (Selvagem Grande, 27 Ma) was formed prior to the disappearance of subtropical laurel vegetation, the hypothetical existence of these Palaeo-Archipelagos strengths the idea that Macaronesian islands acted as *refugia* of Tertial flora and helps to admit relictual nature of some elements of current flora. In fact: (1) if emerged islands had existed at the outset of Tertiary (Ormond with 65-67 Ma) it would have expanded the time of propagules availability; (2) being much closer to Iberian Peninsula, they would stand nearby to the last refugium of Palaeotropical geoflora, and (3) by forming a chain of volcanic islands, they would have acted as stepping stones, helping colonisation by species with less dispersion capacity (Fernández-Palacios *et al.* 2011, and the references made therein).

Some of the plants belonging to current Madeiran flora (e.g. *Salix* L., *Sambucus* L.) are related to another Tertiary Vegetation type: the Arctotertiary vegetation which was also originated due to climate changes from the Eocene onwards. The so called Arctotertiary geoflora comprised elements frequently linked to riparian formations and more adapted to cold climate. The several tectonic events of the mid and late Tertiary led to periodic variations in temperature causing climate shift from tropical into Mediterranean being the exchange gradual and interspersed by glaciation cycles, and periods of warm-temperate or subtropical climate. Consequently, the substitution of the laurophyll flora by Arcotertiary plants was very slow and both coexisted in mixed forests, being the two main vegetation types that existed in European Tertiary from Oligocene onwards until the complete disappearance of the former in the Pliocene (Mai 1989; Barrón *et al.* 2010).

The establishment of the Mediterranean climate had a drastic effect on vegetation: much of the elements did not adjust to such environmental alterations and became globally extinct. Others, as noted previously, although without adaptive response were able to survive in *refugia* with appropriate conditions. Some others developed adaptive response to climate seasonality, characterised by cold rainy winters and hot dry summers, and originated the xerophytic Mediterranean vegetation. Some elements of the palaeo-mediterranean thermophilous and sclerophyllous flora were also able to colonise Macaronesian islands. Although these archipelagos were not affected by the severe alterations that have occurred in continental areas also suffered some climatic changes. These, which came together with recurrent volcanic eruptions, caused extinctions and enlarged the islands creating new areas. The emergence of empty niches must have opened up opportunities for newcomers that successfully colonised those new habitats (Mai 1989; Barrón *et al.* 2010; Fernández-Palacios *et al.* 2011)

Some elements with circum-mediterranean-african-arabic affinities arrived on the island in several rounds of colonisation and constitute the Palaeo-mediterranean xerophytic, thermophilous and sclerophyllous flora (e.g. *Olea* L.) that is found especially in lower altitudes characterised by dryness. It comprises both succulents and sclerophyllus shrubs, including many sprouters adapted to disturbance by fire, lop off branches, and herbivory. It is a type of vegetation very similar to scrubland of Mediterranean climate areas (*maquis*) and African xeric vegetation (Capelo *et al.* 2004; Capelo *et al.* 2005; Capelo *et al.* 2007).

Most recent colonisation cycles correspond to neo-mediterranean elements. Some plants show affinities with t*axa* from European mainland (e.g. *Genista* L.) and others appear to derive from *taxa* from other Macaronesian archipelagos (e.g. *Teline* Medik.). Species within this group have adaptations to dry conditions as thick, waxy cuticle, and reduced surface covered with hairs. Those species normally produce large number of seeds and have efficient dispersal strategies, and for this reason belong to seral stages that quickly colonises leptosols after disturbance (Capelo *et al.* 2004; Capelo *et al.* 2005; Capelo *et al.* 2007).

Contrarily to Canaries islands, that became inhabited more than 1000 B.P. (Fernández-Palacios *et al.* 2011), Madeiran archipelago was occupied by Portuguese settlers in early 15th century, and since that time that exotic plants have been deliberately or accidentally introduced from other parts of the world. It is known that some are *archeophytes* were introduced prior 16th century (e.g. *Castanea sativa*), and many are *neophytes* [e.g. *Ageratina adenophora* (Spreng.) R.King & Rob.][1] introduced after that century. They were introduced for a large variety of purposes, particularly agriculture, forestry and gardening, and many of those exotic plants are currently invasive species causing different types of impacts (Sjögren 2000; Vieira 2002; Capelo *et al.* 2004; Capelo *et al.* 2005; Capelo *et al.* 2007). It is not an easy task to prove that a species is native if it is not endemic. This difficulty was handed down by Bowdich (1825) who stated that because a great sort of plants were early introduced, and became naturalised, it is sometimes

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[1] Commonly known as eupatorium and locally by *abundância.*

difficult to verify whether the *taxa* is native or not. To this, he added that the strong sirocco that blows from Africa together with birds bringing seeds from mainland and neighbouring islands, as occurred prior to man occupation, help to compound even further the situation.

Thus, the Flora of Madeira Island can be grouped in five types, according to their origin, and can be summarised as follows: (1) Palaeo-endemic palaeo-subtropical forest flora of tethysian origin (e.g. trees as: *Laurus*; *Ocotea*; *Apollonias* Nees; *Persea*; *Clethra; Ilex* L.; *Picconia*; *Heberdenia* Banks ex A. DC.; *Myrica* L.; *Prunus* L.*; Dracaena* Vand. ex L.*; Sideroxylon* L., and pteridophyte as: *Diplazium*; *Woodwardia*; *Dryopteris* Adans.; *Pteris* L.); (2) Neo-endemic flora with *island woodiness* physiognomy (e.g. *Aeonium*, *Sonchus*, *Echium*, *Sinapidendron*, *Euphorbia*, *Monizia*, *Isoplexis*, *Musschia*, *Melanoselinum*, *Plantago* L.); (3) Palaeo-mediterranean xerophytic, sclerophylous flora (e.g. *Olea*, *Maytenus* Molina, *Myrtus* L., *Rhamnus* L., *Asparagus* L.); (4) Neo-mediterranean seeder flora of late-tertiary continental eurossiberian origin (*Micromeria* Benth., *Siderites* L., *Teline*, *Genista*); and (5) Flora introduced by Man (e.g. some *archeophytes* as: *Castanea* Mill.; *Pinus* L.; *Vitis* L.*,* and *neophytes* as: *Ageratina* Spach; *Duchesnea* Sm.; *Ulex* L.; *Cytisus* L.; *Erigeron* L.; *Hedychium* J. Köeni) (Capelo *et al.* 2005, p. 98; Capelo *et al.* 2007, pp. 84-85).

2.1.2 The vegetation of Madeira Island: belts and vegetation series

Until the end of the eighteenth century, botanists were primarily focused on finding plants and classifying the specimens. This does not mean that they ignored vegetation, especially since they often recourse to vegetation features to describe more accurately the new species and the place where it was found. However, it was Humboldt[1] in early nineteenth century who triggered interest in vegetation. Since then, it become a primarily object of research, and its character, distribution, and links to environmental parameters have become central concern to study units occurring as specific kinds of vegetation (Nicolson 1987).

In Madeira Island, several authors, following Humboldt steps, made significant attempts to explain the different vegetation types that succeeded each other in altitude and also varied with slope, clearly limited by the temperature and rainfall patterns (Capelo *et al.* 2007). Some prior authors such as Bowdich (1825); Kuhl (1826)[2], Macaulay (1841), Lowe (1857), and Vahl (1904)[3], established vegetation regions which share certain aspects, although presenting small differences in what concerns zones number, altitudinal range, and dominant plants of each zone. A point in common is the fact that they all included cultivated plant species, in stark contrast with current vegetation models, although the classification proposed by Lowe, and Vahl that followed him, separated the cultivated plants from those occurring naturally and, within these, the native ones. Another common thing was that designations given to lower belts (under 800-900 m high) clearly showed that these areas had already lost, in large part, the native vegetation which was replaced by exotic plants. At a very coarse approach it may be stated that those authors considered one or two areas closer to the sea where plants from tropical and subtropical climates were grown, and one or two areas where European

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[1] A short biographical note was presented on p. 11.

[2] Heinrich Kuhl (1797-1821) the German naturalist and zoologist, but also an active researcher in botany and mineralogy. He was for five days in Madeira in his way to East Indies, and took the opportunity to visit inland areas and to write about the vegetation of Madeira Island. Its accounts were published in 1826, after his dead from a letter sent by him to Nees Von Esenbeck (German botanist) (Kuhl1826; Klaver 2007).

[3] Martin Vahl (1869-1946) Danish geographer, botanist. His Doctoral thesis presented at the University of Copenhagen, in 1904, was about vegetation of Madeira Island. He is sometimes designated by Martin II Vahl to avoid confusion with the Danish-Norwegian botanist of the same name who was pupil of Linnaeus (1779-1782) (Vahl 1904; tidsskrift.dk 1946).

plants from Mediterranean and temperate climates have been planted, being those zones recognised by the most outstanding species (e.g. Lowes first region: *Cactus and Banana*; and Lowes second region: *Vine and Chestnut*). Above these belts the regions that were defined included native vegetation. Some of those authors have considered relevant to separate the thickets of heath that grew higher up in the mountains (e. g. Bowdich fourth region, Kuhl fifth region, and Macaulay first region: *Region of Heaths*), from the forest of indigenous evergreen trees. For the designation of the latter it was given particular attention to dominance of laurel trees (e.g. Macaulay second region: *Region of Laurels*) or alternatively, taking into account the substantial presence of species other than laurel trees (e.g. Bowdich third region: *Region of Vaccinium and Laurels*, Kuhl fourth region: Region of *Spartium*[1], and Lowe third region: *Laurel and Heath*. With the exception of the model proposed by Lowe, that clearly separated the highest peaks as a zone characterised by barren nature where very few plants grew, the remaining approaches extended the last region nearly to the summits (Bowdich 1825; Macaulay 1841; Lowe 1857; Vahl 1904). In this context, mention also shall be made to Buch (1825) who, although not having defined regions for Madeira, made an appreciation of its vegetation by comparing it with Canarian vegetation pointing out the absence of some of plants in the Regions identified by him (e.g. lack of palm trees in the Region of African forms).

In the twentieth century several other contributions helped to understand the differentiation and zonation of the vegetation of Madeira. By 1913 Rübel[2], whose importance for the geobotany is widely recognised, divided the plant communities of the world, after which the laurel forests, as the occurring in Macaronesia, started to be classified as *Laurisilvae*. This classification, based on the physiognomy of vegetation, consider the community where dominant trees are dicotyledons with evergreen glossy leaves (laurel) a *silvae* (forest), included in the broader group denominated *Laurilignosa* (*lignosa*, i.e. woody vegetation) (Fuller 1932). Other significant input was the bioclimatic vegetation zonation suggested by Dansereau (1966)[3], in spite of the tough criticism showed by Sjögren (1972) to the fact that species were not phytosociologically related, and some inaccuracy of the limits that were established, specially concerning differences between the north and south. However, this model no longer included cultivated plants, assumed the existence of six bioclimatic belts in the southern face, and proposed the separation of the barbusano-tree forest (*Forêt-parc*) from stink-laurel forest (*Forêt ombrophile de lauriers*). First investigation aiming to study the sociology and ecology of plant communities, and succession sequence was performed by Sjögren (1972)[4]. In his work he described two *alliances*, and several *associations* of natural vegetation, that are currently *pp. nom. inval*. (Costa *et al.* 2004). Albeit very few communities are currently accepted, and yet redefined (e.g. *Deschampsietum argenteae* Sjögren ex Capelo, J. C. Costa, Lousã, Fontinha, Jardim, Sequeira & Rivas-Martinez 2000), the paper includes relevant remarks on the ecology of the differential species, and the negative impact of exotic plants, especially on the natural succession. By the end of the twentieth century some other phytosociological studies (Capelo *et al.* 1999; Foucault

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[1] Although it was not indicated the species and a *Spartium* region was defined for the Canary islands ("Die Region of *Spartium nubigenum*, der Retoma blanca) by Buch (1825, p. 129) the species does not exist in Madeira island and the list of plants drawn up by Sloane during his visit in 1687 referred the presence of *Genista non spinosa prima, seu angulosa et scoparia,* C.B., i.e. *Spartium scoparium* Linn., currently accepted as *Cytisus scoparius* (L.) Link (Menezes de Sequeira *et al.* 2010).

[2] Eduard August Rübel (1876-1960) the Suiss botanist who founded the 'Geobotanisches Institut Rübel' aiming to promote research in the recently born science of geobotany (ETH 2007).

[3] Pierre Mackay Dansereau (1911-2011) the Canadian plant ecologist, Professor of botany. He get involved in ecology in early 1940s and focused in the interaction of man, plants and animals in the ecosystems, extending ecological concepts to human environments. His interest in vegetation science led him to the study the vegetation of Macaronesian archipelagos (Cayouette, 2011; Dansereau 1961, 1966).

[4] Erik Sjögren (1933-) the Swedish botanist Professor at the University of Upsalla and Member of Macaronesian Botanical Society. He was the author of the first phytosociological study of the vascular plant communities of Madeira Island (Sjögren 1972; prabook 2015).

1999) resulted in the description of new plant communities, and redefinition of some other, paving the way to develop a model of Natural Potential Vegetation (NPV).

The model of Natural Potential Vegetation proposed by Capelo *et al.* (2004) resulted of phytosociological typology of non-synantropic vegetation (Capelo *et al.* 1999; Capelo *et al.* 2003a; Capelo *et al.* 2003b; Capelo *et al.* 2003c; Costa *et al.* 2004) that was modelled with reference to Bioclimatic Classification of the Earth of Rivas-Martinez (for further detail see Mesquita *et al.* 2004 and references therein). Although helped by several source of information NPV models are supported by vegetation currently seen in the landscape. However, while in mountainous areas of difficult access the so called laurisilva forest still remains providing a valuable overview, it cannot be deemed as NPV in all ecologies. To complicate matters in the lower parts the intensive anthropisation does not help characterisation of the communities. Nonetheless, because native vegetation still occurs in small patches interspersed among agricultural fields and afforested areas, it was possible to establish the NPV and the stages of forest succession (Capelo *et al.* 2004; Mesquita *et al.* 2004; Capelo *et al.* 2005; Capelo *et al.* 2007).

Bioclimate of Madeira Island (Figure 1.2.) varies considerably, ranging from inframediterranean and dry, with summer drought (near the sea in south coast) to supratemperate and ultrahyperhumid, with none or reduced dryness (at the highest peaks). It crosses seven stages within two main macroclimates: Mediterranean under 800 m (a.s.l.) in southern face and under 300 m (a.s.l.) in northern face, and Temperate, above those altitudes.

Madeiran climatophyllous vegetation series (Figure 1.3) were described according to these two macroclimates, being that three vegetation series (forest vegetation) are found in Mediterranean climate, and other three are found in temperate climate (two forest vegetation and a mountain vegetation complex [*geosigmetum*]) (Capelo *et al.* 2004; Mesquita *et al.* 2007). Information about these climatophyllous vegetation series, their successional stages, and their dominant species, is summarised below based on Capelo *et al.* (2004), Capelo *et al.* (2005), and Capelo *et al.* (2007), being added brief information on correspondent *geocomplex. Sintaxa* of seral stages and potential distribution of vegetation series are shown in tables, adapted from Capelo *et al.* (2004), and Capelo *et al.* (2007).

Mayteno umbellatae - Oleo maderensis sigmetum - The dry, inframediterranean series of madeiran oleaster tree (Table 2.1) is currently restricted to small patches due anthropical occupation of its territory. The climax (Figure 2.1-1) is a microforest of *Olea maderensis* (Lowe) Rivas Mart. & del Arco together with some paleo-mediterranean

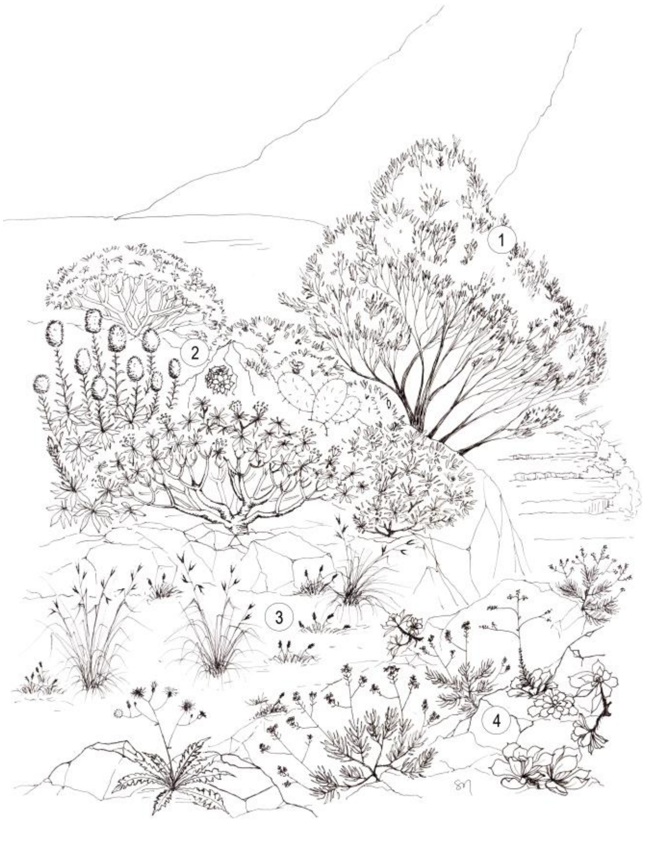

Figure 2.1 *Mayteno umbellatae-Oleo maderensis sigmetum* [ilustration by S. Mesquita in Capelo *et al.* (2004)].

xerophytic shrubs as for instance *Chamaemeles* coriacea Lindl, *Maytenus umbellata* (R. Br.) Mabb., *Dracaena draco* (L.) L. subsp. *draco*, and *Asparagus scoparius* Lowe. It is replaced in moderately depth soils by a scrub community (Figure 2.1-2), rich in woody neo-endemic elements, dominated by *Euphorbia piscatoria* Aiton along with *Globularia salicina* Lam. and *Echium nervosum* Dryand., and in rock outcrops by shrubs of neo-mediterranean origin such as *Artemisia argentea* L' Hér., and *Genista tenera.* Grasslands (Figure 2.1-3) come about as result of advanced degraded stages, and are often co-dominated by exotic herbs. Both potential and serial stages form a mosaic with a rupicolous community rich in crassulacean plants like *Sedum nudum Aiton* and *Aeonium glutinosum* (Aiton) Webb & Berthel. [*Sedo nudi- Aeonietum glutinosae* (Figure 2.1-4)].

Table 2.1 Sintaxa of seral stages and potential distribution of *Mayteno umbellatae-Oleo maderensis sigmetum*

Communities (seral stages)				**Potential distribution**
Microforest/Scrub	Low scrub	Perennial grassland	Annual grassland	Face/altitude (m)
(**1**)*Mayteno umbellatae-Oleetum maderensis*	(**2**)*Euphorbietum piscatoriae*[a] *Artemisio argenteae-Genistetum tenerae*[b]	(**3**)*Cenchro ciliaris-Hyparrhenietum sinaicae*	*Galactito tomentosae-Brachypodietum distachyae*	South/0-200

a: In moderate deep soils; b: In lepptosols; numbers 1, 2, 3 in fgure 2.1.

Helichryso melaleuci-Sideroxylo marmulanae sigmetum – The subhumid, inframediterranean series of marmulano-tree (Table 2.2) occurs mainly on the cliffs highly exposed to maritime winds in North coast, and scattered above oleaster series in South coast. The climax (Figure 2.2-1) is a microforest dominated by *Sideroxylon mirmulans* R. Br., *Maytenus umbellata*, *Globularia salicina*, and in a few spots *Juniperus turbinata* subsp. *canariensis*. On the southern coast this community is substituted by the community of *Euphorbia piscatoria*, and in the north by low scrub (Figure 2.2-4) dominated *by Helichrysum melaleucum and Globularia salicina*. In very rugged areas it appears in mosaic with *Sinapidendro gymnocalicis-Sedetum brissemoreti* (Figure 2.2-2) *a* rupicolous community in which *Aeonium glandulosum* (Aiton) Webb & Berthel. abounds.

Figure 2.2 *Helichryso melaleuci-Sideroxylo marmulanae sigmetum* [ilustration by S. Mesquita in Capelo *et al.* (2004)]

Table 2.2 *Sintaxa* of seral stages and potential distribution of *Helichryso melaleuci-Sideroxylo marmulanae sigmetum*

Communities (seral stages)				**Potential distribution**
Microforest/Scrub	Low scrub	Perennial grassland	Annual grassland	Face/altitude (m)
(**1**)*Helichryso melaleuci-Siderxyletum marmulanae*	*Euphorbietum piscatoriae*[a] (**4**) Community of *Helichrysum melaleucum* and *Globularia salicina*[b]	*Dactylo hylodis-Hyparrhenietum sinaicae*	*Campanulo erini-Wahlenbergietum lobelioidis*	South/200-300 North/0-50(80)

a:Southern face; b:Northern face, numbers 1, 4 in figure 2.2

Semele androgynae - Apollonio barbujanae sigmetum – The subhumid to humid, infra and thermomediterranean laurel forest of barbusano–tree, that is included in the so called laurisilva of Madeira, can be found in both faces of the island. The most mature community (Figure 2.3-1) is dominated by two *Lauraceae: Apollonias barbujana* and *Laurus novocanariensis,* being rich in thermophilous trees like *Myrica faya* and *Ilex canariensis,* and shrubs as *Asparagus umbellatus* Link. subsp*. lowei* (Kunth) Valdés*, Visnea mocanera* L.f., and *Maytenus umbellata.* A conspicuous characteristic is the presence of vines that dominate in the understory, as *Semele androgyna* (L.) Kunth, *Smilax pendulina* Lowe*, Smilax canariensis* Brouss. ex Willd., *Hedera maderensis* K. Koch ex S. Rutherf.subsp. *maderensis, Convolvulus massonii* F. Dietr.*,* and *Rubia agostinhoi* Dans. & P. Silva*.* Two facies are recognised: one that is solely found in south face (Table 2.3-a) in which the climax is replaced by a community dominated by *Myrtus communis* L. and *Hypericum canariense* L., and another one (Table 2.3-b) found in both faces where first substitution stage is a heath community dominated by *Erica arborea, Myrica faya* and *Erica platycodon* subsp. *maderincola*, and very rich in xero-thermophilous shrubs as *Globularia salicina*, *Echium nervosum,* and *Teucrium betonicum* L' Hér., most decayed stages are common in both successional facies.

Figure 2.3 *Semele androgynae-Apollonio barbujanae sigmetum* [ilustration by S. Mesquita in Capelo *et al.* (2004)].

Table 2.3 *Sintaxa* of seral stages and potential distribution of *Semele androgynae-Apollonio barbujanae sigmetum* [facies with *Myrto communis–Hypericetum canariensis* (a); facies with *Globulario salicinae-Ericetum arboreae* (b)].

Communities (seral stages)					Potential distribution
Forest	Scrub	Low scrub	Perennial grassland	Annual grassland	Face/altitude (m)
(**1**)*Semele androgynae-Apollonietum barbujanae*	[a]*Myrtus communis–-Hypericetum canariensis*	*Euphorbietum piscatoriae*	*Dactylo hylodis--Hyparrhenietum sinaicae*	*Campanulo erini--Wahlenbergietum lobelioidis*	South/300-600
	[b]*Globulario salicinae--Ericetum arboreae*				South/600-800 North/50-300(450)

number 1 in figure 2.3

Clethro arboreae-Ocoteo foetentis sigmetum – The humid to hiperhumid, infra to mesotemperate forest of stink-laurel (Table 2.4), that is included in the so called laurisilva of Madeira, still covers large areas in high mountainous areas in both faces of the island. The climax (Figure 2.4-1) is a multi-stratified forest with high diversity in the several layers. The overstory which goes up 30 m high is dominated by *Ocotea foetens*, *Laurus novocanariensis*, and *Clethra arborea*, and where are also found more or less frequently some other trees like: *Heberdenia excelsa, Persea indica, Picconia excelsa, Ilex perado* subsp. *perado and Prunus hixa* Willd. It is rich in ferns, both epiphytic (Figure 2.4-10) and terrestrial (Figure 2.4-9), as for instance *Davallia canariensis* (L.) Sm., *Polypodium macaronesicum A. E. Bobrov*, *Diplazium caudatum* (Cav.) Jermy, *Pteris incompleta* Cav., *Dryopteris maderensis* Altston, *Woodwardia radicans* (L.) Sm.*;* herbaceous plants (Figure 2.4-2) that cover the lower stratum as *Festuca donax* Lowe, *Carex lowei* Bech., *Sibthorpia peregrina* L., *Ruscus streptophyllus* Yeo, *Phyllis nobla* L.*,* and *Viola odorata* L.; and climbers as *Rosa mandonii* Déségl., *Rubus grandifollium* Lowe, and *Rubia agostinhoi*. The huge floristical diversity that is associated with this mesoforest is also due to the existence of many microhabitats, created by complex terrain. Different communities occur associated to shady earthy walls and wet rocks comprising many endemic species as *Hymenophyllum maderense* Gibby & Lovis and *Aichrysum divaricatum* (Aiton) Praeger (Figure 2.4-5). Other communities are related to clearings formed by catastrophic landslides where

Figure 2.4 *Clethro arboreae-Ocoteo foetentis sigmetum* [ilustration by S. Mesquita in Capelo *et al.* (2007)].

neo-endemic caulirosetted phanerophytes are common as *Euphorbia mellifera* Aiton, *Musschia wollastonii* Lowe, *Melanoselinum decipiens* (Schrad. & J.C. Wendl.) Hoffm., *Isoplexis sceptrum* (L.f.) Loudon, and *Sonchus fruticosus L.f.*. And finally, hygrophilous communities, which occur in permanent streams, can be found in upper course, dominated by *Sambucus lanceolata R. Br.*[1], in middle stretches dominated by *Persea indica*[2],and in lower parts dominated by *Salix canariensis* C. Sm. ex Link [3]. The first seral stage (Figure 2.4-3), which fulfils the hedges and cover large areas where forest has been destroyed, is a heath high-scrub, dominated by *Erica platycodon* subsp. *maderincola*, *Vaccinium padifolium*, and *Erica arborea,* often attaining a secondary forest character. Over rocky scarps and steep cliff this community is usually found as permanent community (*paraclimax* or *topographical climax)*. Seral stages formed by shrubs, dominated by *Teline maderensis* and *Bystropogon punctatus* L´Hér., and tall forbs as *Geranium palmatum* Cav., *Pericallis aurita* (L' Hér.) B. Nord., *Ranunculus cortusifolius* Willd. subsp. *major* (Lowe) Rivas Mart., Capelo, J.C. Costa, Lousã, Fontinha, R. Jardim & M. Seq., and *Cirsium latifolium* Lowe, are some of the species that colonise forest borders and clearings, being also greatly responsible for the biodiversity associated to stink-laurel forest. Huge disturbance leads to annual grasslands dominated by *Ornithopus perpusillus* L. and *Leontodon taraxacoides* (Vill.) Mérat subsp. *longirostris* Finch & P.D. Sell, highly impoverished by the presence of exotic grasses.

Table 2.4 *Sintaxa* of seral stages and potential distribution of *Clethro arboreae-Ocoteo foetentis sigmetum*

Communities (seral stages)					**Potential distribution**
Forest	Scrub	Low scrub	Perennial grassland	Annual grassland	**Face/altitude (m)**
(**1**)*Clethro arboreae-Ocoteetum foetentis*	(**3**)*Vaccinio padifoli-Ericetum maderincolae*	*Bystropogono puntacti-Telinetum maderensis*	(**2**)*Pericaulido auritae-Geranietum palmatae*	*Leontodo longirostris-Ornithopetum perpusilli*	South/800-1450 North/300-1400

numbers 1, 2, and 3 in figure 2.4

***Polysticho falcinelli-Erico arboreae sigmetum* –** The hiperhumid and ultrahyperhumid, meso-supra temperate forest of tree-heath (Table 2.5) occurs in exposed mountain tops where average winter temperatures drops below 0ºC, and hailstorms and even blizzards frequently happen during that season. The forest (Figure 2.5-1) is dominated by *Erica arborea* that grows beyond eight metres high, being sometimes accompanied by *Erica platycodon* subsp*. maderincola.* In the past, it probably should have been co-dominated by *Juniperus cedrus* subsp. *maderensis*, currently almost extinct in the wild due to overexploitation. Some other tree species as *Ilex perado* subsp.*perado* and *Laurus novocanariensis* can also be found, although it is a very rare situation and only seen in very in protected shelters. *Sorbus maderensis* (Lowe) Dode, a palaeo-temperate element which is scarce in Madeiran flora, is also part of this assemblage.

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[1] *Rhamno glandulosi-Sambucetum lanceolati*
[2] *Diplazio caudati-Perseetum indicae*
[3] *Scrophulario hirtae-Salicetum canariensis*

Figure 2.5 *Polysticho falcinelli-Erico arboreae sigmetum* [ilustration by S. Mesquita in Capelo *et al.* (2004)].

The forest understory (Figure 2.5-2) is very poor dominated by the xeromorphic fern *Polystichum falcinellum* (Sw.) C. Presl that appears together with *Sibthorpia peregrina* and *Viola riviniana* Rchb. In most disturbed areas is found the annual grasslands dominated by *Ornithopus perpusillus* and *Leontodon taraxacoides* subsp. *longirostris*. Two different herbaceous communities usually develop in little less disrupted habitats: one community dominated by *Teucrium francoi* M. Seq., Capelo, J.C. Costa & R. Jardim and *Origanum vulgare* L. subsp. *virens* (Hoffmanns. & Link) Bonnier & Layens, and another dominated by *Vicia capreolata* Lowe and *Odontites holliana* (Lowe) Benth. The first substitution community occupies natural edges and clearings of the forest comprising almost *Erica platycodon* subsp. *maderincola.* The second hedge and also a rocky permanent community (geocomplex), which is also found at higher altitudes (Figure 2.6-2), is rich in several endemics like *Argyranthemum pinnatifidum* (L.f.) Lowe subsp. *montanum* Rustan, *Erica maderensis* (Benth.) Bornm., *Teline maderensis*, *Genista tenera*, *Echium candicans* L.f. and *Thymus micans* Lowe.

Table 2.5 *Sintaxa* of seral stages and potential distribution of *Polysticho falcinelli-Erico arboreae sigmetum*

Communities (seral stages)					**Potential distribution**
Forest	Scrub	Low scrub	Perennial grassland	Annual grassland	**Face/altitude (m)**
(**1**)*Polysticho falcinelli-* *-Ericetum arboreae*	Shrub community of *Erica platycodon* subsp *maderincola*	*Argyranthemo montanae-* *-Ericetum maderensis*	*Vicio capreolatae-* *-Odontietum hollianae;* *Teucri francoi-* *-Origanetum virentis*	*Leontodo longirostris-* *-Ornithopetum perpusilli*	South/1450-1650 North/1400-1650

number 1 in figure 2.5

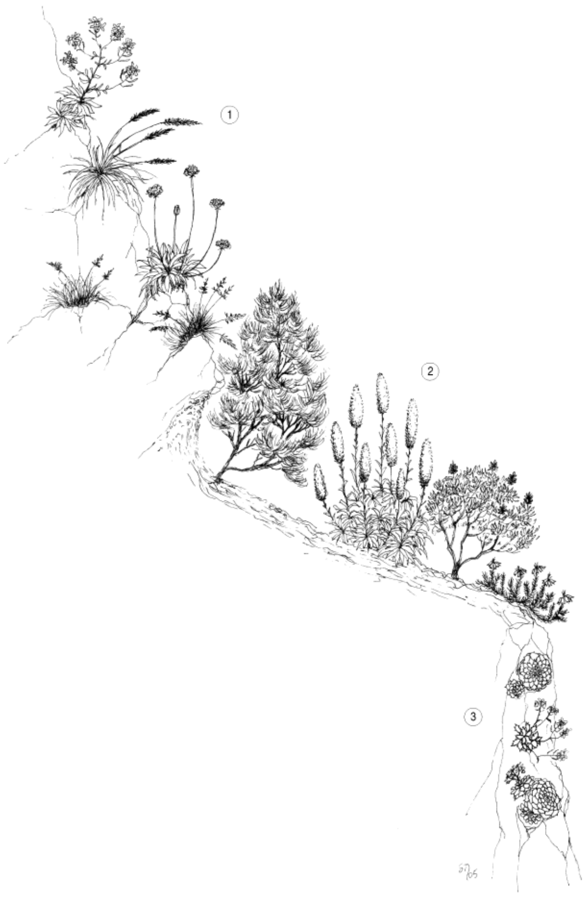


Figure 2.6 *Armerio maderensis-Parafestuco albidae microgeosigmetum* [ilustrations by S. Mesquita in Capelo *et al.* (2007)].

Armerio maderensis-Parafestuco albidae microgeosigmetum – The ultrahypermhumid, supratemperate bioclimate stage comprises three single, non-stratified, permanent communities of rupicolous plants. They occurr above 1650 metres of altitude, and form a mosaic according to the different microhabitats: soil accumulations in rock crevices and banks on the cliffs where *Anthyllis lemmaniana* Lowe, *Anthoxanthum maderense* Teppner, and *Deschampsia maderensis* (Hack. & Bornm.) Buschm. occur in a community dominated by *Armeria maderensis* Lowe and *Parafestuca albida* (Lowe) E.B.Alexeev (*Armerio maderensis-Parafestucetum albidae*) (Figure 2.6-1); and (2) vertical rock walls where the rupicolous *Sedum farinosum* Lowe, *Tolpis macrorhiza* (Lowe ex Hook.) DC., *Saxifraga pickeringii* C. Simon coexist in a community dominated by *Aeonium glandulosum* (Aiton) Webb & Berthel and *Sinapidendron frutescens* (Sol.) Lowe subsp. frutescens (*Sinapidendro frutescentis-Aeonietum glandulosi*) (Figure 2.6-3); and shallow soil related to volcanic pyroclastic formations that supports a community of *Thymus micans* (*Thymetum micantis*).

As previously mentioned vegetation change is the most evident representation of the landscape alteration because it is the landscape feature that is more affected both by natural and man induced instability factors. Therefore, its description is important not only as question of academic knowledge but also because it is relevant for an integrative perspective and practical approach for management purpose (Kent & Coker 1992; Kent 2012). This study did not intend to describe and establish plant communities, being based on former studies (Capelo *et al.* 1999; Capelo *et al.* 2003a; Capelo *et al.* 2003b; Capelo *et al.* 2003c; Capelo *et al.* 2004; Costa *et al.* 2004; Mesquita *et al.* 2007) on which vegetation types and plant communities were recognised and defined.

The objectives that established the main lines of the work presented in this chapter are related to different aims that were previously presented in the general introduction in first chapter:

1. Two objectives related to the main aim of this thesis that was to evaluate progressive change of the landscape in Madeira Island by assessing spatial and temporal vegetation dynamics, by:

1.1. conducting floristic-vegetation surveys (relevés) attempting to collect data about the *phytocoenoses* in photographed landscape to support supervised classification of current landscape;

1.2. comparing the plant assemblages surveyed to native communities proposed Capelo *et al.* (2004) in order to assess similarity between them.

2. Two objectives related to the second subsidiary goal that aimed to examine diversity of plant assemblages occurring in present landscape, by:

2.1 measuring biological indices [Species richness, Shannon-Wiener diversity index, Equitability (evenness)] in order to evaluate diversity and species richness of the plant assemblages surveyed;

2.2. determining colonisation status of taxa included in plant assemblages surveyed and comparing the composition of plant assemblages surveyed intending to identify factors that influenced the development of each *phytocoenosis*.

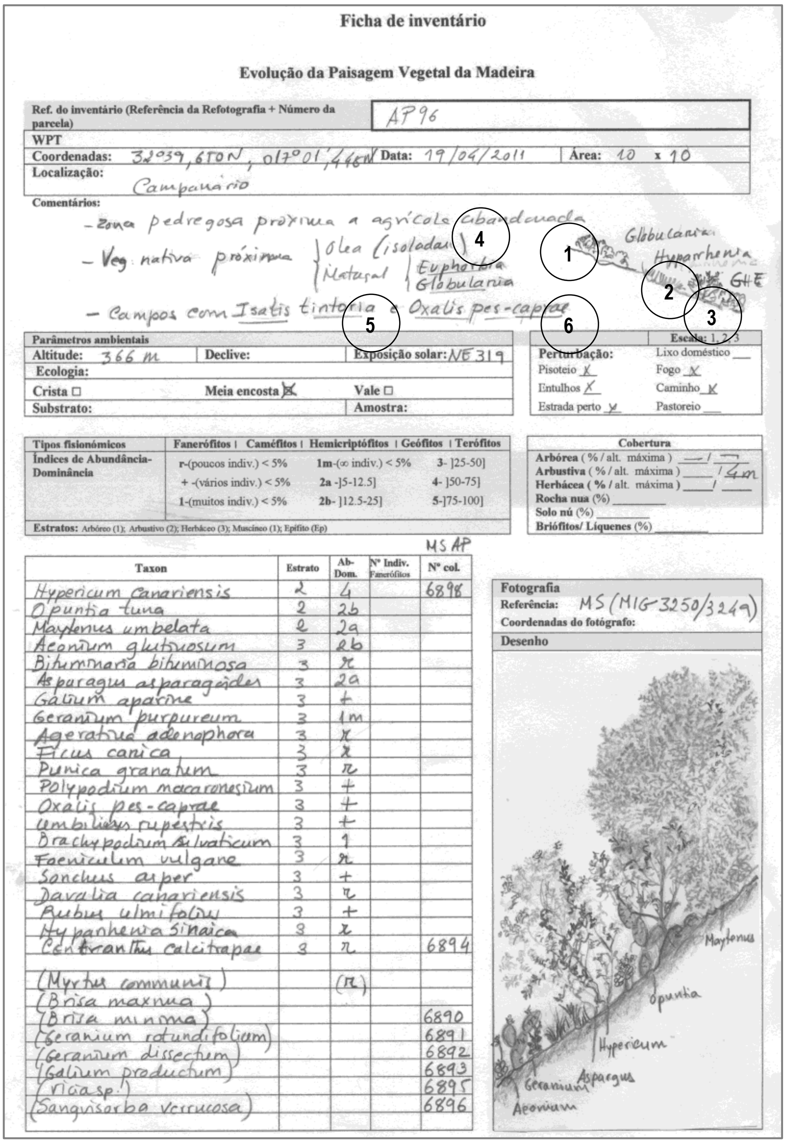
2.2 Methods

The area surveyed and methods applied were mainly driven by the need to gather data about the *phytocoenoses* in photographed landscape to support supervised classification of current landscape and to render information to allow compare surveyed assemblages with each other. The methodology is set out in two points referring respectively the data collection and analysis.

2.2.1 Vegetation sampling

Vegetation surveys followed phytosociological method and used procedures and methodological indications included in Kent & Coker (1992) and Capelo (2003). Although regarded somewhat subjective and observer dependent it is one of the most rapid methods and several strategies can be used to minimise bias (Kent & Coker 1992).

The field work was conducted from early March to mid-July, for four consecutive years (2010-2013), taking advantage of the season to have the highest number of species in the plot and get information about the maximum species diversity. Each sampling plot (phytosociological relevé) was placed within uniform vegetation patches situated in photographed landscape. The size of the sampling plots which ranged between 3m^2 (herbaceous plant assemblage) and 400m^2 (woodland) was determined by the area occupied by the plant assemblage to be sampled, avoiding non homogeneous boundaries and areas with environmental and habitat variations, as well as taking into account the minimal area (Kent & Coker 1992). For the latter, which varies with life-form and physiognomy of the vegetation, it was used the range established in phytosociological relevés performed to develop the vegetation model (Costa *et al.* 2004). The *taxa* present in each plot were identified during survey, based on Press & Short (1994), and floristic information was set down using a recording sheet (Figure 2.7). Specimens with botanical interest or with doubtful determination were collected for further examination and subsequent identification, being deposited in the Herbarium of the University of Madeira. Cover-abundance value for each species was estimated by eye using the modified 9-degree Braun-Banquet sampling scale (Barkman *et al.* 1964):   = not present; **r** = < 5%,few individuals; **+** = < 5%, several individuals; **1** = < 5% many individuals; **1m** = < 5%, ∞ individuals; **2a** =]5-12.5%]; **2b** =]12.5-25%]; **3** =]25-50%]; **4** =]50-75%]; **5** =]75-100%]. The field slip was also used to record relevant site-factors information.



Ficha de inventário

Evolução da Paisagem Vegetal da Madeira

Ref. do inventário (Referência da Refotografia + Número da parcela)	AP96
WPT	
Coordenadas: 32º39,610N, 017º01,446W	**Data:** 19/04/2011 | **Área:** 10 x 10
Localização: Campanário	

Comentários:

- Zona pedregosa próxima a agrícola abandonada
- Veg. nativa próxima { Olea (isoladas) / Matagal { Euphorbia / Globulária
- Campos com Isatis tintoria e Oxalis pes-caprae

Globularia
Hyparrhenia
GHE

Parâmetros ambientais		
Altitude: 366 m	**Declive:**	**Exposição solar:** NE 319
Ecologia:		
Crista ☐	**Meia encosta** ☒	**Vale** ☐
Substrato:		**Amostra:**

	Escala: 1, 2, 3
Perturbação:	Lixo doméstico ___
Pisoteio X	Fogo X
Entulhos X	Caminho X
Estrada perto X	Pastoreio ___

Tipos fisionómicos	**Fanerófitos | Caméfitos | Hemicriptófitos | Geófitos | Terófitos**		
Índices de Abundância-Dominância	**r**-(poucos indiv.) < 5%	**1m**-(∞ indiv.) < 5%	**3**-]25-50]
	+ -(vários indiv.) < 5%	**2a** -]5-12.5]	**4**-]50-75]
	1-(muitos indiv.) < 5%	**2b**-]12.5-25]	**5**-]75-100]
Estratos: Arbóreo (1); Arbustivo (2); Herbáceo (3); Muscíneo (1); Epífito (Ep)			

Cobertura
Arbórea (% / alt. máxima) — / —
Arbustiva (% / alt. máxima) _____ / 4m
Herbácea (% / alt. máxima) _____ / _____
Rocha nua (%) _________
Solo nú (%) _________
Briófitos/ Líquenes (%) _________

MS AP

Taxon	Estrato	Ab-Dom.	Nº Indiv. Fanerófitos	Nº col.
Hypericum canariensis	2	4		6898
Opuntia tuna	2	2b		
Maytenus umbelata	2	2a		
Aeonium glutinosum	3	2b		
Bituminaria bituminosa	3	r		
Asparagus asparagoides	3	2a		
Galium aparine	3	+		
Geranium purpureum	3	1m		
Ageratina adenophora	3	r		
Ficus carica	3	r		
Punica granatum	3	r		
Polypodium macaronesicum	3	+		
Oxalis pes-caprae	3	+		
Umbilicus rupestris	3	+		
Brachypodium sylvaticum	3	1		
Foeniculum vulgare	3	r		
Sonchus asper	3	+		
Davallia canariensis	3	r		
Rubus ulmifolius	3	+		
Hyparrhenia sinaica	3	r		
Centranthus calcitrapae	3	r		6894
(Myrtus communis)		(r)		
(Brisa maxima)				
(Brisa minima)				6890
(Geranium rotundifolium)				6891
(Geranium dissectum)				6892
(Galium productum)				6893
(Vicia sp.)				6895
(Sangvisorba verrucosa)				6896

Fotografia
Referência: MS (MIG 3250/3249)
Coordenadas do fotógrafo:

Desenho

Figure 2.7 Data sheet used to record field information and photographs taken in the area showing the surrounding landscape (a, b) as well as the plot located over a long time ago abandoned terrace where it was performed the relevé (b, c). The area is currently covered with plants belonging to *Myrtus communis-Hypericetum canariensis*, a high shrub stage of the barbusano-tree series, with remnants of former crops as pomegranate (*Punica granatum* L.) and common fig (*Ficus carica* L.), and it was invaded by *Ageratina adenophora*, *Asparagus asparagoides* (L.) Druce (commonly known as bridal-creeper and locally as *alegra-campo de folha miúda*), *Opuntia tuna*, and *Oxalis pes-caprae* L. (commonly known as sourgrass, Bermuda buttercup, and locally as *azeda, trevo-azedo).*

2.2.2 Data analysis

The170 phytosociological relevés were grouped together in a floristic table. To this table were added the relevés which were used to describe the communities of Madeiran climatophyllous vegetation series (Costa *et al.* 2004), resulting in a matrix with 308 relevés. Being each relevé characterised by various attributes entails that vegetation information, in the form of phytosociological tables, are multivariate data (Kent & Coker 1992). One method of multivariate analysis which is often used in phytosociology is *classification* (cluster analysis). Within the different methods of numerical classification the agglomerative classification using similarity or dissimilarity coefficients it is used quite frequently (Capelo, 2003). This method which consists in progressively combine single relevés based on their similarity or dissimilarity until they are gathered in very similar groups and separated from very different clusters. Clustering can use several similarity/dissimilarity coefficients and different sorting strategies. In all of them the raw data table is transformed in a matrix and results presented in a form of dendrograms. Biological diversity of the assemblages surveyed was assessed in order to compare assemblages dominated by exotic plants or, even dominated by native, greatly invaded by exotics plants, with the ones mainly constituted by native plants. Most methods to measure diversity comprise two components: species richness and their relative abundance (evenness) which may be examined singly or together into index form (Kent & Coker 1992).

The data were analysed in abundance form and for calculations the scale of abundance-coverage was converted in cardinal numbers (Table 2.6) expressing the middle value of percentage bracket for each class.

Table 2.6 Correspondence between abundance values used for calculations and classes representing abundance-coverage of each *taxa*.

Modified Braun-Banquet sampling scale (Barkman *et al.* 1964)		Abundance
Classes used in current work	Classes used by (Costa *et al.* 2004),	
(not present)	(not present)	**0**
r, +, 1, 1m	r, +, 1	**2.5**
2a, 2b	2	**15.0**
3	3	**37.5**
4	4	**62.5**
5	5	**87.5**

The analysis was broken in several stages:

2.2.2.1 Numerical classification

This analysis was performed with the program NTSYSpc (Version 2.21c) (Rohlf 2009). Analysis used Bray-Curtis coefficient (dissimilarity) and UPGMA (un-weighted pair-group method using arithmetic averages) as sorting strategy (Kent & Coker 1992, Capelo 2003). The goodness of the classification was assessed by cophenetic correlation (Sokal & Rohlf 1981; Rohlf 2009). Cluster analysis was applied to:

i) 138 relevés used to describe the communities of Madeiran climatophyllous vegetation series (Costa *et al.* 2004);

ii) 170 relevés resultant from vegetation surveyed in present research;

iii) 34 relevés of native plant assemblages over forsaken agricultural areas, plus 35 relevés of native plant assemblages over cliffs and rocky outcrops, plus 138 relevés used to describe the communities of Madeiran climatophyllous vegetation series (Costa *et al.* 2004).

2.2.2.2 Diversity and species richness determination

Diversity and species richness in each plot were quantified by using three components (Kent & Coker 1992, p. 95-98):

i) Species richness (number of plant species in a relevé);

ii) Shannon-Wiener Diversity Index : $H' = -\sum_{i=1}^{s} p_i \ln p_i$

iii) Equitability or evenness (also known as Equitability of Pielou) $J = \frac{H'}{H'_{max}} = \frac{-\sum_{i=1}^{s} p_i \ln p_i}{\ln s}$

where: s = the number of species; p_i = proportion of individuals or the abundance of the ith species expressed as a proportion of total cover; and ln = log base$_n$.

Calculations were applied to relevés of:

i) Assemblages dominated by *Acacia mearnsii*
ii) Assemblages dominated by *Arundo donax*
iii) Assemblages dominated by *Eucalyptus globulus*
iv) Assemblages dominated by *Pinus pinaster*
v) Areas over dead *Pinus pinaster* (by fire or due to pine wilt disease).
vi) Native vegetation growing over forsaken agricultural areas.
vii) Native vegetation growing over cliffs and rocky outcrops.

2.3 Results

The 308 phytosociological relevés contained a total amount of 474 taxa. The non-introduced *taxa* more frequently found (Table 2.7- native, Macaronesian endemics and Madeiran endemics) belong to seral stages (grassland as e.g. *Hyparrhenia sinaica* (Delile) Llauradó ex G. López[1], *Brachypodium sylvaticum* (Huds.) P. Beauv.[2], *Bituminaria bituminosa* (L.) C.H. Stirt.[3] scrubland as *Globularia salicina*[4], *Erica arborea*[5], *Erica platycodon subsp. maderincola*[6], *Echium nervosum*[7], *Myrica faya*[8] *and* early stages of laurel forests as e.g. *Laurus novocanariensis*[9]) and also species found more frequently in the lower stratum of woodlands and in ruderal and rupicolous communities as e.g. *Aeonium glutinosum*[10], *Pteridium aquilinum* (L.) *Kuhn* subsp*. aquilinum*[11], *Davallia canariensis*[12], and *Phyllis nobla*[13]. For the exotic species (Table 2.7, introduced species) was found *Ageratina adenophora*, *Oxalis pes-caprae*, *Acacia mearnsii* De Wild*.*, *Arundo donax*, *Opuntia tuna*, and *Asparagus asparagoides* as the species most frequently encountered in all relevés.

Table 2.7 The species most frequently found.

Taxa	Colonisation status	Number of relevés
Bituminaria bituminosa	Native species	92
Globularia salicina	Macaronesian endemic species	91
Hyparrhenia sinaica	Native species	86
Brachypodium sylvaticum	Native species	72
Ageratina adenophora	Introduced species	69
Aeonium glutinosum	Madeiran endemic species	68
Davallia canariensis	Native species	58
Pteridium aquilinum subsp. aquilinum	Native species	58
Laurus novocanariensis	Macaronesian endemic species	54
Erica arborea	Native species	51
Oxalis pes-caprae	Introduced species	50
Erica platycodon subsp. maderincola	Madeiran endemic species	49
Myrica faya	Native species	46
Echium nervosum	Madeiran endemic species	45
Acacia mearnsii	Introduced species	44
Arundo donax	Introduced species	43
Opuntia tuna	Introduced species	43
Phyllis nobla	Macaronesian endemic species	43
Asparagus asparagoides	Introduced species	42
Sonchus oleraceus	Possible native species	42

---

[1] Commonly known as blue grass and locally as *feno.*

[2] Commonly known as purple false brome and locally as *erva* (grass), not being made distinction from other common Poaceae.

[3] Commonly known as Arabian pea and locally as *fedegoso.*

[4] A species of globe daisy shrub locally known as *malfurada.*

[5] The tree heath locally known by the common name of *urze-molar*, *betouro.*

[6] Besom heath locally known by the common name of urze-das-vassouras, urze-durázia.

[7] Commonly known as pride of Madeira and locally known as *massaroco,* not being made distinction from *Echium candicans*.

[8] Commonlly known as firetree and locally as *faia*, faia-das-ilhas, samouco.

[9] Laurel tree locally known as *louro*, l*oureiro.*

[10] A species of tree houseleek locally known as *ensaião.*

[11] Commonly know as braken and locally as *feiteira.*

[12] A species of deersfoot fern locally known as *cabrinha*

[13] Commonly known as noble hare's-ear and locally by *cabreira*

Numerical classification applied to relevés included in Costa *et al* (2004) have shown groupings which are almost an exact match with communities recognised by vegetation model (Figure 2.8). Only three relevés (marked with a cross) were classified under a different group (*Cenchro ciliaris-Hyparrhenietum sinaicae* and *Dactylo hylodis-Hyparrhenietum sinaicae*), (*Argyranthemo montanae-Ericetum maderensis* and *Armerio maderensis-Parafestucetum albidae*), (*Clethro arboreae-Ocoteetum foetentis and Vaccinio padifoli-Ericetum maderincolae*). Several distinct groups emerged from the cluster analysis applied to relevés performed over the photographed area (Figure 2.9). Assemblages dominated by exotic species as *Arundo donax, Acacia mearnsii*, *Eucalyptus globulus*, *Pinus pinaster*, A*cacia melanoxylon*, and *Quercus ilex* appeared as distinct groups*.* Relevés performed in assemblages of native plants growing over forsaken terraces and rocky outcrops and cliffs appear jumbled together.

Classification applied to the latter data, together with relevés used to recognise vegetation communities (Costa *et al*. 2004) (Figure 2.10), have shown that:

i) some vegetation types were not found in surveyed area as *Artemisio argenteae-Genistetum tenerae*, *Rhamno glandulosi-Sambucetum lanceolati*, *Diplazio caudate-Perseetum indicae, Pericaulido aurita-Geranietum palmatae, Campanulo erini-Wahlenbergietum lobelioidis*, *Thymetum micantis*, *Bystropogono puntacti-Telinetum maderensis, Argyranthemo montanae-Ericetum maderensis, Armerio maderensis-Parafestucetum albidae*, *Sinapidendro frutescentis-Aeonietum glandulosi*, *Vicio capreolatae-Odontietum hollianae*, *Teucri franco-Origanetum virentis*;

ii) one group of relevés did not aggregate to the communities of the model. It correspond to relevés performed over abandoned fields, dead pine areas, and rocky outcrops where was found a community dominated by *Myrica faya.*

iii) all the others formed clear groups with relevés of *Galactito tomentosae-Brachypodietum distachyae Cenchro ciliaris-Hyparrhenietum sinaicae*, *Dactylo hylodis-Hyparrhenietum sinaicae, Euphorbietum piscatoriae*, *Mayteno umbellatae-Oleetum maderensis*, *Myrtus communis-Hypericetum canariensis*, *Globulario salicinae-Ericetum arboreae, Vaccinio padifoli-Ericetum maderincolae, Clethro arboreae-Ocoteetum foetentis, Semele androgynae-Apollonietum barbujanae, Scrophulario hirtae-Salicetum canariensis, Polysticho falcinelli-Ericetum arboreae*.

iii) most of the native vegetation which regenerated over abandoned fields belong to *Euphorbietum piscatoriae* and *Hyparrhenietum sinacae* (*Cenchro ciliaris-Hyparrhenietum sinaicae*, *Dactylo hylodis-Hyparrhenietum sinaicae*).

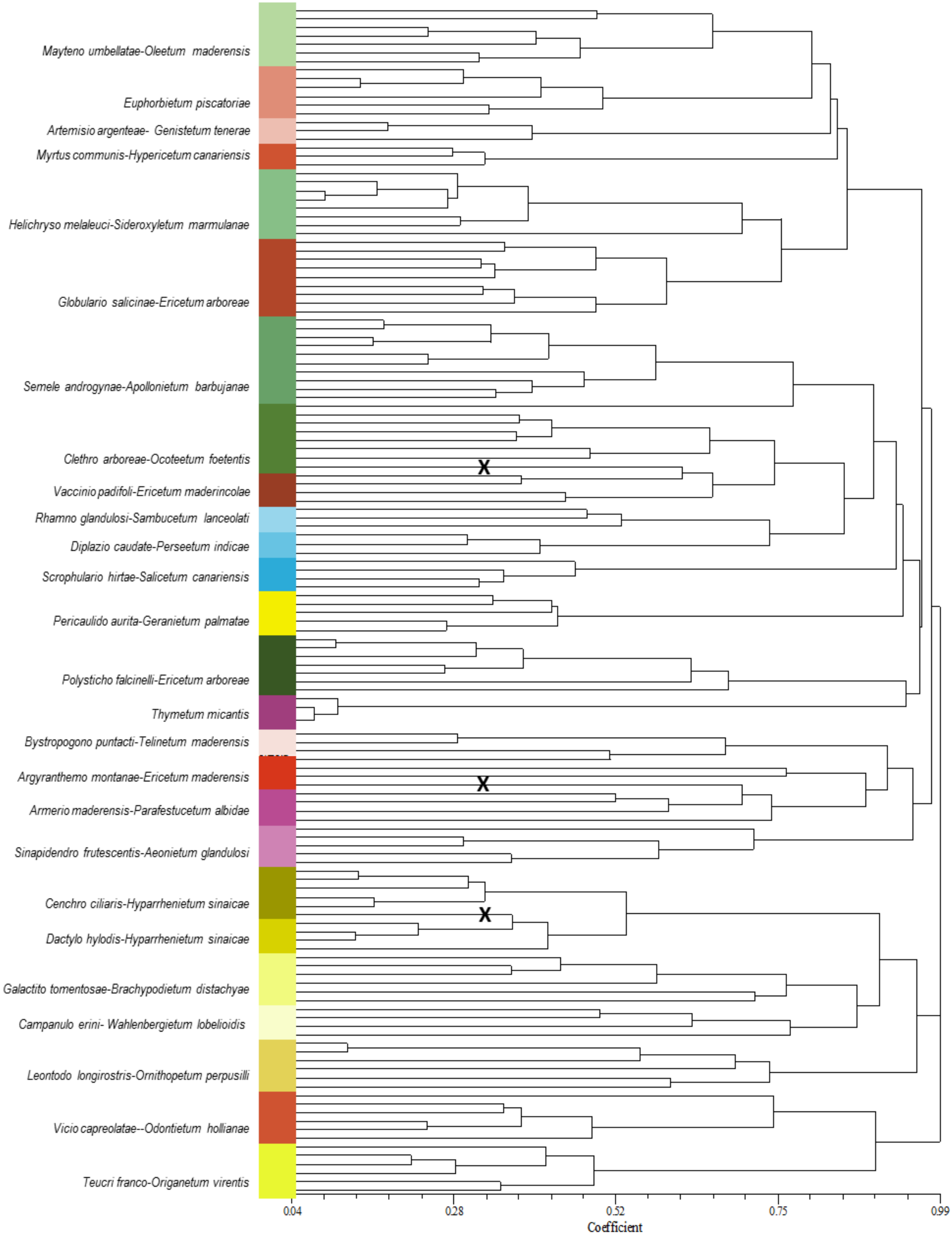


Figure 2.8 Dendrogram from cluster analysis (UPGMA, Bray-Curtis coefficient) of relevés used to describe the communities of Madeiran climatophyllous vegetation series (Costa et al. 2004). Cophenetic correlation 0.91.

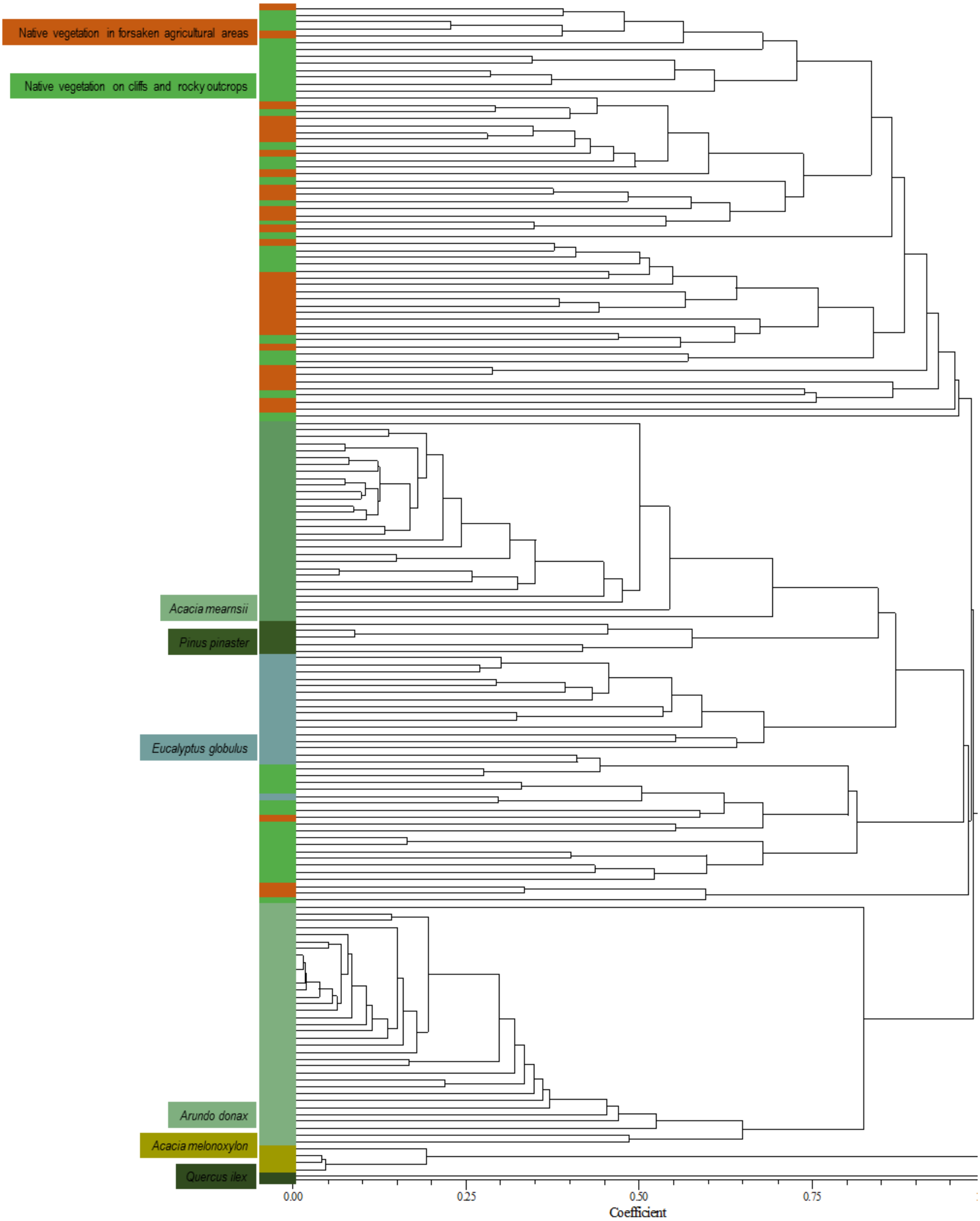


Figure 2.9 Dendrogram from cluster analysis (UPGMA, Bray-Curtis coefficient) of relevés resultant from vegetation surveyed in present research. Cophenetic correlation 0.94.

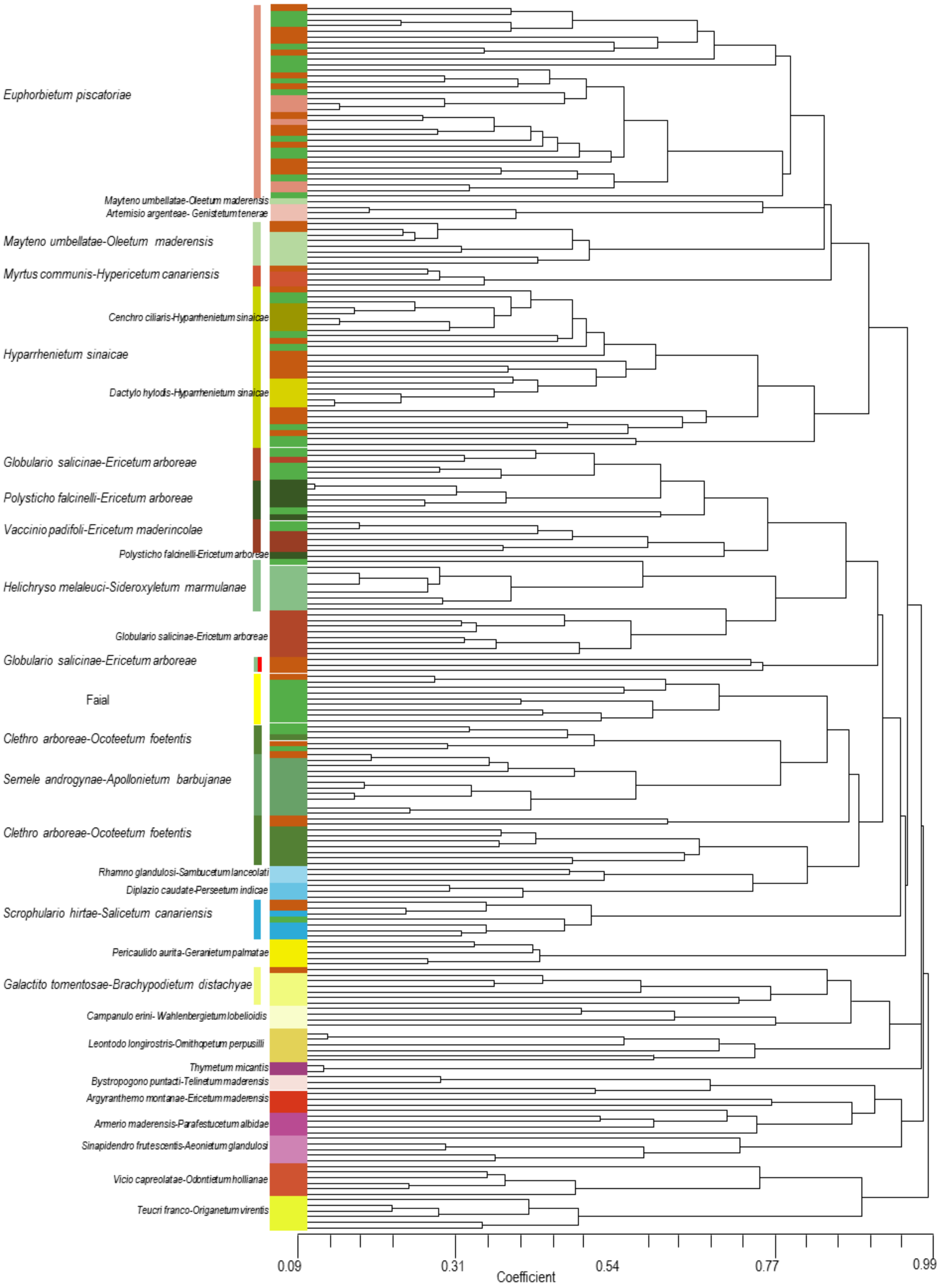


Figure 2.10 Dendrogram from cluster analysis (UPGMA, Bray-Curtis coefficient) of native plant assemblages surveyed over forsaken agricultural areas (orange bars, same as in figure 2.9), over cliffs and rock outcrops (bright green bars, same as in figure 2.9), and communities of Madeiran climatophyllous vegetation series (Costa *et al.* 2004) (bars of different colors, same as in figure 2.8). Cophenetic correlation 0.80.

Diversity and species richness evaluation as well as determination of colonisation status of the *taxa* (Jardim & Menezes de Sequeira 2008) were used to characterise the resulting groups:

i) Assemblages dominated by *Acacia mearnsii* have shown species richness between 3 and 16, and only in 6 out of the 28 relevés the number of species was higher than 10 (Tables 2.8 and 2.9). In addition the number of native species (gathering endemics and non-endemics) it was almost caught up by the number of exotic species (Figure 2.11). In the latter group the species *Oxalis-pescaprae* and *Asparagus asparagoides* were the ones more often found. With regard to the native species, they were in accordance with the PNV but only very common species as *Brachypodium sylvaticum*, *Davallia canariensis*, *Euphorbia peplus* L.,[1] and *Galium aparine* L.[2] appeared more frequently and more abundantly, and only in open woodlands (Figure 2.12-a). Frequently the species forms very dense stands without understory (Figure 2.12-b, c). Values of Shannon-Wiener index always scored under 1.5 and mostly below 1. Equitability or evenness values ranged between 0.26 and 0.69 (Tables 2.8, 2.9).

ii) The 35 relevés in assemblages dominated by *Arundo donax* have shown that this type of plant formation is very dense (Figure 2.14-a, b) and very poor in number of species. The maximum number of species was 9 and in a couple of relevés *Arundo donax* was the only species identified. Maximum value of Shannon-Wiener index reached 1.67 but the majority of the values ranged between 0 and 1. This was the same range seen for the values of Equitability or evenness, being however the majority of the values below 0.50 (Tables 2.10, 2.11). Most of the species found in these assemblages are non-native (Figure 2.13), being the *taxa* most frequently identified *Oxalis pes-caprae, Ageratina adenophora* and climbers as *Senecio mikanioides* Otto ex Walp[3], *Cardiospermum grandiflorum* Sw.[4] (Figure 2.14-c), *Ipomoea indica* (Burm.) Merr[5], and *Podranea ricasoliana* (Tanfani) Sprague[6]. The native species in addition to the fact that they tended to be of low abundance, only very common species were more frequently found as *Bituminaria bituminosa*, *Brachypodium sylvaticum*, and *Pteridium aquilinum.*

iii) Relevés in assemblages dominated by *Eucalyptus globulus* have shown higher diversity and species richness than previous formations, ranging the number of species between 2 and 35, the Shannon-Wiener index between 0.67 and 2.78, with more than a half above 1.5, and Equitability or evenness between 0.52 and 0.97 (Tables 2.12). In very old and open eucalyptus woodlands regeneration of native vegetation occurred being found occasionally some rare endemics as *Solanum patens* Lowe[7] (Figure 2.15-d), although most of the native species observed belong to fairly common *taxa* as *Pteridium aquilinum*, *Brachypodium sylvaticum, Euphorbia peplus,* and *Hedera maderensis* subsp. *maderensis*[8] (Figure 2.15-c). Despite the total number of native *taxa* exceeded the number of exotic ones (Figure 2.15-a) the latter were more frequently found. Species as *Acacia mearnsii*, *Acacia melanoxylon*, *Ageratina adenophora* were abundant in a large part of the relevés, especially in eucalyptus woodlands affected by recent fires (Figure 2.15-b).

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[1] Commonly know as petty spurge and locally as *trovisco.*

[2] Commonly known as robin-run-the-hedge and locally as raspa-lingua.

[3] Commonly known as German ivy and locally as *tasneirinha.*

[4] Commonly known as ballon-vine, and locally as *corriola-dos-balões.*

[5] Commonly known as blue morning glory and locally as *campaínhas*

[6] Commonly known, in its native area, as Port St Johns Creeper and locally as *begónia-rosa, corriola.*

[7] An endemic type of nightshade, locally without common name.

[8] Commonly know as ivy and locally as *Hera.*

Table 2.8 Relevés of assemblages dominated by *Acacia mearnsii* in areas of different PNV: Mu-Om (*Mayteno umbellatae-Oleo maderensis sigmetum*) Ca-Of (*Clethro arboreae-Ocoteo foetentis sigmetum*), and Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum,* Facies with *Globulario salicinae-Ericetum arboreae*).

PNV	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Mu-Om	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Ca-Of	Ca-Of	Sa-Ab2	Sa-Ab2	Ca-Of
Relevé	A7	A8	A9	A12	A13	A14	A16	A17	A18	A20	A30	A32	A33	A34	A36	A38	A39	A41	A45	A46	A54
Altitude (m)	181	240	220	340	307	141	421	398	411	460	335	492	515	491	534	529	778	905	410	390	283
Acacia mearnsii	4	5	5	5	5	4	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5
Brachypodium sylvaticum (Huds.) P. Beauv.				+	+								1	+	+	+	r	+	r		1
Asparagus asparagoides	+		r	1	1	+					+	+	+	r							
Oxalis pes-caprae		r	r	+	r			+	1			+	+	r					+	3	r
Achyranthes sicula (L.) All.						1	r	+	1		+	r		r						r	
Sonchus oleraceus	r	r	+							r	1	r	+	r							r
Davallia canariensis		+	+			+							+	r							
Euphorbia peplus	r		r	r	r						+		+		r				r		
Galium aparine.	r				r	+			+								r				
Eucalyptus globulus				2a								3	3	r			2a				
Carex divulsa Stokes subsp. *divulsa*					r										r			r			r
Mercurialis annua L.	1		+				r				r				r						
Pittosporum undulatum					r					r					r	r					
Polypodium macaronesicum A.E. Bobrov		+	r	r	r																
Crassula multicava Lem.																					
Ageratina adenophora	+			r													r				
Rubus ulmifolius				r												1	r	1			
Acanthus mollis L.							+	+		r											
Agapanthus praecox Willd. subsp. *orientalis* (F.M. Leight.) F.M. Leight.									r												
Asplenium onopteris L.				r														r			
Bidens pilosa L.	r	r	r																		
Centranthus calcitrapae (L.) Dufr.	r	r	r																		
Erica arborea L.		1																			
Zantedeschia aethiopica (L.) Spreng.										r											r
Ageratina riparia (Regel) R.M. King & Rob.										1						1					
Allium triquetrum L.								+	+												
Araujia sericifera Brot.	r	r																			
Bituminaria bituminosa (L.) C.H. Stirt.											+										
Chelidonium majus L.					r																r
Erica platycodon subsp. *maderincola*																					
Fumaria sepium Boiss.									+			r									
Myrtus communis																					
Opuntia tuna			+												r						
Podranea ricasoliana								2a	r												
Selaginella denticulata (L.) Spring					r										r						
Semele androgyna										+											
Tolpis succulenta	r		r																		
Species richness	13	10	16	11	11	6	4	8	9	9	8	7	8	8	8	7	6	6	6	3	9
Shannon-Wiener Diversity Index (H')	1,47	0,96	1,42	1,21	1,04	0,72	0,36	0,97	0,87	1,05	0,77	1,01	1,20	0,77	0,77	0,68	0,80	0,58	0,58	0,70	0,87
Equitability or evenness (J)	0,57	0,42	0,51	0,50	0,43	0,40	0,26	0,47	0,39	0,48	0,37	0,52	0,58	0,37	0,37	0,35	0,45	0,32	0,32	0,63	0,39

Plus:r *Galactites tomentosa* Moench, + *Pelargonium inquinans,* r *Polycarpon tetraphyllum* (L.) L., and r *Senecio sylvaticus* L. in A9; 2a *Duchesnea indica* (Jacks.) Focke, r *Laurus novocanariensis,* r *Passiflora mollissima* (Kunth) L.H. Bailey, and r *Vitis vinifera* in A55; r *Asplenium aethiopicum* (Burm.f.) Bech. subsp. *braithwaitii* Ormonde, r *Lapsana communis* L. subsp. *communis*, and r *Ocotea foetens* in A55; 1 *Brachiaria mutica* (Forssk.) Stapf, r *Rubus bollei*, and 2b *Tradescantia fluminensis* Vell. in A64; 4 *Kalanchoe pinnata* (Lam.) Pers. and r *Lotus parviflorus* Desf. in A7; 2b *Hedera maderensis* subsp. *maderensis* and 4 *Pteridium aquilinum* (L.) Kuhn subsp. *aquilinum* in A97; 2a *Solanum mauritianum* Scop. and r *Stellaria media* (L.) Vill. in A20; + *Ipomoea indica* (Burm.) Merr. and 1 *Pseudosasa japonica* (Siebold & Zucc. ex Steud.) Makino;in A17; 1 *Senecio mikanioides* Otto ex Walp. and r *Vinca major* L. in A38; r *Cytisus scoparius* subsp. *scoparius* and r *Pinus pinaster* in A45; r *Aeonium glutinosum* in A131¸ r *Asplenium adiantum-nigrum* L.. in A18; r *Bromus diandrus* Roth in A30; r *Cynosurus echinatus* L. in A62; r *Carpobrotus edulis* (L.) N.E. Br. in A14; and r *Castanea sativa* in A41.

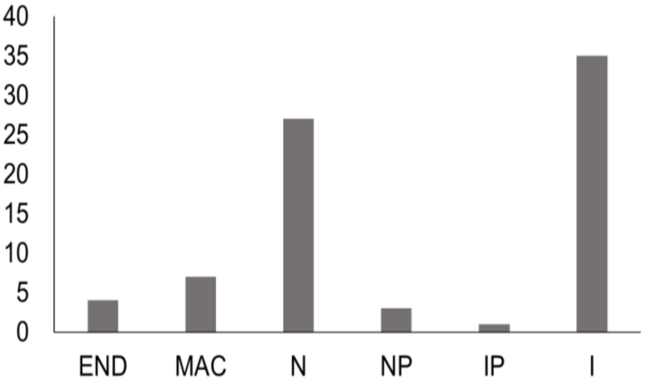


Figure 2.11 Number of plant taxa (species and subspecies) found in assemblages dominated by Acacia mearnsii distributed according to colonisation status. Madeiran endemics (END), Macaronesian endemics (MAC), Native (N), Possible native (NP), Possible introduced (IP

Table 2.9 Continued from Table 2.8: Ca-Of (*Clethro arboreae-Ocoteo foetentis sigmetum*), and Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum,* Facies with *Globulario salicinae-Ericetum arboreae*), and Sh-Sc (*Scrophulario hirtae-Salicetum canariensis*).

PNV	Ca-Of	Sa-Ab2	Sa-Ab2	Sh-Sc	Sa-Ab1	Sa-Ab2	Sa-Ab2
Relevé	A55	A56	A62	A64	A97	A119	A131
Altitude (m)	538	425	246	49	462	430	242
Acacia mearnsii De Wild.	4	5	4	4	4	5	4
Brachypodium sylvaticum (Huds.) P. Beauv.	1	1	+	+	+	2a	
Asparagus asparagoides (L.) Druce			+	r	+		+
Oxalis pes-caprae L.					+		
Achyranthes sicula (L.) All.			+	3			
Sonchus oleraceus L.							
Davallia canariensis (L.) Sm.			r			1	r
Euphorbia peplus L.							
Galium aparine L.	r				r		
Eucalyptus globulus Labill.							
Carex divulsa Stokes subsp. *divulsa*	r						
Mercurialis annua L.							
Pittosporum undulatum Vent.							3
Polypodium macaronesicum A.E. Bobrov						+	
Crassula multicava Lem.		1		r	+	4	
Ageratina adenophora (Spreng.) R.M. King & H. Rob.					+		
Rubus ulmifolius Schott							
Acanthus mollis L.							
Agapanthus praecox Willd. subsp. *orientalis* (F.M. Leight.) F.M. Leight.		+				3	
Asplenium onopteris L.	r						
Bidens pilosa L.							
Centranthus calcitrapae (L.) Dufr.							
Erica arborea L.						1	r
Zantedeschia aethiopica (L.) Spreng.				r			
Ageratina riparia (Regel) R.M. King & Rob.							
Allium triquetrum L.							
Araujia sericifera Brot.							
Bituminaria bituminosa (L.) C.H. Stirt.				r			
Chelidonium majus L.							
Erica platycodon subsp. *maderincola*		+				1	
Fumaria sepium Boiss.							
Myrtus communis L.		r					r
Opuntia tuna (L.) Mill.							
Podranea ricasoliana (Tanfani) Sprague							
Selaginella denticulata (L.) Spring							
Semele androgyna (L.) Kunth	r						
Tolpis succulenta (Dryand.) Lowe							
Species richness	11	6	6	10	9	8	7
Shannon-Wiener Diversity Index (H')	1,41	0,58	0,72	1,48	1,28	1,43	1,12
Equitability or evenness (J)	0,59	0,32	0,40	0,64	0,58	0,69	0,57

Figure 2.12 (a) Open woodland of *Acacia mearnsii*. Machico, 2009 (MS, AP); (b) Stand of *Acacia mearnsii* in dead pine area. Cruzinhas do Faial, 2010 (AP, MB). (c) Stand of *Acacia mearnsii* regenerating after a fire, with trees growing very densely. Caniço, 2009 (MS, AP).

Table 2.10 Relevés of assemblages dominated by *Arundo donax* in areas of different PNV: Mu-Om (*Mayteno umbellatae-Oleo maderensis sigmetum*), Hm-Sm (*Helichryso melaleuci-Siderxyleo marmulanae sigmetum*), Sa-Ab1 (*Semele androgynae-Apollonio barbujanae sigmetum, Facies with Myrto communis-Hypericetum canariensis*), Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum, Facies with Globulario salicinae-Ericetum arboreae*), Dc-Pi (*Diplazio caudate-Perseetum indicae*), and Sh-Sc (*Scrophulario hirtae-Salicetum canariensis*).

PNV	Sa-Ab2	Dc-Pi	Mu-Om	Sh-Sc	Sh-Sc	Sh-Sc	Mu-Om	Mu-Om	Sa-Ab1	Sh-Sc	Sa-Ab1	Dc-Pi	Sa-Ab2	Sa-Ab2	Sh-Sc	Sh-Sc	Sa-Ab2	Hm-Sm
Relevé	A6	A19	A21	A24	A25	A26	A27	A28	A29	A42	A43	A44	A47	A48	A49	A50	A57	A58
Altitude (m)	21	400	65	30	19	22	27	32	225	91	44	325	157	98	14	26	63	48
Arundo donax	2b	5	5	5	4	5	4	5	5	5	5	5	5	5	5	5	5	5
Oxalis pes-caprae			2a					+	+				r	+				
Achyranthes sicula				1			5	+	+	r	+							
Ipomoea indica		3		r			r		2b							3		
Rubus bollei													r			3	r	
Brachypodium sylvaticum								1				r					r	r
*Pteridium aquilinum*subsp. *aquilinum*													r					4
Ageratina adenophora					r					r							r	
Bituminaria bituminosa			r	+				r										
Sonchus oleraceus			r							r								
Senecio mikanioides																		r
Asparagus asparagoides			+															
Cardiospermum grandiflorum					3	2a	r		r									
Crocosmia x *crocosmiflora* (G. Nicholson) N.E. Br.																		
Kalanchoe pinnata																		
Araujia sericifera																	r	
Opuntia tuna			r								R							
Tradescantia fluminensis																		
Ageratina riparia																		
Podranea ricasoliana					2a	r												
Tamarix gallica L.	2b																	
Pittosporum undulatum													1				+	
Boussingaultia cordifolia Ten.						r				r								
Euphorbia peplus					r			r										
Lantana camara L.				r	+													
Rubus ulmifolius		r		r														
Solanum mauritianum		+																
Urtica membranacea						r				r								
Species richness	6	4	7	6	6	7	5	8	5	6	3	2	5	2	1	3	6	6
Shannon-Wiener Diversity Index (H')	1,51	0,78	0,89	0,58	1,20	0,89	0,59	0,77	0,71	0,58	0,25	0,13	0,47	0,13	0,00	1,01	0,58	0,96
Equitability or evenness (J)	0,84	0,56	0,46	0,32	0,67	0,46	0,37	0,37	0,44	0,32	0,23	0,18	0,29	0,18	0,00	0,92	0,32	0,53

Plus: 2a *Carpobrotus edulis*, + *Dactylis smithii* Link subsp. *hylodes* Parker, + *Paspalum dilatatum* Poir., r *Plantago lanceolat*a L. in A6; + *Arrhenatherum elatius* (L.) J. Presl & C. Presl subsp. *bulbosum* (Willd.) Schübl. & G. Martens, + *Tolpis suculenta*, r *Geranium robertianum* L. in A60; r *Dichanthium annulatum* (Forssk.) Stapf, r *Galium aparine* in A26; r *Bidens pilosa* and r *Geranium purpureum* Vill. in A28; r *Hedera maderensis* subsp. *maderensis* and *Oxalis debilis* in A58; 1 *Crassula multicava* and *Vitis vinifera* in A61; r *Cenchrus ciliaris* L. in A27; r *Pelargonium inquinans* in A21; r *Zantedeschia aethiopica* in A67.

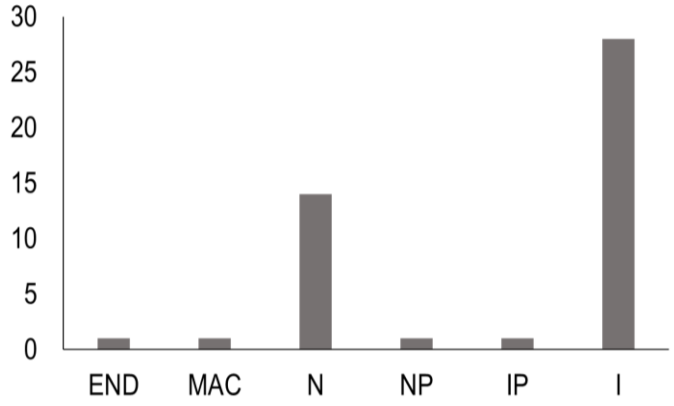


Figure 2.13 Number of plant taxa (species and subspecies) found in assemblages dominated by *Arundo donax* distributed according to colonisation status. Madeiran endemics (END), Macaronesian endemics (MAC), Native (N), Possible native (NP), Possible introduced (IP), and Introduced (I).

Table 2.11 Continued from table 2.10. Mu-Om (*Mayteno umbellatae-Oleo maderensis sigmetum*), Hm-Sm (*Helichryso melaleuci-Siderxyleo marmulanae sigmetum*), Ca-Of (*Clethro arboreae-Ocoteeo foetentis sigmetum*), Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum,* Facies with *Globulario salicinae-Ericetum arboreae*), and Sh-Sc (*Scrophulario hirtae-Salicetum canariensis*).

PNV	Hm-Sm	Sa-Ab2	Dc-Pi	Sh-Sc	Sh-Sc	Hm-Sm	Hm-Sm	Ca-Of	Ca-Of	Ca-Of	Mu-Om	Mu-Om	Sh-Sc	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sh-Sc
Relevé	A59	A60	A61	A63	A65	A66	A67	A68	A69	A70	A71	A72	A73	A120	A123	A129	A130
Altitude (m)	29	208	232	47	50	90	87	382	457	788	36	120	25	46	101	234	244
Arundo donax	5	5	4	4	5	5	5	5	5	4	5	5	5	5	5	3	3
Oxalis pes-caprae	1													r	3	1	2a
Achyranthes sicula											r				3		
Ipomoea indica	+											r					
Rubus bollei			1	2b	2b		r										
Brachypodium sylvaticum		+			r												r
*Pteridium aquilinum*subsp. *aquilinum*		+						3	2a	2a							
Ageratina adenophora		+		r													2b
Bituminaria bituminosa			r								r				r		
Sonchus oleraceus	r	+					r				+						
Senecio mikanioides				r			r		+	3							
Asparagus asparagoides			r		r											2b	
Cardiospermum grandiflorum																	
Crocosmia x *crocosmiflora* (G. Nicholson) N.E. Br.			1					2a		r							1
Kalanchoe pinnata			r	1												2a	2a
Araujia sericifera				r												1	
Opuntia tuna											r						
Tradescantia fluminensis				1					4								
Ageratina riparia			r														2b
Podranea ricasoliana																	
Tamarix gallica L.														1			
Pittosporum undulatum																	
Boussingaultia cordifolia Ten.																	
Euphorbia peplus																	
Lantana camara L.																	
Rubus ulmifolius																	
Solanum mauritianum					r												
Urtica membranacea																	
Species richness	4	8	9	7	5	1	5	3	4	4	5	2	1	3	4	5	5
Shannon-Wiener Diversity Index (H')	0,36	0,77	1,06	1,05	0,71	0,00	0,47	0,89	0,99	1,04	0,47	0,13	0,00	0,25	1,07	1,23	1,67
Equitability or evenness (J)	0,26	0,37	0,48	0,54	0,44	0,00	0,29	0,81	0,71	0,75	0,29	0,18	0,00	0,23	0,77	0,76	1,04

Figure 2.14 (a) Large stands of *Arundo donax* throughout riparian areas. Ribeira de São Jorge, 2010 (AP, MB). (b) Stand of *Arundo donax*, almost mono-specific and growing very densely. Porto Moniz, 2010 (AP, MB). (c) Assemblage dominated by *Arundo donax* with *Cardiospermum grandiflorum* using giant reed as support to climb. Funchal, 2011 (AP).

Table 2.12 Relevés of assemblages dominated by *Eucalyptus globulus* in areas of different PNV. Sa-Ab1 (*Semele androgynae-Apollonio barbujanae sigmetum*, Facies with *Myrto communis-Hypericetum canariensis*), Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum,* Facies with *Globulario salicinae-Ericetum arboreae*), Ca-Of (*Clethro arboreae-Ocoteo foetentis sigmetum*), and Dc-Pi (*Diplazio caudate-Perseetum indicae*).

PNV	Sa-Ab2	Sa-Ab1	Ca_Of	Ca_Of	Ca_Of	Sa-Ab2	Sa-Ab2	Dc-Pi	Sa-Ab1	Ca_Of	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2
Relevé	A35	A99	A110	A111	A112	A146	A147	A148	A149	A151	A156	A157	A159	A162
Altitude (m)	535	380	435	434	408	464	642	610	589	956	753	747	162	192
Eucalyptus globulus	4	3	3	4	4	5	4	4	4	4	3	5	5	4
Ageratina adenophora		2a			r	1			r	+	2a	+		+
Acacia mearnsii	3					3			2b	r	1	4		
Pteridium aquilinum subsp. *aquilinum*			4		+					2b	2b		1m	+
Laurus novocanariensis			r				r	3		+			+	2b
Brachypodium sylvaticum .			+		+					r	r	r		+
Asparagus asparagoides		+				r		R			r	r		+
Euphorbia peplus L.		+				r			r	r				+
Pittosporum undulatum	2b					2b							+	r
Agapanthus praecox subsp. *orientalis*	r					+				1				r
Ulex europaeus L. subsp. *latebracteatus* (Mariz) Rothm.			+		r						+	r		
Acacia melanoxylon R. Br.	r			5			2b							
Bituminaria bituminosa		2a			+	r								
Rubus ulmifolius Schott			+			r				2a				
Calamintha nepeta (L.) Savi subsp. *sylvatica* (Bromf.) R. Morales									r	r	r			
Hypericum humifusum L.			+							+			r	
Pinus pinaster		r			r									+
Aeonium glutinosum			r											1m
Myrica faya			2a		+									
Oxalis pes-caprae	r	3												
Hypericum perforatum L.										1	1			
Solanum patens							r			1				
Centranthus calcitrapae (L.) Dufr.		+			r									
Galactites tomentosa		+								+				
Galium aparine		+												r
Globularia salicina		r	+											
Briza maxima L.					r	r								
Carex divulsa Stokes subsp. *divulsa*	r									r				
Geranium molle L.										r				r
Helichrysum foetidum (L.) Cass.										r	r			
Reseda luteola L.										r	r			
Sibthorpia peregrina							r			r				
Solanum nigrum L.						r	r							
Sonchus oleraceus	r		r											
Vinca major									r				r	
Species richness	10	17	16	2	11	18	10	3	9	35	18	6	9	18
Shannon-Wiener Diversity Index (H')	1,48	2,07	1,84	0,68	1,26	1,88	1,32	0,76	1,52	2,78	2,26	0,96	1,22	1,91
Equitability or evenness (J)	0,64	0,73	0,66	0,98	0,52	0,65	0,58	0,69	0,69	0,78	0,78	0,53	0,55	0,66

Plus: 2b *Scrophularia scorodonia*, 1 *Rumex maderensis*, + *Solanum nigrum* L. subsp. *schultesii* (Opiz) Wessely, *r Lapsana comm*unis L. subsp. *communis*, r *Origanum vulgare* L. subsp. *virens* (Hoffmanns. & Link) Bonnier & Layens, r *Plantago lanceolata*, r *Prunella vulgaris* L., r *Senecio vulgaris* L., r *Sonchus asper* (L.) Hill subsp. *asper*, r *Trifolium arvense* L., r *Trifolium scabrum* L., r *Umbilicus rupestris* (Salisb.) Dandy, and r *Vicia cordata* Hoppe in A151; 1 *Cistus psilosepalus* Sweet, + *Crepis vesicaria* L. subsp. *haenseleri* (Boiss. ex DC.) P.D. Sell, + *Verbena officinalis* L., + *Viola riviniana*, r *Clinopodium vulgare* L., r *Lagurus ovatus* L., and r *Trifolium campestre* Schreb. in A 156; + *Convolvulus althaeoides* L., + *Crepis divaricata* (Lowe) F.W. Schultz, + *Cynosurus echinatus* L., + *Geranium purpureum* Vill., + *Leontodon taraxacoides* (Vill.) Mérat subsp. *longirostris* Finch & P.D. Sell, + *Vicia disperma* DC. in A99; + *Acanthus mollis* L., + *Araujia sericifera*, + *Chelidonium majus* L., + *Tradescantia zebrina* Hort. ex Bosse, r *Senecio mikanioides*, and r *Solanum mauritianum* in A146; + *Brachiaria mutica*, + *Euphorbia segetalis* L., r *Holcus lanatus* L. subsp. *lanatus*, and r *Tolpis suculenta* in A110; r *Duchesnea indica* (Jacks.) Focke, r *Salix canariensis*, r *Scrophularia hirta*, and r *Semele androgyna* in A147; r *Davallia canariensis*, r *Helichrysum melaleucum*, r *Polypodium macaronesicum*, and r *Sonchus pinnatus* in A162; 2a *Castanea sativa* and 2a *Quercus robur* in A149; 2a *Eriobotrya japonica (*Thunb.) Lindl., 2a *Ficus carica* in A159; 1 *Crocosmia x crocosmiflora* and r *Achyranthes sicula* in A35; + *Hyparrhenia sinaica* in A112.

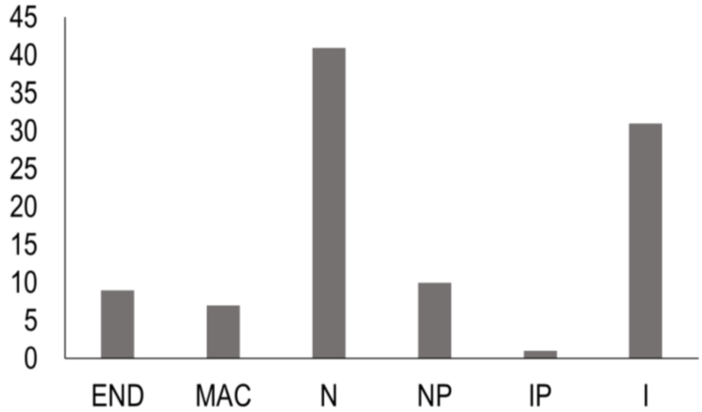


Figure 2.15 Number of plant *taxa* (species and subspecies) found in assemblages dominated by *Eucalyptus globulus* distributed according to colonisation status. Madeiran endemics (END), Macaronesian endemics (MAC), Native (N), Possible native (NP), Possible introduced (IP), and Introduced (I).

Figure 2.16 (a) Stand of *E. globulus* after a fire: regeneration of *E. globulus*, invasion of *Acacia* spp and low diversity (e.g. A157-Table 2.12); Curral dos Romeiros, 2012 (AP, JP). (b, c) Old and very open woodlands of eucalyptus allowing regeneration of native plants in the understory. Depending on the location was possible to found endemic species from the more common as *Hedera maderensis* subsp. *maderensis* (c) to more rare as *Solanum patens* (b) (e.g. A 151, Table 2.12); Caminho dos Pretos, 2012 (AP, JP).

iv) Relevés in open pine woodlands caused by death of some individuals due to fire or pine wilt disease have shown that although pine regeneration (Figure 2.18-a) those clearings were greatly invaded by other exotic trees as *Eucalyptus globulus* (2.18-b), *Acacia mearnsii* and *Pittosporum undulatum* (2.18-c). The number of species ranged from seven to 16 and the two relevés with the lower value matched to pine stands invaded by *Acacia mearnsii* (Table 2.13 - A152, A155). Shannon-Wiener index ranged between 1.12 and 2.24, and Equitability or evenness between 0.57 and 0.81 (Table 2.13). In these stands, still dominated by *Pinus pinaster* although the number of native species exceeded the number of introduced species (Figure 2.17) and were seen some Madeiran and Macaronesian endemic species, as *Hedera maderensis* subsp. *maderensis, Globularia salicina,* and *Helichrysum melaleucum*[1], as well as some not very common native species as *Verbena officinalis* L[2], the majority of native species seen belog to t*axa* rather common. In fact, some the native *taxa* are quite common as *Brachypodium sylvaticum* and *Pteridium aquilinum* (Table 2.13).

v) Relevés in areas of dead pine have shown two different groups. In areas close to native vegetation not invaded by exotic tree species vegetation installed correspond to plant associations of the vegetation series of PNV. Cluster analysis allowed to clearly relate them to communities of *Semele androgynae-Apollonio barbujanae sigmetum* and *Clethro arboreae-Ocoteo foetentis sigmetum*. Three relevés correspond to a community dominated by *Myrica faya* (*Faial*) (Figure 2.19-b). The communities dominated by native plants showed higher species richness than assemblages dominated by exotic plants (Table 2.14). Values of species richness ranged between nine and 25 in native plant associations, and between four and nine in assemblages dominated by exotic species. In general, the number of native species (including Madeiran endemics and Macaronesian endemics) was superior to the number of introduced species (Figure 2.19-a), but this relation was more significant in the formations dominated by native *taxa* (i.e. 38 native species against 14 introduced, and eight native species against seven introduced in formations dominated by exotic species). In the assemblages dominated by native species the number of endemic *taxa* was higher. Some Madeiran endemics as e.g. *Clethra arborea*, *Erica platycodon* subsp. *maderincola*, *Festuca donax*[3], *Hedera maderensis* subsp. *maderensis*, *Helichrysum melaleucum, Ruscus streptophyllus*[4]; *Sibthorpia peregrina*[5], *Teucrium betonicum*[6] were found as well as some Macaronesian endemics as *Apollonias barbujana*, *Arum italicum* Mill. subsp. *canariense* (Webb & Berthel.) P.C. Boyce[7], *Asplenium anceps* Lowe ex Hook. & Grev.[8], *Cedronella canariensis* (L.) Webb & Berthel.[9], *Globularia salicina*, *Hypericum grandifolium* Choisy[10], *Laurus novocanariensis*, *Phyllis nobla*, *Rubus bollei* Focke[11], and *Semele androgyna*[12]. Whilst in areas of dead pine far from native vegetation and occupied by exotic species just a couple of endemics were seen, and only common *taxa* as *Hedera maderensis* subsp. *maderensis* and *Laurus novocanariensis.*

---

[1] An endemic shrub belonging to plants commonly known as everlasting, locally known as perpétua-branca

[2] Commonly known as common vervain and locally as *jarvão*

[3] A species of fescue locally know as *palha-carga.*

[4] A species of butcher's broom, locally without common name.

[5] A species of moneywort, locally known as *hera-terrestre* or *erva-redonda*.

[6] A species of germander, locally know as *erva-branca* or *abrotona*.

[7] A subspecies of arum-lily locally know as bigalhó

[8] A species of fern locally know as *feto* not being made distinction from other ferns.

[9] Commonly know as canary-balm and locally as *Hortelã-de-cabra*, *mentastro*.

[10] A species of St Johns wort locally known as *malfurada*

[11] A species of blackberry bush locally know as *silvado* not being made distinction from the other species of brambles.

[12] Commonly known as climbing butcher's broom, and locally as *alegra-campo.*

Table 2.13 Relevés of assemblages dominated by *Pinus pinaster* in areas of different PNV. Hm-Sm (*Helichryso melaleuci-Siderxyleo marmulanae sigmetum*), Sa-Ab1 (*Semele androgynae-Apollonio barbujanae sigmetum*, Facies with *Myrto communis-Hypericetum canariensis*), Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum,* Facies with *Globulario salicinae-Ericetum arboreae*).

PNV	Sa-Ab1	Hm-Sm	Sa-Ab2	Sa-Ab2	Sa-Ab2
Relevé	A81	A152	A153	A154	A155
Altitude (m)	442	284	709	729	729
Pinus pinaster Aiton	4	4	3	4	4
Ageratina adenophora (Spreng.) R.M. King & H. Rob.	1		2a	2b	
Eucalyptus globulus Labill.			2a	2a	r
Brachypodium sylvaticum (Huds.) P. Beauv.	+		2a	r	
Pteridium aquilinum (L.) Kuhn subsp. *aquilinum*		1	r	r	
Ulex europaeus L. subsp. *latebracteatus* (Mariz) Rothm.		1	r		r
Globularia salicina Lam.	r	+		r	
Acacia mearnsii De Wild.		3			3
Cistus psilosepalus Sweet			2b		r
Hyparrhenia sinaica (Delile) Llauradó ex G. López	+	+			
Verbena officinalis L.			+	+	
Hypericum perforatum L.			r	+	
Andryala glandulosa Lam. subsp. *cheirantifolia* (L'Hér.) Greuter			r	r	
Lonicera etrusca Santi			r	r	
Species richness	16	7	16	15	7
Shannon-Wiener Diversity Index (H')	1,87	1,12	2,24	1,88	1,12
Equitability or evenness (J)	0,68	0,57	0,81	0,69	0,57

Plus: 2a *Geranium purpureum* Vill., 2a *Oxalis pes-caprae*, + *Centranthus calcitrapae* (L.) Dufr., + *Galactites tomentosa*, + *Holcus mollis* subsp. *mollis*, + *Hypochoeris glabra* L., + *Polycarpon tetraphyllum*, + *Sonchus oleraceus*, and r *Sonchus asper* in A81; 1 *Leontodon taraxacoides* (Vill.) Mérat subsp. *longirostris* Finch & P.D. Sell, + *Adenocarpus complicatus* (L.) J. Gay, r *Lagurus* ovatus, r *Pinus nigra* Aiton, and r *Tolpis suculenta* in A153; 3 *Pittosporum undulatum*, r *Calamintha nepeta* subsp. *sylvatica*, r *Carlina salicifolia*, r *Helichrysum melaleucum*, and r *Silene gallica* L. in A 154; r *Albizia lophantha* (Willd.) Benth., r *Hedera maderensis* subsp. *maderensis* in A155; and + *Erica arborea* in A152.

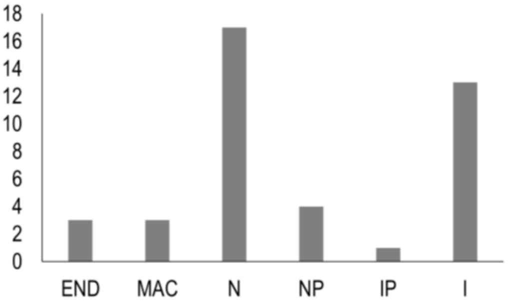


Figure 2.17 Number of plant taxa (species and subspecies) found in plant assemblages in areas *were Pinus pinaster* is dominant distributed according to colonisation status. Madeiran endemics (END), Macaronesian endemics (MAC), Native (N), Possible native (NP), Possible introduced (IP), and Introduced (I).

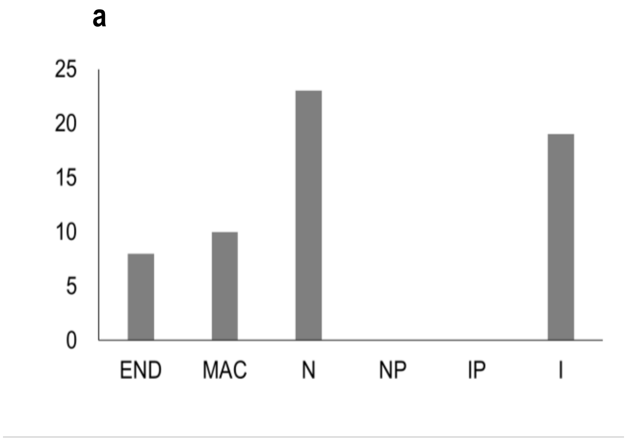
Figure 2.18 (a) Open pine woodlands with grassy clearings where pine seedlings are growing; Caminho do Lombo, 2012 (AP, JP) or starting to be invaded by other tree species as *Eucalyptus globulus* as in (b) Caminho do Lombo, 2012 (AP, JP), or *Acacia mearnsii* and *Pittosporum undulatum*; as in (c) Camacha, 2013 (AP).

Besides, the communities dominated by native plants showed higher diversity: Shannon-Wiener index ranged between 1.52 and 2.51, higher values than the obtained for exotic stands (ranging between 0.72 and 1.28), and values of Equitability were in general higher in native formations (ranging between 0.69 and 0.78) than in exotic formations. Only one relevé in this last assemblages surpass the evenness found for native communities (0.82) but although individuals were well distributed among the different species it correspond to the formation with lowest richness (Table 2.14).

Table 2.14 Relevés of assemblages established in areas of dead *Pinus pinaster* (by fire or due to pine wilt disease) under different PNV: Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum,* Facies with *Globulario salicinae-Ericetum arboreae*); Ca-Of (*Clethro arboreae-Ocoteo foetentis sigmetum*); and Dc-Pi (*Diplazio caudate-Perseetum indicae*). Communities identified: *Globulario salicinae-Ericetum arboreae* (Gs-Ea); community dominated by *Myrica faya* (*Faial*), and *Semele androgynae-Apollonietum barbujanae* (Sa-Ab). Shaded columns correspond to relevés of assemblages dominated by exotic trees and already presented in other Tables (2.8, 2.9 – A62, A97, and 2.12– A148).

PNV	Sa-Ab2	Sa-Ab1	Sa-Ab2	Ca_Of	Ca_Of	Dc-Pi	Sa-Ab2	Sa-Ab2
Relevé	A62	A97	A132	A140	A142	A148	A158	A163
Altitude (m)	246	462	270	544	531	610	173	241
Myrica faya			2a	3	3		4	2a
Laurus novocanariensis				1	2ª	3	3	3
Hedera maderensis subsp. *maderensis*		2b		+			2a	+
Ageratina adenophora		+		2a	R		+	
Brachypodium sylvaticum	+	+		2a			r	
Asparagus asparagoides	+	+	r			r		
Erica arborea			4	3	+			
Davallia canariensis	r		r	r				
Acacia mearnsii	4	4						
Pteridium aquilinum subsp. *aquilinum*		5	r					
Myrtus communis.			2a	1				
Apollonias barbujana				r				3
Vinca major							2b	+
Globularia salicina.			2b	r				
Ageratina riparia				+	2a			
Erica platycodon subsp. *maderincola*				r	+			
Semele androgyna				r				+
Sibthorpia peregrina.				r	+			
Asplenium onopteris					R			r
Geranium purpureum					R		r	
Phyllis nobla				r			r	
Ruscus streptophyllus Yeo				r				r
Species richness	6	9	9	25	17	4	17	10
Shannon-Wiener Diversity Index (H')	0,72	1,28	1,52	2,51	2,14	1,14	1,98	1,62
Equitability or evenness (J)	0,40	0,58	0,69	0,78	0,76	0,82	0,70	0,70

Plus: + *Agapanthus praecox* subsp. *orientalis*, + *Rubia agostinhoi* Dans. & P. Silva, r *Arum italicum* Mill. subsp. *canariense* (Webb & Berthel.) P.C. Boyce, r *Cytisus scoparius* subsp. *scoparius*, r *Helichrysum melaleucum*, r *Hypericum grandifolium* Choisy, r *Oxalis purpurea* L., r *Rubia agostinhoi* Dans. & P. Silva, r *Teucrium betonicum* L'Hér., and r *Umbilicus rupestris* (Salisb.) Dandy in A140; + *Euphorbia peplus*, r *Bituminaria bituminosa*, r *Calamintha nepeta* subsp. *sylvatica*, r *Carex divulsa* Stokes subsp. *divulsa*, r *Hypericum humifusum* L., r *Mercurialis annua* L., r *Plantago lanceolata*, r *Psidium cattleyanum* Sabine, r and *Solanum mauritianum* in A158; 3 *Clethra arborea*, + *Duchesnea indica*, r *Cedronella canariensis*, r *Doodia caudata* (Cav.) R. Br., r *Polystichum setiferum* (Forssk.) Woyn., and r *Pteris incompleta* Cav. and in A142; + *Crassula multicava*, + *Oxalis pes-caprae*, and r *Galium aparine* in A97; 4 *Acacia longifolia* and *Eucalyptus globulus* in A148; + *Festuca donax* and + *Pittosporum undulatum*; + *Achyranthes sicula* and r *Cynosurus echinatus* L.; and r *Hyparrhenia sinaica* and r *Rubus bollei* in A132.



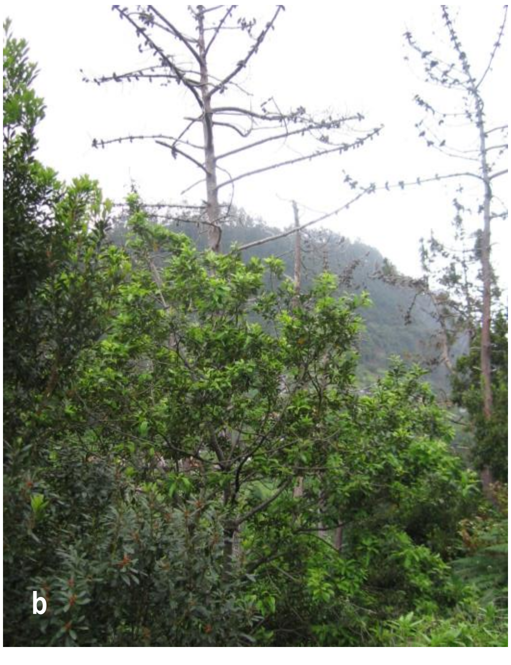


Figure 2.19 (a) Number of plant *taxa* (species and subspecies) found in plant assemblages installed in dead pine areas distributed according to colonisation status. Madeiran endemics (END), Macaronesian endemics (MAC), Native (N), Possible native (NP), Possible introduced (IP), and Introduced (I). (b) Native vegetation (*Laurus novocanariensis* and *Myrica faya*) regenerating in dead pine area (A 142-table 2.14). Cruzinhas, 2012 (MS, AP).

vi) Relevés of herbaceous plants assemblages established over forsaken agricultural fields revealed that native grasslands regenerated correspond to assemblages dominated by *Hyparrhenia sinaica* or at least assemblages where its presence was significant.Those grasslands were mostly associated with two perennial grassland communities *Cenchro ciliaris-Hyparrhenietum sicaicae* and *Dactylo hylodis-Hyparrhenietum sinaicae*, although some of them were seen in situations where the other perennial grassland was more likely to be found, or correspond to an advanced phase of this stage being identified seedlings of shrubs as *Euphorbia piscatoria*[1]*, Globularia salicina, and Echium nervosum* (Table 2.15). Although characterised by the presence of exotic plants the number of native was higher than the number of introduced species (Figure 2.20-a), in spite of the fact that only common species as *Bituminaria bituminosa* and *Galactites tomentosa* Moench[2] were abundant and very few endemic species were found in these assemblages (Table 2.15). The relevé with lower values of Shannon-Wiener index and Equitability was the one identified asannual grassland *Galactito tomentosae-Brachypodietum distachyae* (H'= 1.05, J'=0.54). All the others have shown higher diversity with Shannon-Wiener values ranging between 1.42 and 3.39, and Equitability from 0.52 up to 0.98 (Table 2.15).

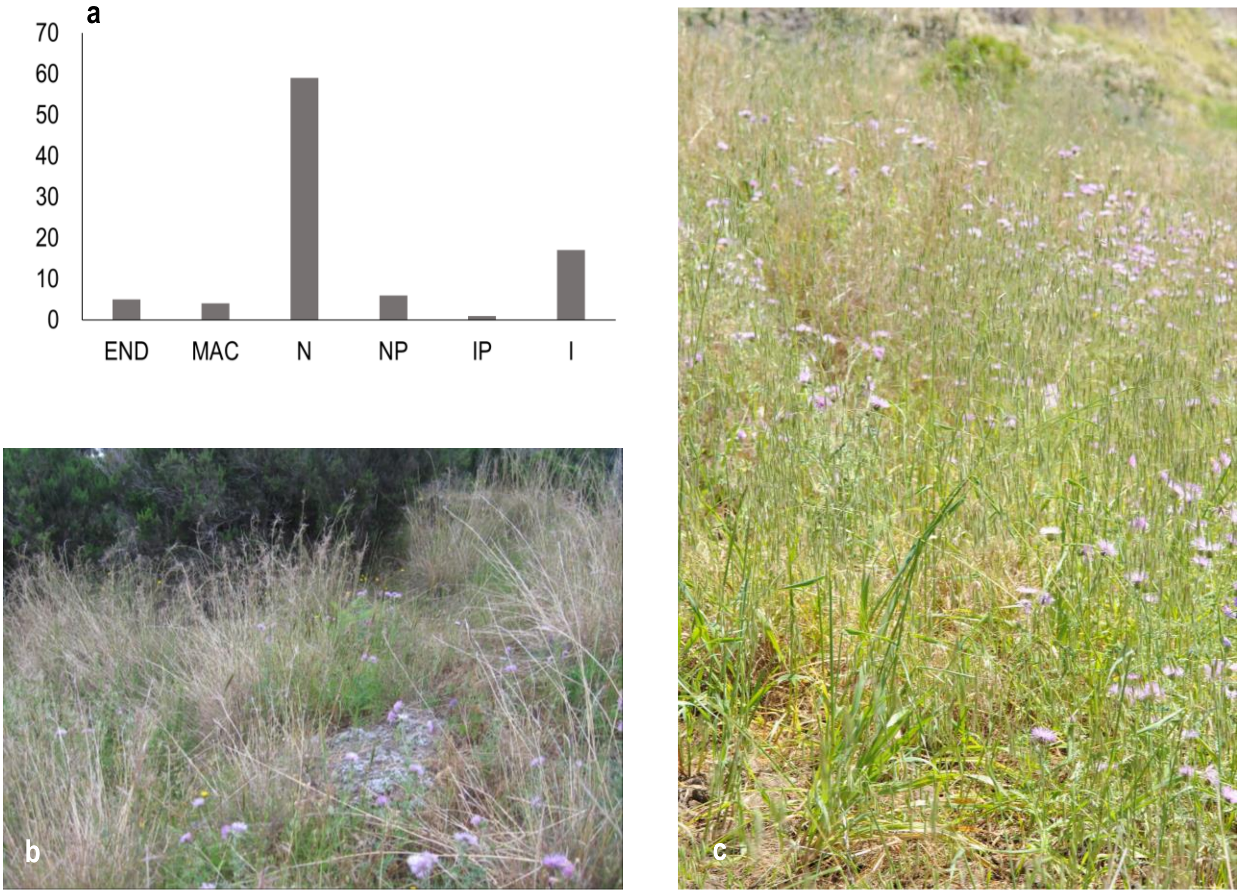


Figure 2.20 (a) Number of plant taxa (species and subspecies) found in forb/grass assemblages installed over forsaken fields, distributed according to colonisation status. Madeiran endemics (END), Macaronesian endemics (MAC), Native (N), Possible native (NP), Possible introduced (IP), and Introduced (I). Examples of native grassland communities: (b) *Cenchro ciliaris-Hyparrhenietum sinaicae,* relevé A10 (tables 2.15) in Machico, 2010 (MS, AP); (c) *Galactito tomentosae-Brachypodietum distachyae,* relevé A100 (tables 2.15) in Campanário, 2011 (MS, AP). These early stages of ecological succession were found in fields recently abandoned or although dropped long time ago subjected to continued disturbances (Figure 2.21).

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[1] Tree-spurge, locally known as *figueira-do-inferno.*

[2] Commonly known as purple milk thistle and locally as *cardo.*

Table 2.15 Relevés of herbaceous plants assemblages established over forsaken agricultural fields in differente PNV areas: Mu-Om (*Mayteno umbellatae-Oleo maderensis sigmetum*), and Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum,* Facies with *Globulario salicinae-Ericetum arboreae*). Communities identified: *Galactito tomentosae-Brachypodietum distachyae* (Gt-Bd), *Cenchro ciliaris-Hyparrhenietum sicaicae* (Cc-Hs), *Dactylo hylodis-Hyparrhenietum sinaicae* (Dh-Hs).Shade cells correspond to situations where the other perennial grassland was more likely to be found.

PNV	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Sa-Ab2	Sa-Ab2	Sa-Ab2
Community	Gt-Bd	Cc-Hs	Cc-Hs	Cc-Hs	Cc-Hs	Cc-Hs	Dh-Hs	Dh-Hs	Dh-Hs	Cc-Hs	Cc-Hs	Dh-Hs
Relevé	A100	A77	A85	A87	A134	A136	A22	A94	A104	A10	A11	A31
Altitude (m)	390	115	142	70	41	138	65	123	100	153	269	462
Hyparrhenia sinaica	+	5	3	3	4	3	2b	2b	2b	5	3	2b
Bituminaria bituminosa (	+	r	2a	2b	+	2ª		+	1m	r	2a	+
Galactites tomentosa	2a	r			+	R	+		+	+	r	+
Avena barbata Pott ex Link	+	r					+	2a	2a			2a
Vulpia bromoides (L.) S.F. Gray				2a	3		+	+		+		+
Briza maxima		r					r	2a		1	r	+
Petrorhagia nanteuilii (Burnat) P.W. Ball & Heywood							+	+	+	r	r	
Sonchus oleraceus			r		r		r	+				+
Opuntia tuna			2a	r			2b		+			
Euphorbia piscatoria			+				2b	r	r			
Globularia salicina			2a	r		R				r		
Leontodon taraxacoides (Vill.) Mérat subsp. *longirostris* Finch & P.D. Sell				+			+	1		+		
Trifolium arvense L.				+			+	+				+
Anagallis arvensis L.		r		r			+		r			
Geranium purpureum Vill.		r			r					+		r
Misopates orontium (L.) Raf. subsp. *orontium*			r		r		r					+
Aeonium glutinosum			r					r	+			
Cenchrus ciliaris			3	2b				1				
Stipa capensis Thunb.							r			r	4	
Stachys ocymastrum (L.) Briq.									+	2b	+	
Torilis arvensis (Huds.) Link subsp. *neglecta* (Spreng.) Thell.		1			1	R						
Cynosurus echinatus							+	1		r		
Silene gallica L.							+	+				+
Briza minor L.										+	r	+
Polycarpon tetraphyllum subsp. *tetraphyllum*				r			+		+			
Vicia articulata Hornem.								+	+			r
Lagurus ovatus										r	r	+
Phagnalon saxatile (L.) Cass.				r			+			r		
Achyranthes sicula		5									+	
Trifolium campestre Schreb.							+					2b
Foeniculum vulgare Mill.								r	1m			
Trifolium angustifolium L.			1				+					
Vicia hirsuta (L.) Gray		1						+				
Centranthus calcitrapae										+		+
Linum bienne Mill.							+					+
Mercurialis annua									+	+		
Oxalis pes-caprae		+			+							
Polycarpon tetraphyllum (L.) L.								+				+
Sherardia arvensis L.							+		+			
Aira caryophyllea L.										r		+
Brachypodium distachyum (L.) P. Beauv.		r							+			
Echium plantagineum L.	r											+
Linum trigynum L.							+				r	
Sonchus asper		r							+			
Trifolium scabrum L.				r			+					
Vicia disperma DC.							+					r
Acacia mearnsii										r		r
Species richness	7	15	10	12	16	8	35	21	18	25	14	32
Shannon-Wiener Diversity Index (H')	1,05	1,42	1,83	1,94	1,75	1,52	3,23	2,66	2,56	2,05	1,73	3,39
Equitability or evenness (J)	0,54	0,52	0,79	0,78	0,63	0,73	0,91	0,88	0,89	0,64	0,66	0,98

Plus: 2b *Nothoscordum gracile* (Aiton) Stearn, + *Antirrhinum majus* L., + *Campanula erinus* L., + *Lantana camara*, + *Logfia gallica* (L.) Coss. & Germ., + *Paronychia echinulata* Chater, *Scorpiurus sulcatus* L., r *Brachypodium phoenicoides*, and r *Plantago leiopetala* Lowe in A22; 2a *Holcus lanatus* subsp. *lanatus*, + *Brachypodium sylvaticum*, + *Bromus diandrus*, + *Crepis divaricata* (Lowe) F.W. Schultz, + *Geranium dissectum* L., + *Sanguisorba verrucosa* (Link ex G. Don) Ces., + *Vicia cordata* Hoppe, r *Ageratina adenophora*, and r *Rubus ulmifolius* in A31; 1 *Kalanchoe pinnata*, + *Carex divulsa* subsp. *divulsa*, + *Kalanchoe delagoensis* Eckl. & Zeyh., + *Pelargonium inquinans*, r *Bidens pilosa*, r *Plantago arborescens* subsp. *maderensis*, and r *Tropaeolum majus* L. in A134; + *Bromus hordeaceus* L. subsp. *hordeaceus,* + *Erodium cicutarium* (L.) L'Hér., + *Euphorbia peplos*, + *Linum strictum* L., r *Stachys arvensis* (L.) L., and *Tolpis barbata* (L.) Gaertn. subsp. *barbata* in A10; 2b *Tolpis suculenta*, + *Trifolium glomeratum* L., and + *Wahlenbergia lobelioides* (L.f.) Link subsp. *lobelioides* in A94; 2ª *Vitis vinifera* L., + *Asclepias fruticosa* L., and r *Echium nervosum* in A136; + *Geranium molle* L., r *Plantago lagopus* L., and r *Sonchus asper* subsp. *asper* in A77; + *Crepis vesicaria* subsp. *haenseleri*, r *Plantago lagopus* L., and r *Ruta chalepensis* L. in A11; 4 *Avena sterilis* L. and *Gladiolus italicus* Mill. In A100; and + *Convolvulus althaeoides* L. in A104.

Figure 2.21 Agricultural fields abandoned long time ago subjected to continued disturbances as mowing (a) and grazing (b), Machico, 2012 (AP, ZF, CM)

vii) Relevés of scrub assemblages established over forsaken fields allowed to identify three shrubby communities: *Euphorbietum piscatoriae*, *Myrtus communis-Hypericetum canariensis*, and *Globulario salicinae-Ericetum arboreae*, clearly in accordance with the vegetation model. This regeneration occurred in terraces located in less accessible places wich were abandoned some time ago, and was for the most part the community dominated by *Euphorbia piscatoria*. Some of the exotic plants found in these assemblages were remnants of former crops as *Ficus carica*, *Punica granatum*, and *Vitis vinifera* L.[1], however most of them correspond to exotic species that invaded also other environments as *Ageratina adenophora*, *Araujia sericifera* Brot.[2], *Arundo donax*, *Asparagus asparagoides Cardiospermum grandiflorum*, *Oxalis pes-caprae*, *Opuntia tuna*, *Pelargonium inquinans* (L.) L'Hér. ex Aiton[3], and *Pennisetum purpureum* Schum.[4]. The number of native species identified in these assemblages was higher than the number of exotic species (Figure 2.22-a). Some of them are quite rare Madeiran or Macaronesian endemics as *Crambe fruticosa* L.f.[5], *Crepis divaricata* (Lowe) F.W. Schultz[6], *Maytenus umbellata*[7], *Sinapidendron angustifolium* (DC.) Lowe[8], *Carlina salicifolia* (L.f.) Cav.[9], *Hypericum canariense*[10], *Notholaena marantae* (L.) R. Br. subsp. subcordata (Cav.) G. Kunke[11], and *Vicia capreolata* Lowe[12],. However, most were locally common or even rather widespread as *Aeonium glutinosum*, *Echium nervosum*, *Globularia salicina, Tolpis succulenta* (Dryand.) Lowe[13] As regards other native species, with the exception of *Phragmites australis* (Cav.) Trin. ex. Steud.[14] which became rare due habitat destruction and occupation of potential areas by *Arundo donax*, all of them are fairly common. Richness ranged from a minimum of 7 corresponding to the assemblage with lowest diversity (Shannon-Wiener = 1.39, and Equitability = 0.71) to 28 corresponding to a relevé with high diversity (Shannon-Wiener = 2.78, and Equitability = 0.83) (Table 2.16).

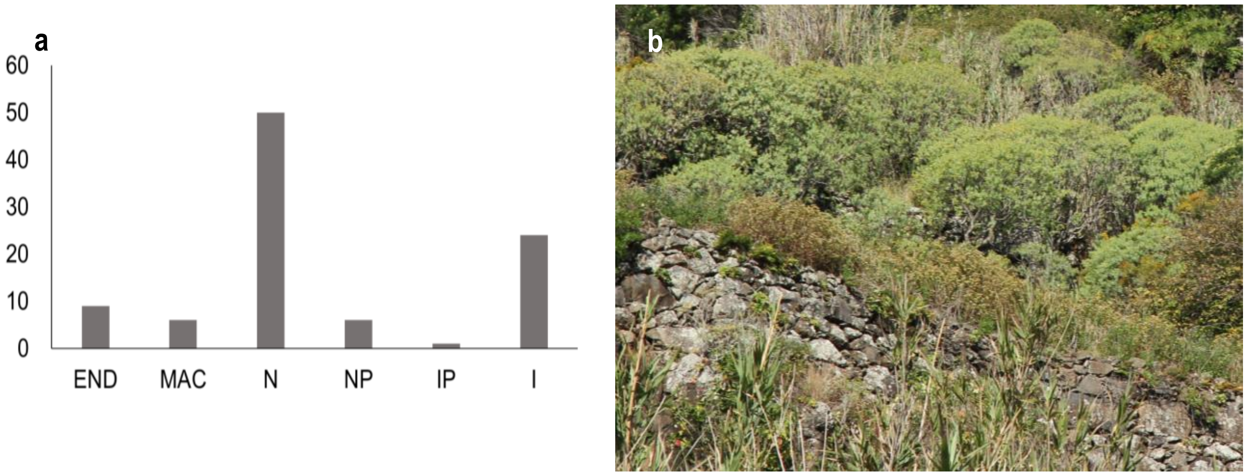

Figure 2.22 (a) Number of plant *taxa* (species and subspecies) found in scrub assemblages installed over forsaken fields, distributed according to colonisation status. Madeiran endemics (END), Macaronesian endemics (MAC), Native (N), Possible native (NP), Possible introduced (IP), and Introduced (I). (b) *Euphorbietum piscatoriae*, relevé A75 (Table 2.16) in Campanário, 2011 (AP, AF)

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[1] Known as common grape vine and locally called by the Portuguese name of *vinha*, *videira*.

[2] Commonly known as moth vine and locally without common name.

[3] Commonly known as scarlet pelargonium and locally by *malva*

[4] Commonly known as napier grass, elephant grass, and locally as *capim-elefante or erva-elefante*.

[5] A species of flowering sea Kale locally known as *couve-da-rocha.*

[6] A species of hawksbeard locally known as *almeirante*, *letubra mansa*

[7] A species of spike thorn locally known as *buxo da rocha*.

[8] A shruby mustard locally known as *sinapidendro de folha estreita*.

[9] A species of carline thistles locally known as *carlina*, *cardo branco.*

[10] A species of St John's wort locally known as *hipericão.*

[11] A species of cloak fern locally known as *maranta.*

[12] A species of vetch locally without common name.

[13] A species of umbrella milkwort locally known as *visgo*

[14] Known as common reed and locally by the Portuguese name of *caniço.*

Table 2.16 Relevés of scrub assemblages established over forsaken fields in differente PNV areas: Mu-Om (*Mayteno umbellatae-Oleo maderensis sigmetum*); Sa-Ab1 (*Semele androgynae-Apollonio barbujanae sigmetum, Facies with Myrto communis-Hypericetum canariensis*); and Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum, Facies with Globulario salicinae-Ericetum arboreae*). Communities identified: *Euphorbietum piscatoriae* (Ep), *Myrtus communis-Hypericetum canariensis* (Mc-Hc), and *Globulario salicinae-Ericetum arboreae* (Gs-Ea).

PNV	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Mu-Om	Sa-Ab1	Sa-Ab2	Sa-Ab1	Sa-Ab2
Community	Ep	Ep	Ep	Ep	Ep	Ep	Ep	Ep	Ep	Ep	Ep	Ep	Ep	Ep	Mc-Hc	Gs-Ea
Relevé	A74	A75	A76	A78	A80	A83	A86	A88	A90	A105	A135	A138	A98	A1	A96	A126
Altitude (m)	127	140	113	110	68	133	90	111	45	120	127	160	380	80	366	163
Bituminaria bituminosa	2a	+	1	+	1	r	2b	+	2b	+	1	2a	2b	+	r	1
Globularia salicina	+	r		+	2a	r	3	2b	2a	2b	3	3	3	5		r
Hyparrhenia sinaica	r	r		+	1		3		r	r	2b	2b	+	+	r	r
Aeonium glutinosum	+	2b	+	+	2a	2a		+	r	r	+			r	2b	
Oxalis pes-caprae	+	r	3	+	1	2a		2b					2b	r	+	2b
Euphorbia piscatoria	2a	4	4	5	3	5	2a	4	3	3						
Echium nervosum	2a	2a	2a	1	1		2a	+	2b			3	2a			
Opuntia tuna	2a	2b	2b	+		2a	2a		2b				2b		2b	
Pelargonium inquinans	+	+	r	+	+			2ª	1	+				r		
Ageratina adenophora .	+	1	1	+	1				+					r	r	
Sonchus oleraceus	r	r		+	r				r				+	r		
Foeniculum vulgare		r		+					+	2a			+		r	
Davallia canariensis						r		+			+			r	r	r
Mercurialis annua	r		r		+				r			r	+			
Asparagus asparagoides		r	1											r	2a	2a
Araujia sericifera		1	1	+	+											
Galactites tomentosa			r	r								+	1m			
Polycarpon tetraphyllum subsp. *tetraphyllum*									r	r			+	r		
Conyza bonariensis (L.) Cronquist		r	5		r											
Myrtus communis											3			2a		r
Arundo donax	1				+			2b								
Bidens pilosa	1												+	r		
Geranium purpureum		r												r	1m	
Sonchus asper subsp. *asper*		r											+		+	
Geranium dissectum									r			r				+
Vicia hirsuta				+								r		r		
Brachypodium sylvaticum															1	2b
Rubus ulmifolius					1										+	
Cardiospermum grandiflorum	1	r														
Cenchrus ciliaris	r						1									
Brachypodium phoenicoides						r			+							
Polypodium macaronesicum															+	r
Anagallis arvensis						r				r						
Ficus carica															r	r
Misopates orontium subsp. *orontium*	r						r									
Notholaena marantae (L.) R. Br. subsp. *subcordata* (Cav.) G. Kunkel						r		R								
Sinapidendron angustifolium				r					r							
Sonchus asper (L.) Hill subsp. *glaucescens* (Jord.) Ball				r					r							
Tolpis succulenta												r		r		
Vitis vinifera			r													r
Species richness	19	23	14	18	17	10	11	13	26	11	7	10	28	20	21	20
Shannon-Wiener Diversity Index (H')	2,56	2,31	1,78	1,56	2,20	1,42	1,86	1,73	2,63	1,87	1,39	1,83	2,78	1,79	2,27	2,40
Equitability or evenness (J)	0,87	0,74	0,68	0,54	0,78	0,62	0,78	0,68	0,81	0,78	0,71	0,79	0,83	0,60	0,75	0,80

Plus: + *Achyranthes sícula*, + *Calendula arvensis* L., + *Cerastium glomeratum* Thuill., + *Convolvulus althaeoides*, + *Crepis divaricata*, + *Cynosurus echinatus*, + *Euphorbia peplos*, + *Silene galica*, + *Trifolium glomeratum*, + *Vicia articulata*, + *Vicia disperma*, and r *Hedypnois cretica* (L.) Dum.-Cours. in A98; 3 *Rubus bollei*, + *Crocosmia* x *crocosmiflora*, + *Myosotis discolor* Pers., + *Pteridium aquilinum* subsp. *aquilinum*, + *Sanguisorba verrucosa* (Link ex G. Don) Ces., r *Erica arborea*, r *Lathyrus sphaericus* Retz., and r *Vicia lutea* subsp. *lutea* in A126; r *Avena sterilis*, r *Eleusine indica* (L.) Gaertn., r *Helminthotheca echioides* (L.) Holub, r *Ipomoea indica*, r *Kalanchoe delagoensis*, r *Melilotus segetalis* (Brot.) Ser., and r *Nicotiana glauca* Graham in A90; 4 *Hypericum canariense* L., 2a *Maytenus umbellata* (R. Br.) Mabb., r *Centranthus calcitrapae* (L.) Dufr., and *Punica granatum* Lineu in A96; r *Hypochoeris glabra* L., r *Linum bienne* Mill., r *Linum trigynum* L., and r *Lotus parviflorus* Desf. in A1; 4 *Micromeria thymoides* (Sol. ex Lowe) Webb & Berthel. subsp. *thymoides*, r *Nothoscordum gracile* (Aiton) Stearn, and r *Trifolium angustifolium* L. in A86 ; r *Avena barbata*, r *Geranium molle*, and r *Parietaria debilis* G. Forst. in A75; + *Sisymbrium erysimoides* Desf. and r *Carlina salicifolia* in A80; + *Vicia capreolata* and r *Crambe fruticosa* in A88; r *Malva parviflora* L. and r *Petrorhagia nanteuilii* (Burnat) P.W. Ball & Heywood in A74; 2a *Ageratina riparia* (Regel) R.M. King & Rob. in A105; 2a *Torilis arvensis* (Huds.) Link subsp. *neglecta* (Spreng.) Thell. in A138; and 1 *Phragmites australis* (Cav.) Trin. ex. Steud. in A78.

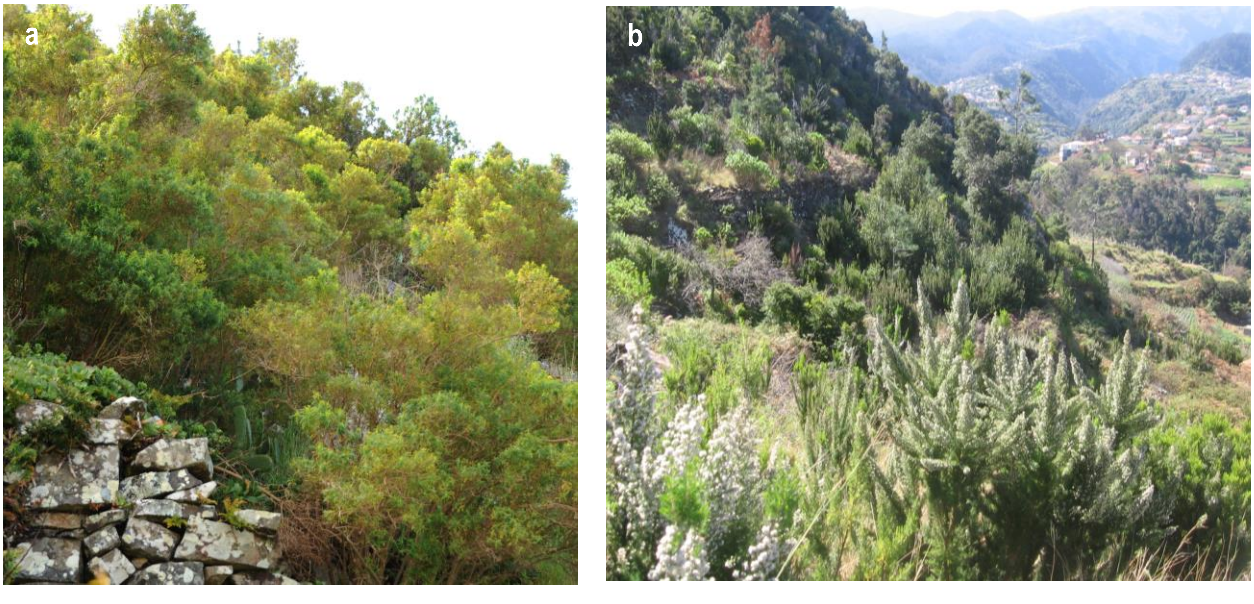

Figure 2.23 (a) *Myrtus communis-Hypericetum canariensis,* relevé A96 (Table 2.16) in Quinta Grande, 2011 (MS, AP); (b) *Globulario salicinae-Ericetum arboreae,* relevé A 126 (Tables 2.16) in Faial, 2012 (AP).

viii) Relevés of woodland assemblages established over forsaken fields have shown regeneration of *Mayteno umbellatae-Oleetum maderensis*, *Scrophulario hirtae-Salicetum canariensis*, in accordance with the PNV and a community dominated by *Myrica faya* (*Faial*), in substitution of the climax that should exist in those areas, i.e. *Semele androgynae-Apollonietum barbujanae and Clethro arboreae-Ocoteetum foetentis.* The assemblage dominated by *Olea maderensis*[1] showed low richness (7 and 8 species in each relevé) and low diversity (Shannon-Wiener index varying between1.05 and 1.15, and Equitability varying between 0.54 and 0.55) (Table 2.17). The number of exotic *taxa* identified was almost the same of native plants (Figure 2.24-a). The relevés of assemblages growing over abandoned fields in close proximity to water courses identified as a community of *Salix canariensis*[2] revelead assemblages with higher diversity indices (i.e. Shannon-Wiener ranging from 1.77 to 2.12; and Equitability ranging from 0.61 to 0.57) and also with larger number of species (18-19) than other two communities under anlysis (Table 2.17) but great part of species found are not native (Figure 2.24-b). The community dominated by *Myrica faya* showed intermediate values of richness and diversity índices (Richness reached 17 different *taxa* and Shannon-Wiener ranged from 1.18 to 2.14 and Equitability rangedg from 0.57 to 0.85) (Table 2.17) possessing, hoever, a higher number of native plants (Figure 2.25-a). Some Madeiran endemics as *Aeonium glutinosum, Euphorbia piscatoria, Hedera maderensis subsp. maderensis* and *Olea maderensis* were found as well as Macaronesian endemics as *Apollonias barbujana, Globularia salicina, Hypericum glandulosum* Aiton[3], *Laurus novocanariensis, Phyllis nobla, Plantago arborescens* Poir. subsp. *maderensis* (Decne.) A. Hansen & G. Kunkel[4], *Rubus bollei*, *Rumex maderensis* Lowe[5], *Salix canariensi*s, *Semele androgyna*. However, some common *taxa* as *Echium nervosum* and *Scrophularia hirta* Lowe which characterise respectivily *Mayteno umbellatae-Oleetum maderensis* and *Scrophulario hirtae-Salicetum canariensis*, were not found (Table 2.17). The native species were also litle abundant and only the very common and unharacteristic species were found as *Rubus ulmifolius* Schott[6], *Torilis arvensis* (Huds.) Link subsp. *neglecta* (Spreng.)[7] Thell., *Apium graveolens* L.[8], *Galium aparine,* and *Polygonum persicaria* L. [9]. Some of the exotic species identified are related to previous occupation of the land as *Colocasia esculenta* (L.) Schott[10], *Punica granatum*, *Sechium edule* (Jacq.) Sw.[11], *Eriobotrya japonica* (Thunb.) Lindl.[12], and *Vitis vinifera*. However a great part were species that spread into these areas as *Ageratina adenophora*, *Araujia sericifera*, *Arundo donax*, *Commelina benghalensis* L.[13], *Crocosmia x crocosmiiflora* (G. Nicholson) N.E. Br.[14], *Oxalis-pescaprae*, *Pennisetum purpureum*, *Pittosporum undulatum*, *Psidium cattleyanum* Sabine[15], *Solanum mauritianum* Scop.[16], *Tradescantia zebrina* Hort. ex Bosse[17], among many others (Table 2.17).

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[1] A species of oleaster locally known as *oliveira*, *zambujeiro.*

[2] A species of willow locally known as *seixeiro* or *sieceiro.*

[3] A species of St John's wort locally known as *malfurada.*

[4] A species of woody fleawort without common name.

[5] A species of sorrel locally known as *azeda*.

[6] A species of blackberry bush locally known as *silvado* not being made distinction from the other species of brambles

[7] Commonly known as spreading hedge parsley and locally without no common name.

[8] Commonly known as celery and locally by the Portuguese name of *aipo*.

[9] Commonly known as lady's thumb and locally as *herva pecegueira*

[10] Commonly known as taro, and locally by the Portuguese name of *inhame.*

[11] Commonly known as chayote, chow-chow, and locally by the Portuguese name of *chu-chu* or the local name of *pepinela.*

[12] Commonly known as loquat and locally called *nespera, nespereira.*

[13] Commonly known as dayflowers and locally by the Portuguese name of *erva-da-fortuna* not being made distinction from other Commelinaceae (e.g. *Tradeschantia* spp.).

[14] Commonlly known as montbretia and locally by the Portuguese name of *palmas-de-São-Lourenço.*

[15] Commonly known as strawberry guava, and locally by *aracá, araçaleiro.*

[16] Commonly known as woolly nightshade, tobacco weed, and locally as *tabaqueira.*

[17] Commonlly known as inch plant and locally by the Portuguese name of *erva-da-fortuna*.

Table 2.17 Relevés of woodland assemblages established over forsaken fields in differente PNV areas: Mu-Om *(Mayteno umbellatae-Oleo maderensis sigmetum*), Sa-Ab2 (*Semele androgynae-Apollonio barbujanae sigmetum,* Facies with *Globulario salicinae-Ericetum arboreae*), Ca-Of (*Clethro arboreae-Ocoteo foetentis sigmetum*), and Sh-Sc (*Scrophulario hirtae-Salicetum canariensis*). Communities identified: *Mayteno umbellatae-Oleetum maderensis* (Mu-Om), *Scrophulario hirtae-Salicetum canariensis* (Sh-Sc), and Community dominated by *Myrica faya* (Faial).

PNV	Mu-Om	Mu-Om	Sh-Sc	Sh-Sc	Sa-Ab2	Sa-Ab2	Sa-Ab2	Sa-Ab2	Ca_Of
Community	Mu-Om	Mu-Om	Sh-Sc	Sh-Sc	Faial	Faial	Faial	Faial	Faial
Relevé	A115	A139	A79	A89	A109	A158	A164	A165	A142
Altitude (m)	33	219	326	71	82	173	296	272	531
Ageratina adenophora	r		2b	2ª		+	1		r
Myrica faya					3	4	3	4	3
Psidium cattleyanum					1	r	1	2b	
Oxalis pes-caprae			+	R			+	2a	
Pittosporum undulatum					4		3	4	
Laurus novocanariensis						3	3		2a
Rubus ulmifolius	r		2b	2a					
Salix canariensis			4	5					
Olea maderensis	4	4							
Eriobotrya japonica					1		5		
Hedera maderensis subsp. *maderensis*						2a	1		
Vinca major						2b	+		
Araujia sericifera			+	+					
Zantedeschia aethiopica			+				+		
Aeonium glutinosum	r	+							
Galium aparine			+	R					
Phyllis nobla		+				r			
Solanum mauritianum						r	+		
Asparagus asparagoides	r			R					
Geranium purpureum						r			r
Polystichum setiferum (Forssk.) Woyn.			r						r
Species richness	8	7	19	18	7	17	15	4	17
Shannon-Wiener Diversity Index (H’)	1,15	1,05	2,12	1,77	1,12	1,98	1,75	1,18	2,14
Equitability or evenness (J)	0,55	0,54	0,72	0,61	0,57	0,70	0,65	0,85	0,76

Plus: 2a *Crocosmia x crocosmiflora*, + *Polygonum persicaria* L., + *Rumex conglomeratus* Murray, + *Apium graveolens* L., + *Colocasia esculenta* + *Commelina benghalensis* L., + *Physalis peruviana* L., r *Ranunculus repens* L., and r *Hypericum glandulosum* Aiton in A79; 1 *Torilis arvensis* subsp. *neglecta*, 1 *Pennisetum purpureum*, + *Tropaeolum majus*, r *Poa trivialis* L., r *Punica granatum*, r *Sechium edule* (Jacq.) Sw., r *Sonchus oleraceus*, r *Euphorbia segetalis*, r *Helminthotheca echioides*, and r *Lactuca serriola* L. in A89; + *Euphorbia peplos*, r *Bituminaria betuminosa*, r *Brachypodium sylvaticum*, r *Calamintha nepeta* subsp. *sylvatica,* r *Carex divulsa* subsp. *divulsa*, r *Hypericum humifusum* L., r *Mercurialis annua*, and r *Plantago lanceolata* in A158; 2b *Globularia salicina*, 1 *Phagnalon saxatile*, 1 *Plantago arborescens* subsp. *maderensis*, and + *Tolpis suculenta* in A139; 2b *Ligustrum lucidum* W. T. Aiton, r *Apollonias barbujana*, r *Rubus bollei*, and r *Semele androgyna* in A109; 1 *Pteridium aquilinum* subsp. *aquilinum*, + *Hedychium gardneranum* Sheppard ex Ker Gawl., + *Rumex maderensis* L, and + *Senecio mikanioides* in A164; 2b *Euphorbia piscatoria*, r *Opuntia tuna*, and r *Vitis vinífera* in A115.

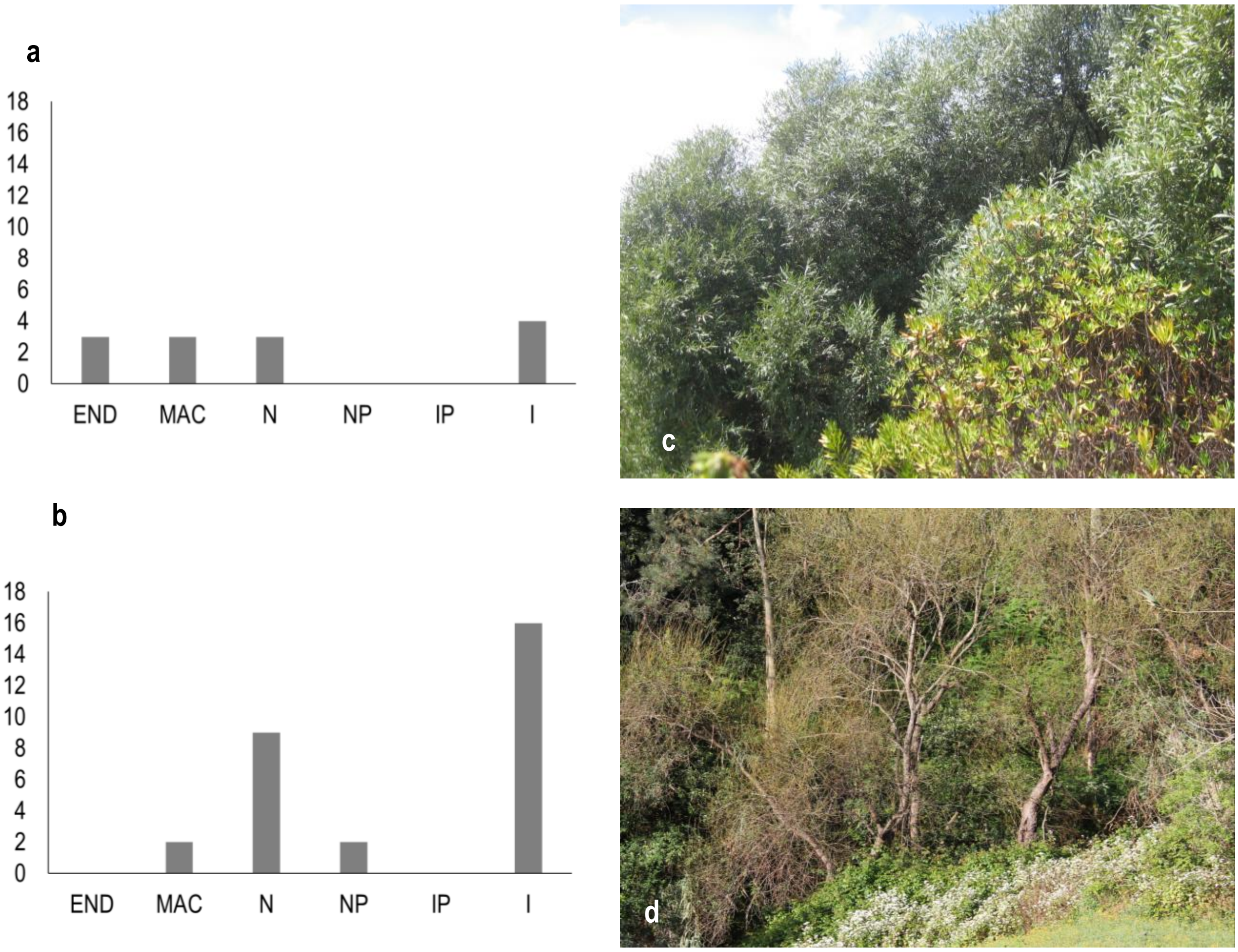
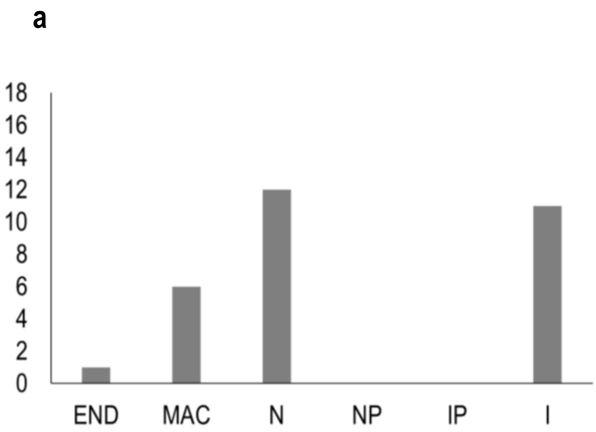


Figure 2.24 Number of plant *taxa* (species and subspecies) found in assemblages dominated by *Olea maderensis* (a) and *Salix canariensis* (b) installed over forsaken fields, distributed according to colonisation status. Madeiran endemics (END), Macaronesian endemics (MAC), Native (N), Possible native (NP), Possible introduced (IP), and Introduced (I). (c) *Mayteno umbellatae-Oleetum maderensis* (A 139-table 2.17), Machico 2012 (AP, ZF, CM). (d) *Scrophulario hirtae-Salicetum canariensis*, relevé A89 (Table 2.17) in Tabua, 2011 (MS, AP).



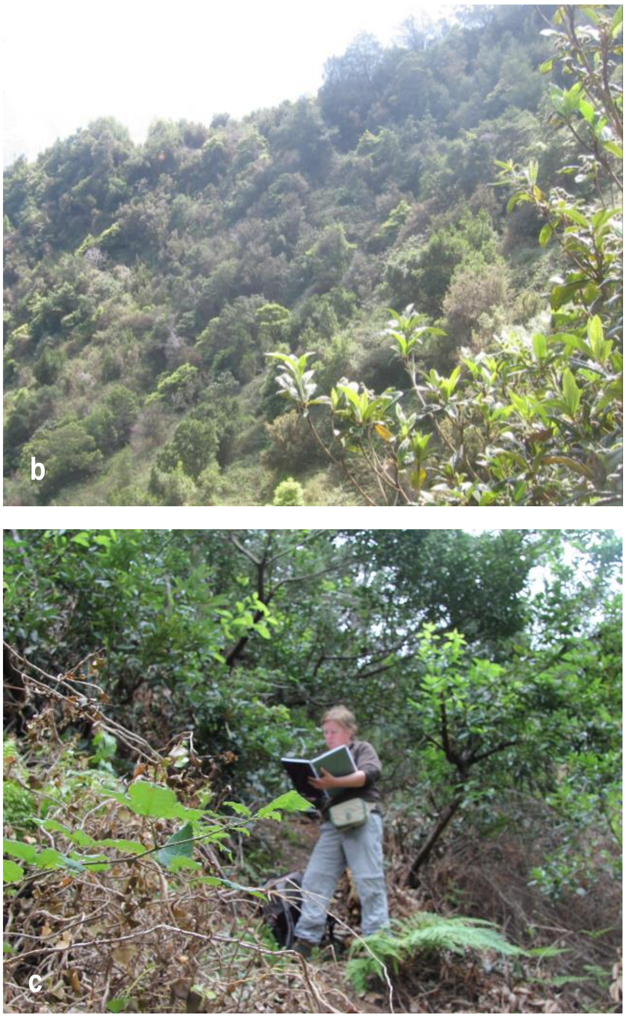


Figure 2.25 (a) Number of plant *taxa* (species and subspecies) found in assemblages dominated by *Myrica faya* installed over forsaken fields, distributed according to colonisation status. Madeiran endemics (END), Macaronesian endemics (MAC), Native (N), Possible native (NP), Possible introduced (IP), and Introduced (I). (b) Faial (urzal-faial) over a quite large area of abandoned agricultural terraces, Porto da Cruz, 2012 (AP). (c) Faial (urzal-faial) relevé A 158 (Tables 2.17) in São Vicente, 2013 (AP, JP).

Native vegetation growing over abandoned agricultural fields is similar to plant associations growing in clifs and rock outcrops surrounding them (see Figures 2.9 and 2.10), but comparing colonisation status of *taxa* growing over those places (Figure 2.26) it becomes clear that in assemblages over forsaken terraces have larger number of exotic plants, less endemisms, and although no great significance in the number of native taxa, only common species are normally found, as seen previously.

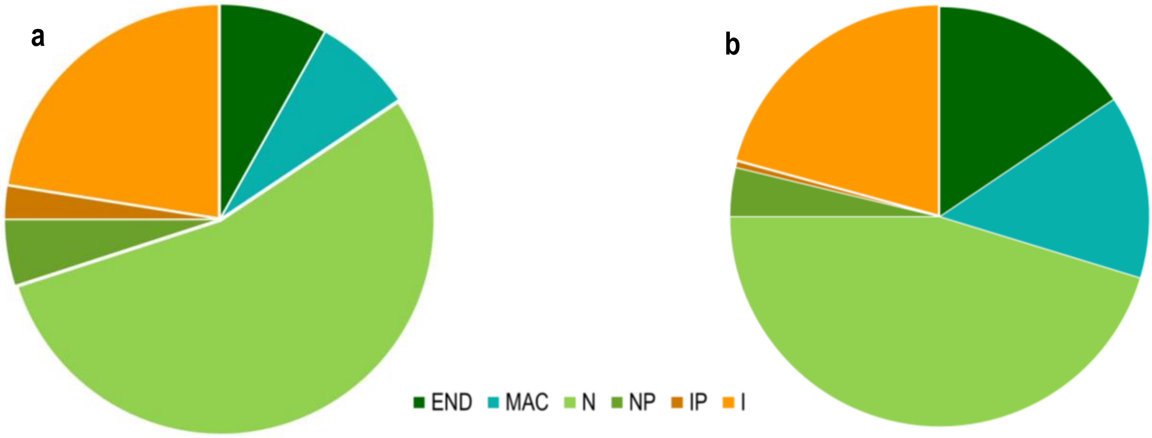


Figure 2.26 Comparison of colonisation status of *taxa* found in native vegetation assemblages growing over abandoned agricultural fields (a) and cliffs and rock outcrops surrounding those fields (b).

2.4 Discussion

As previously mentioned, the main objective of this survey was to collect data about the *phytocoenoses* present in photographed landscape and identify them by comparison with native communities proposed by Capelo *et al.* (2004) in order to support supervised classification of current landscape (Chapter 4). Because comparing dendrograms and group structures is not possible if they are not produced with the same classification method (Kent & Coker 1992) it was selected a single classification method equally appropriate to classify relevés of assemblages surveyed in current research and compare those relevés to communities recognised by the phytosociological model of native vegetation of Madeira Island.

Cluster analysis applied to the total data set followed a two-step approach. Apart from the fact that the large number of data (308 relevés and 474 taxa) interfere with the proper running of the software NTSYSpc (Version 2.21c) (Rohlf 2009), Kent & Coker (1992) advised to break the analysis in different stages whenever it is needed to handle large sets of floristic data. It was selected UPGMA as sorting strategy, although other strategies as complete-linkage and Ward method have been more frequently used in phytosociology, due to their higher homology with Braun-Blanquet's tabular comparison. However, being UPGMA also adequate to the process of tabular rearrangement and interpretation of associations it represents a more intermediate solution in terms of balance of dissimilarity intra and inter groups than those methods, which tend to overestimate dissimilarities between groups (Capelo, 2003). All the more since, the UPGMA agglomerative clustering method (combined with Bray-Curtis coefficient) proved to be a suitable option when applied to relevés included in Costa *et al.* (2004). The groups formed were almost an exact match with communities recognised by vegetation model (Figure 2.8) and the goodness of the classification was acceptable due large cophenetic correlation coefficient (0.91) (Sokal & Rohlf 1981). Nevertheless, three relevés were classified under a different group. Comparison of those "outliers" have shown that they belong to closely resembling associations (*Cenchro ciliaris-Hyparrhenietum sinaicae* and *Dactylo hylodis-Hyparrhenietum sinaicae*), correspond to communities found side by side in mosaic on rock crevices and cliff banks in altitude (*Argyranthemo montanae-Ericetum maderensis* and *Armerio maderensis-Parafestucetum albidae*), and are different stages of same climatophyllous series (*Clethro arboreae-Ocoteetum foetentis and Vaccinio padifoli-Ericetum maderincolae*), having therfore many species in common. Thereby, depending on the approach, such relevés can be gathered in one or another group (Kent & Coker (1992), and does not preclude the ecological sense of the classification.

The first analytical step applied to the two subsets (Costa *et a*l 2004-Figure 2.8 and current survey-Figure 2.9) allowed to assess the goodness of the classification method (Figure 2.8) and to separate assemblages of native vegetation from non-native vegetation (Figure 2.9). As seen in results clusters corresponding to assemblages dominated by *Arundo donax, Acacia mearnsii*, A*cacia melanoxylon*, and *Quercus ilex* appeared as clear distinct groups. Assemblages dominated by *Eucalyptus globulus* and *Pinus pinaster* although forming separated groups expressed further heterogeneity, due to greater richness and diversity, differences that will be discussed further on. Relevés performed in assemblages of native plants growing over forsaken terraces and surrounding cliffs and rock outcrops appeared jumbled together, showing low dissimilarity between vegetation regenerated over abandoned agricultural fields and vegetation growing in nearby safe sites. The goodness of this classification was supported by cophenetic correlation value obtained (0.94) and reinforced by the ecological sense of the results obtained.

In the second analytical step the relevés of assemblages dominated by native vegetation were added to relevés of recognised communities and all set subjected to further classification. Like previous classifications the cophenetic correlation value obtained (0.80) confirmed the goodness of the classification. As seen in results some vegetation types were not found in the surveyed area. This happened because some of those communities occur on small patches mainly outside of the photographed area (see Chapter 4) as e.g. *Thymetum micantis, Armerio maderensis-Parafestucetum albidae, Sinapidendro frutescentis-Aeonietum glandulosi*, and some others were largely replaced by other vegetation type (mainly exotic species), or human occupation as e.g. as *Artemisio argenteae-Genistetum tenerae*, *Rhamno glandulosi-Sambucetum lanceolati*, *Diplazio caudate-Perseetum indicae, Pericaulido aurita-Geranietum palmatae, Campanulo erini-Wahlenbergietum lobelioidis*, *Bystropogono puntacti-Telinetum maderensis, Argyranthemo montanae-Ericetum maderensis, Vicio capreolatae-Odontietum hollianae*, and *Teucri franco-Origanetum virentis.*

One group of relevés did not aggregated to the communities of the vegetation model, corresponding to plant assemblages dominated by *Myrica faya.* This vegetation type (Faial or urzal-faial) was considered by Capelo *et al.* (2004) within *Globulario salicinae-Ericetum arboreae*, as seral stage of *Semele androgynae-Apollonio barbujanae sigmetum,* and within *Vaccinio padifoli-Ericetum maderincolae*, as seral stage of *Clethro arboreae-Ocoteo foetentis sigmetum.* Further work field has shown that this community tends to substitute those states when succession is following progressive dynamics, being Faial the first substitution stage of barbusano-tree forest and stink-laurel forest (Figueiredo & Menezes de Sequeira 2010). Same authors have also shown that this community can assume the character of a secondary forest, largely maintained due to disturbance, and also occurs as permanent community (topographical climax) in association with *Ilex canariensis*[1] covering escarpments, mainly on north coast. The group of relevés clustered in this classification were performed both over rocky outcrops, dead pine areas (Table 2.14 and Figure 2.19b), and abandoned fields (Table 2.17 and Figure 2.25-b, c). Floristic composition of current survey have shown to be in accordance with the proposal mentioned above: some relevés have species that bring these assemblages close to heath scrubs, and others push them to a young phase of the climax woodland. So, Faial (urzal-faial) can be clearly considered an intermediate state which arises at the end of high-scrub community and triggers the forest, i.e. a state where still abound shade intolerant species but semi-tolerant and shade tolerant ones begun to emerge.

As stated in results some of the assemblages surveyed were associated to several communities which were recognised by the model. Some were connected to grasslands (Tables 2.15) as *Galactito tomentosae-Brachypodietum distachyae, Cenchro ciliaris-Hyparrhenietum sinaicae*, and *Dactylo hylodis-Hyparrhenietum sinaicae;* some other to scrublands (Tables 2.16) as *Euphorbietum piscatoriae*, *Myrtus communis-Hypericetum canariensis*, and *Globulario salicinae-Ericetum arboreae;* and also to woodlands (Tables 2.17) as *Mayteno umbellatae-Oleetum maderensis* and *Scrophulario hirtae-Salicetum canariensis,* equally over abandoned agricultural areas and surrounding cliffs and rock outcrops. A few were only found in those surrounding save sites as *Vaccinio padifoli-Ericetum maderincolae, Semele androgynae-Apollonietum barbujanae,* and *Clethro arboreae-Ocoteetum foetentis,* and assemblages installed over abandoned terraces, initially recorded such as those, turn out to be the community dominated by *Myrica faya*, i.e. Faial.

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[1] A Macaronesian species of holly locally known as *azevim*, *azevinho.*

In general, the communities installed where they were expected to develop in accordance to VNP (Mesquita *et al.* 2004) independently of being early stages or more mature phases. This aspect is very important as far as vegetation identification in historical photographs, which cannot be checked, depends on matching the most plausible vegetation community to a vegetation patch. This identification which is mostly based on spatial organisation, photographic tone and texture also relies on the most likely community following PNV (see point 4.2.3). However, there was one exception. Some of the grass/forbs assemblages dominated by *Hyparrhenia sinaica,* which although occurring in more likely locations, also appeared where it was expected the other community i.e. *Cenchro ciliaris-Hyparrhenietum sinaicae* where it was probable *Dactylo hylodis-Hyparrhenietum sinaicae* and vice-versa. This means that to supervise classification of current landscape (Chapter 4) when it was not possible to survey the community the perennial grasslands were merely classified as community of *Hyparrhenia sinaica,* to avoid misunderstandings.

Comparing the assemblages of native plants regenerated over forsaken agricultural fields and similar vegetation type growing in less disturbed surrounding areas have shown that although being the same community the plant association over more disturbed places tend to have more exotic species, less endemic plants and more abundant native species are the most common and widespread (see Figure 2.26). The fact that plant communities growing over abandoned agricultural lands typically have many common species and do not have the rarest ones it was also reported by Dutoit *et al.* (2003) as consequence of agricultural practices which effects last for long periods after abandonment. Indeed, some native species did not appear to be affected by the disturbance, quite the contrary because they are so abundant they seemed to have been favoured as for instance *Bituminaria bituminosa, Globularia salicina, Hyparrhenia sinaica, Brachypodium sylvaticum, Aeonium glutinosum, Davallia canariensis, Pteridium aquilinum, Laurus novocanariensis, Erica arborea*, *Erica platycodon* subsp. *maderincola, Myrica faya, Echium nervosum, Phyllis nobla.* For some of these *taxa* it was already reported the fact that they are encouraged by disturbance as *Laurus novocanariensis* (Arévalo *et al*. 1998), *Pteridium aquilinum* subsp. *aquilinum* (Marrrs *et al*. 2000, Ouden, 2002), and *Myrica faya* (Walker 1990 among many).

Likewise, although more mature states were found outside the fields, in these most of the native vegetation regenerated belong to lower successional stages as *Euphorbietum piscatoriae* and *Hyparrhenietum sinacae* (*Cenchro ciliaris-Hyparrhenietum sinaicae*, *Dactylo hylodis-Hyparrhenietum sinaicae*). Although other shrubby communities were also found and even more mature states as *Mayteno umbellatae-Oleetum maderensis, Scrophulario hirtae-Salicetum canariensis*, and *Faial* as initial state of *Clethro arboreae-Ocoteetum foetentis,* and *Semele androgynae-Apollonietum barbujanae* also arose, its regeneration was far less common. This stagnation in most immature states is both consequence of the alteration of the soil conditions, preventing some native plants development (D'Antonio & Meyerson 2002; Kent 2012), and, as shown in results, due to continuous disturbance. In reality, even though those fields stopped being cultivated many years ago they still are grazed by cows, mowed, and they are often affected by fire propagated from “traditional burning” to clear land still in agricultural use.

Determination of the colonisation status of the taxa, species richness, diversity index, and equitability index allowed to profile plant assemblages and to compare different plant formations. Although species richness is somehow regarded as diversity it is also important their relative abundance (i.e. evenness) within the community. All together they and can provide more information about the community composition than simply species richness. Shannon diversity index, which takes into account the number of individuals as well as number of taxa can vary from 0 for communities with only a single *taxon* to high values for communities with many *taxa*. However, it ranges normally between 1.5 and 3.5 (values below represent very low diversity, and above represent exceptional diversity). Equitability index, that measures the evenness with which individuals are divided among the *taxa* present, assumes a value between 0 and 1, with 1 being complete evenness (Kent & Coker 1992).

Plant communities dominated by native species presented, in general, greater species-richness and higher diversity and equatibility values than communities dominated by exotic species. Although it was not found an extraordinary diversity (maximum Shannon value found reached 3.39), and majority of values ranged between the normal diversity interval, being higher in less mature communities of the vegetation series. Some relevés reached 35 species and values of Equitability (or evenness) were steadily above the average level reaching complete evenness between species (0.98). On the contrary, assemblages dominated by exotic species have shown in general a lower species richness value, especially the ones dominated by *Acacia mearnsii* and *Arundo donax*, being the latter the only species present in some relevés. Shannon values, obtained in relevés performed in these two vegetation formations, only very rarely attained a regular diversity value and in general they were below 1 indicating a very low diversity. Equitability also presented very low values, reaching zero in mono-specific assemblages of *Arundo donax*. Other two exotic species under analysis: *Pinus pinaster* and *Eucalyptus globulus* showed indicators that revealed richer and more diverse communities, when not invaded by other exotic trees as for instance *Acacia mearnsii*.

The analysis of *taxa* colonisation status showed that the number of exotic species compared with native taxa was variable and dependent not only of the community type but also it is influenced by the former land use and current disturbance. The influence of the community installed was very clear when assemblages dominated by *Arundo donax* and *Acacia mearnsii*, showed a number of introduced species always superior to native species, while in native plant communities, and some other assemblages also dominated by exotic plants, as *Pinus pinaster* and *Eucalyptus globulus*, the number of native plants was frequently superior to exotic species, and infrequent endemic species were allowed to install. However, comparing relevés within the same vegetation formation, as for instance assemblages dominated by eucalyptus it appears that the significantly presence of native taxa is related with propagule availability due to the existence of save sites on the neighbourhood and the existence of proper ecological conditions as open woodland and absence of fire. This nurse effect by *Eucalyptus globulus* on some native species was also suggested by Arevalo *et al.* (2011). On the contrary, the absence of native vegetation on the vicinity and recurrent fires lead to a young and dense eucalyptus stand invaded by pyrophylous species as *Acacia mearnsii*, where the number of native species decreased. This behaviour in eucalyptus woodlands is very is similar to seen in Tasmania, were *Eucalyptus* and *Acacia* species dominate the wet sclerophyll forest and persist regenerating only after fire. If such disturbance does not occur eucalyptus form a mixed forest with a rain forest understory and with time the sclerophyll forest is replaced by the rain forest (Noble & Slatyer 1980).

2.5 Conclusion

Data regarding the *phytocoenoses* present in the photographed landscape allow to conclude that:

i) some vegetation types are not found in surveyed area, corresponding to vegetation types occuring on small patches mainly outside of the photographed area (*Thymetum micantis, Armerio maderensis-Parafestucetum albidae, Sinapidendro frutescentis-Aeonietum glandulosi*) or some vegetation types that become replaced by other vegetation type (mainly exotic species), or human occupation (*Artemisio argenteae-Genistetum tenerae*, *Rhamno glandulosi-Sambucetum lanceolati*, *Diplazio caudate-Perseetum indicae, Pericaulido aurita-Geranietum palmatae, Campanulo erini-Wahlenbergietum lobelioidis*, *Bystropogono puntacti-Telinetum maderensis, Argyranthemo montanae-Ericetum maderensis, Vicio capreolatae-Odontietum hollianae*, and *Teucri franco-Origanetum virentis*).

ii) Some vegetation types are seen both over forsaken agricultural fields and surrounding cliffs and outcrops (*Galactito tomentosae-Brachypodietum distachyae, Cenchro ciliaris-Hyparrhenietum sinaicae*, *Dactylo hylodis-Hyparrhenietum sinaicae; Euphorbietum piscatoriae*, *Myrtus communis-Hypericetum canariensis*, *Globulario salicinae-Ericetum arboreae; Mayteno umbellatae-Oleetum maderensis,* and *Scrophulario hirtae-Salicetum canariensis*), while others are only seen out of abandoned fields (*Vaccinio padifoli-Ericetum maderincolae, Semele androgynae-Apollonietum barbujanae, and Clethro arboreae-Ocoteetum foetentis),* being assemblages installed over abandoned terraces, initially recorded as the latter, a community dominated by *Myrica faya*.

iii) The group of relevés which did not aggregate to the communities of the vegetation model (Capelo *et al.* 2004), correspond to plant assemblages dominated by *Myrica faya.* This community seen over rocky outcrops, dead pine areas and abandoned fields correspond to the community suggested by Figueiredo & Menezes de Sequeira (2010) as being *Faial* (*urzal-faial*). This confirms the existence of an intermediate state which arises at the end of high-scrub communities (*Globulario salicinae-Ericetum arboreae* and *Vaccinio padifoli-Ericetum maderincolae*) and triggers the forest (*Semele androgynae-Apollonietum barbujanae,* and *Clethro arboreae-Ocoteotum foetentis*).

iv) In general, the plant communities are installed where they are expected to develop in accordance to PNV (Mesquita *et al.* 2004) independently of being early stages or more mature phases. This aspect allows to use this information to support supervised classification of landscape.

v) Plant communities dominated by native species present, in general, greater species-richness and higher diversity and equatibility values than communities dominated by exotic species.

vi) Plant assemblages dominated by exotic species have shown in general lower species richness value, and less diversity and equitability. Among the exotic species *Arundo donax* and *Acacia mearnsii* are the ones that tend to form assemblages with less richness and diversity, predominantly constitute by introduced species and where only the most common native species are present. On the contrary *Pinus pinaster* and, especially *Eucalyptus globulus* tend to form richer assemblages with an acceptable diversity. In some of those assemblages the number of introduced species can be inferior to native and some less frequent endemic species are found. These two exotic formations if not invaded by other exotic species as *Acacia mearnsii* and *Pittosporum undulatum*, not being affected by fire and receiving diaspores of native vegetation, allow the development of native vegetation, suggesting a nurse effect especially by *Eucalyptus globulus* on some native species.

viii) Assemblages of native plants regenerating over forsaken agricultural fields and similar vegetation type growing in surrounding areas have shown that although being the same community the plant association regenerated over the abandoned terraces tend to have more exotic species, less endemic plants and native species present are almost the most common and widespread.

ix) Some native species do not appear to be affected by the disturbance, on contrary they seem to be encouraged. Some of them were already been reported as being favoured by disturbance as *Laurus novocanariensis Pteridium aquilinum* subsp. *aquilinum* and *Myrica faya.*

Futher research may be directed to understand successional pathways and causes of species turnover by using these sites were are found diferent successional stages within each vegetation series. It can be investigate, for instance, the role of seed rain and seed bank in recolonisation of those sites, the biotic interactions between plants, and the role of mycorrhizae in each successional stage.

3 Dendrochronology

> “I have heard many discussions about the status of dendrochronology. People ask if it is a discipline, a tool, or an application. The answer depends upon who is doing the research and how they approach their work. I, among others, see dendrochronology as a thriving discipline with its own governing body of principles, theoretical advancements, and areas of important contributions to society. Some may use it as a tool to obtain dates or long-term records of past phenomena. Other researchers may work mainly on advancing theory in different fields but call on the techniques of dendrochronology to advance their understanding within their discipline.” (Speer 2010 pp. 8-9).

3.1 Dendrochronology: concept and applications

Theophrastus[1], in 2300 B.P. was the first to write about tree rings formation, and Da Vinci[2], in fifteenth century, was the first to suggest that distinct increment rings could be formed each year and to relate them with environmental changes, advocating that the ring width might be dependent on water availability and tree trunks could be used to get information about past climate (McBride 1983; Speer 2010). However, the annual nature of tree rings was truly proved only in seventeenth century by Malpighi[3], who has shown seasonal cambium activity by distinguishing “spring wood” from “summer wood”, and it was reconfirmed by Schober[4], in the eighteenth century, who matched the rings (which he called “years”) to annual whorled branches of pine trees (McBride 1983). Although many naturalists contributed to further knowledge on this subject it has been highlighted the central role of Linnaeus[5], in the eighteenth century, and De Candole[6], in the nineteenth century that used tree rings to ascertain tree age and to identify specific climatic conditions. It was also stressed the importance of Twinnig[7] and Babbage[8], in early nineteenth century, who proposed to use ring-width patterns to construct sequences of tree rings going back through time and built chronologies (McBride 1983; Speer 2010).

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[1] Short biographical note on p. 10

[2] Leonardo da Vinci (1482-1519) best known as painter and inventor of Italian Renaissance, whose notes and drawings reveal its interest and knowledge in botany. It was in his *Trattato dell Pittura* (Treatise of painting) that he mentioned the annual tree rings (“Leonardo da Vinci." Encyclopedia of World Biography 2004; Speer 2010).

[3] Marcello Malpighi (1628-1694), the Italian physician whose name is associated to histological studies, based on microscopic observations. Being doctor and lecturer of medicine, oriented the research to animal tissues. However, he also undertook anatomical studies on plants, and its work *Anatome Plantarum* (Anatomy of plants, published in 1675) has made him the founder of the microscopic study of plant anatomy ("Malpighi" Complete Dictionary of Scientific Biography 2008).

[4] C.G. Shober (?-?), known by the article published in 1753 in *Magazin* (vol 11, pp. 590-597): *Die Holzringe, oder jahre, in verschiedenen Hölze*r (The wood rings, or years, in various woods) (McBride 1983).

[5] A short biographical note was presented on p. 10. It was after becoming Professor of Botany at the University of Uppsalla (1741) that Linnaeus noted the 1709 frost ring in wood samples in Sweden, a frost damaged that was also noted by Buffon in 1737, in France (Speer 2010).

[6] Alfonse Pyrame de Candolle (1806-1896), the French-Swiss botanist that succeded his father (Agustin Pyrame de Candolle) as chair of botany and director of the botanical garden at Geneva, and retired in his mid-forties to dedicate to research in full-time. Besides carrying on his father's work by doing basic descriptive botany, he became profoundly interested in phytogeographic studies, researching the connections between distribution of plants and environmental factors. It was in this context that he become interest in tree ring, specially ring widths (Mikulinskij *et al.* 1981; Speer 2010).

[7] Alexander Catlin Twining (1801-1884), the North American inventor, engineer and astronomer, whose name is more often linked to his most important invention, which was a machine to produce ice, than to their other interests as mathematics and natural sciences. It was him that in 1833 suggested that patterns among tree rings could be used to synchronise the dendrochronologies of various trees and thereby to reconstruct past climates across entire regions (Hannan & Herman 2008; Speer 2010).

[8] Charles Babbage (1791-1871) was a British inventor and mathematician whose main interest was a calculating machine that originated the concept of a programmable computer. Amongst his many interests there was the study of tree-ring patterns, and the use dendrochronology to reconstruct past climate and to date the remains of trees in peat bogs or even in geological strata ("Charles Babbage" Complete Dictionary of Scientific Biography 2008; Speer 2010).

Although ageing trees by growth ring counting was generally recognised in Europe for centuries, in the United States, especially during the late 19th century, several scientists of the time largely refuted its validity. In the beginning of the 20th century the publication of several pioneering papers clearly showed that growth rings represent a datable chronology, and from then on the relation between growth rings number and tree age, as well as ring widths and environmental conditions[1] became greatly accepted (Briand *et al.* 2006). During this time it has been frequently used to search about past climate, in the field of dendroclimatology (Touchan & Hughes 1999; Helama *et al.* 2004; Martinelli 2004; Copenheaver *et al.* 2006); to date ancient artefacts within dendroarchaeology context (Billamboz 2003; Gonçalves 2008); to date and characterise disturbance events such as fire, within the area of pirodendrochronology (McBride 1983), geomorphic processes, in dendrogeomorphology (Braam *et al.* 1987; Norton & Ogden 1987; Stoffel 2006; Bollschweiler *et al.* 2007; Pierson 2007; Stoffel & Bollschweiler 2008). It has also been used in dendroecology to understand vegetation dynamics in response to disturbance events or to gather information about vegetation dynamics (Bergeron *et al.* 2002; Gutsell & Johson 2002; Worbes *et al.* 2003; Krause 2005; Clark *et al.* 2008)

The age of a plant can be achieved without ring-counting by analysing growth-forms and annual morphological markers (Schweingruber & Poschlod 2005) or by permanent plot surveillance (Ferreira-Fedele *et al.* 2004). However these methods require a profound study of the phenology of each species and are very time consuming, being the main reason why age determination of woody plants is normally carried out by annual rings analysis (Botosso & Mattos 2002; Mattos *et al.* 2011). Yet, there is no need to cut down or drill all trees to count growth rings and find out the age. Because it is not always opportune to use these invasive methods, or because it is not possible to get a complete core due to large size of the trunk or rotten boles of old trees, it is possible to estimate age without drilling trees. If enough tree core and stump evaluations are available it is possible to establish allometric relationships and to estimate the age of a tree with significant accuracy, by means of regression analysis over a well-known variable, such as diameter at a specific ground height. In natural sciences, such as forestry sciences, are often used biophysical variables (e.g. diameter at breast height, total tree height) to estimate values for another biophysical variable (e.g. age) by using regression models (Curtis 1967; Loetsch & Haller 1973; Sit & Poulin-Costello 1994; Patón *et al.* 1998).

However, prior to the statistical procedure, aging the trees must be based on ring counting. The dendrochronological potential of a species depends on having clearly defined growth rings with annual regularity, or at least reliable cyclic increment (Speer *et al.* 2004; Tomazello-Filho *et al.* 2004).

In temperate zones the seasonality of climate regulates tree growth cycles. During the active period, between spring and autumn, the vascular cambium connecting the secondary xylem (wood) and the secondary phloem (inner bark) produces additional xylem and phloem. Because cell formation stops during the dormancy period, one distinct increment ring is formed each year, allowing the age assessment and establishment of chronologies (Schweingruber 2007; Stoffel & Bollschweiler 2008).

In Gymnosperms, the tracheids produced by the reproductive cambium cells during the active period are different: tracheids formed during the first part of growing season (early wood, spring wood) are large and thin-walled cells and cells that are produced later [late wood, summer wood (autumn wood)] are smaller but with thicker cell walls.

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[1] The Principle of limiting factors - this principle states that the different growth-related processes are limited by the most critical environmental variable. For example, precipitation is frequently the most limiting factor (especially in arid habitats), temperature is also often most limiting factor (especially in higher altitude), however processes related to substrate characteristics and stand dynamics can also play a role (Speer 2010).

These differences create a darker layer, making it easier to distinguish annual increments. In Angiosperms the vascular cambium produces vessels in addition to tracheids making the rings identification much harder. Depending on the distribution of the vessels two main types are recognised: (1) ring-porous angiosperms, when vessels are larger in earlywood, forming ring-shaped pores; (2) diffuse-porous angiosperms with pores with uniform size scattered throughout the growth increment. Between these two outermost types there are different transitional structures that can make ring recognition a very difficult task (Schweingruber 2007; Stoffel & Bollschweiler 2008; Speer 2010).

In temperate regions, where the mid-latitude seasonality is strong enough to induce annual rings, the age of trees can be determined with high degree of confidence just by counting growth increments. Even in situations when trees stop growing in the middle of a growth cycle, it is normally easy to distinguish between true rings (primary ring) from false rings (double ring). The false ring formed in these conditions is normally diffuse not showing the sharp boundary that is normally left by abrupt stop of production of thick walled cells in late growing season and the strong growth release of thin walled cells after dormancy period. The possibility to effectively distinguish true rings from false rings is an important characteristic to evaluate the dendrochronological potential of a species (Ogden 1981; Norton & Ogden 1987; Speer *et al.* 2004; Speer 2010).

However, even in temperate climate areas several issues related to anomalous rings can create difficulties for ring analysis. Some trees, especially the ones under active growth, as fast growing species and younger trees as well as portions of the plant near growing branches, are more prone to produce false rings (Vogel *et al*. 2001). In addition, because the tendency to form drought-induced false rings is site and species dependent, it does not always happen a synchrony between climatic conditions and false ring formation in all trees of the same geographical area. Besides, specific environmental stresses other than water-stress (such as: pollution, periodic flooding, frost in late spring and insect defoliation) can also induce false rings formation (Copenheaver *et al*. 2006). It is also important to pay attention to phenology and its relation with climate, because biological processes such as flowering, fruiting and new leaves production can also have impact on wood formation (Ogden 1981).

Several other factors can hinder the dendrochronological analysis such as: (1) micro-rings i.e. very small tree-rings only comprising up to four cells wideness which are formed under extreme unfavorable conditions. These rings are not “true” false rings but, in fact they are true rings that look like false and can mislead age assessment (Speer *et al*. 2004; Schweingruber 2007); (2) missing rings, partial rings or locally absent rings i.e tree-rings not existing at all or absent in certain radii when growth is interrupted or when rings merge in a single one (wedging rings). This happens because trees can produce more tissue in on part of the stem and to suppress growth in another part during the same growth season (Norton & Ogden 1987; Speer *et al*. 2004; Schweingruber 2007).

Ring anomalies are more likely to occur in the lower part of the trunk than in the upper parts of the tree (Norton & Ogden 1987). Although caused by different type of disturbances (environmental or biological) ring anomalies are often found to be related to tilting. A tree subjected to bending always recovers the vertical position by triggering differential cambial activity (reaction wood). In gymnosperms this reaction occurs on the underside of the stem, originating darker and larger and rings (compression wood), and in angiosperms it is formed in the upper side, and growth rings, with thinner walled cells, with longitudinal shrinkage can be detected by fuzzy surface (tension wood) (Braam *et al.* 1987; Grau *et al.* 2003; Stoffel 2006; Stoffel & Bollschweiler 2008; Speer 2010). Because in these circumstances an asymmetric cross section is produced, the rings have imperfect circuit uniformity and cores, extracted along different radii, do not match or have little correspondence (Stoffel & Bollschweiler 2008). These authors stressed that although requiring exceptional care, dendrochronological studies in these situations are still entirely achievable.

3.1.1 Guidelines on methods used in dendrochronology

Whilst the greatest improvement has occurred over the past few decades some of the pioneering studies have contributed to develop dendrochronology methods (Martinelli, 2004). The majority of the authors agreed that the greatest contribution was from Douglass[1], who established the Laboratory of Tree-Ring Research and launched the basis of modern methodology for dendrochronological research. The number of researchers within this area grew up since Douglass's time contributing to the standardisation of general principles and methods of dendrochronology. Some of those considerations about dendrochronological techniques are summarised below.

Depending on the aim of the study it is very important to carefully select the sampling location[2]. Given that the most suitable place to study a particular issue can be completely improper to study another (e.g. a plot located at the limit of a species distribution is adequate for dendroclimatic research but unsuitable for studies about growth rate of the same species). Thus, selection should put a special focus on places with homogeneity for the factor in study, and where other factors are minimised (Norton & Ogden 1987; Kipfmuller & Swetnam 2001; Wilson & Hopfmuller 2001; Speer 2010).

Depending on the type of information to be collected, the selection of trees can be done in different ways: (1) randomly within the sampling area (Krause 2005; Rozas 2005; Liutsko 2008; Speer 2010); (2) focusing on trees located in the area affected by the disturbance and with clear marks related to the event (McBride 1983; Bollschweiler *et al.* 2007; Stoffel & Bollschweiler 2008); (3) just one species (Touchan & Hughes 1999; Wilson & Hopfmuller 2001; Clark *et al.* 2008); (4) only the most common species (Clark & Hallgren 2004); (5) all species (Xiong *et al.* 2000); (6) trees with a given diameter (Worbes *et al.* 2003); (7) tress occupying a certain strata of the forest (Copenheaver *et al.* 2006). However, it is generally agreed that trees affected by human activities, those suffering from diseases, or showing clear signs of decay or large deformations should be avoided, unless that is the purpose of the study (Dwyer *et al.* 1995; Stoffel & Bollschweiler 2008).

The best method to detect ring anomalies and test the dendrochronological potential is to cut a cross section of the trunk (Speer 2010). However, being a destructive method it is normally restricted to stumps and dead trees (Xiong *et al.* 2000; Stoffel & Bollschweiler 2008). It was sporadically used in live specimens located in places with high density of young trees with DBH (diameter at breast height) less than 8 cm (Copenheaver *et al.* 2006), and 3 cm (Clark & Hallgren 2004). Sampling live specimens is usually carried out by using non-destructive methods such as partial cross sections (wedge-shaped) or by extracting samples by means of an increment borer, which is less damaging than wedging (Sheppard *et al.* 1988; Speer 2010). However, despite this system is the least damaging it is also the most

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[1] Andrew Douglass (1867-1962) was an American astronomer, Professor of Physics and Geography in the University of Arizona. His interest in tree rings began when he was looking for evidences of sunspot cycle and its role in climate control on Earth. He established the Laboratory of Tree-Ring Research in 1937, and become the first person to teach Dendrochronology as a discipline. He developed dendrochronological techniques that have been used since then all around the world and applied in different fields (McGraw 2000: Speer 2010).

[2] Principle of Site Selection: principle according to which the location selected is the one that maximises the growth response to the variable in study (Speer 2010).

sensitive to resistance from the tree, and internal pressure and wood hardness can make it a quite difficult procedure. The specimen suitability to recover from the sampling process depends on the method and on tree ability to withstand damaging agents (although almost all trees are able to compartmentalise the area to prevent the entry of pathogens) (Norton 1998). Sometimes, trying to avoid further damages borer operators often protect injuries by covering them with tree wound dressing (McBride 1983; Norton 1998) or plugging the wound with dowels. However these procedures are sometimes not effective and in addition, can hinder the process of compartmentalisation (Norton 1998). The latter author has suggested some procedures to reduce tree damage as: proper maintenance of increment borer; drilling the cores slightly upward; and to scheduling coring to coincide with maximum cambial activity.

The total number of samples needed for a study depends on the purpose of the research and also on the existence of a master chronology of reference. If the latter already exists, the number of samples required does not have to be high. If no average tree-ring chronology is available at least 20 (Norton 1998) or 30 (Stoffel & Bollschweiler 2008) samples should be collected from undisturbed trees with no signs of disease. Thus it is possible to endure an adequate statistical sample and at same time build a reference against which trees affected by disturbances can be compared. Usually only one sample per tree should be collected, except in specific studies which require a minimum of two samples[1] (e.g. dendroclimatology) (Villalba *et al.* 1985; Speer *et al.* 2004; Copenheaver *et al.* 2006; Clark *et al.* 2008; Liutsko 2008). Although it is sometimes necessary to increase this number (for instance when the sample does not include the pith) the number should be limited to minimise injury, especially in endangered small forest fragments (Norton 1998; Rozas 2005; Stoffel & Bollschweiler 2008).

With the exception of works that involve sampling extraction (tree core) on specific locations of the tree trunk (e.g. fire scars), the cores are commonly extracted at breast height (130-140cm) (Ogden 1981; Dwyer *et al.* 1995; Worbes *et al*. 2003; Clark & Hallgren 2004; Krause 2005; Pierson 2007; Clark *et al.* 2008; Liutsko 2008; Speer 2010). However, coring at breast height, although very useful to standardise data for forestry calculation, does not give maximum information about age (Grissino-Mayer 2003). Other sampling heights were used in several works, being the cores extracted at ca. 100 cm above the ground (Wilson & Hopfmuller 2001; Cherubini *et al.* 2003), between 20 and 40 cm (Stoffel & Bollschweiler 2008), 50 cm (Ogden 1981), and as close to the ground as possible (under 10 cm). (McBride 1983; McCarthy *et al.* 1991; Schweingruber & Poschlod 2005; Copenheaver *et al.* 2006). The latter was used in order to get the maximum information from the germination or at least from ecesis, or to avoid errors due to sampling height corrections. However, although sampling at this height allows to intercept first year ring, because in general plants grow up to 5-10 cm during first year (Pierson 2007), coring near ground level is very difficult and can only be carried out by excavating soil, to allow twisting the handles of regular increment borer, by using a Quad-B which has handles bent backward, or by using a powered increment borer. Also, in the lower part of the trunk anomalies in tree-ring patterns are more frequent due to abiotic stresses and biotic agents that cause decay of wood tissues (McAuliffe *et al.* 2006; Speer 2010)

Extracting cores parallel to contour lines enable to get clearer ring patterns and to avoid irregularities related to geomorphological processes, however, in general they are taken along the slope direction. This is because trees growing on slopes have eccentric growth being much more difficult to intercept the off-center pith if the core is taken

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[1] Principle of Replication: principle that states that more than one sample per tree and more than one tree per plot should be collected to identify environmental factors affecting growth rings (Speer 2010).

along the slope contour, and reaching the pith is absolutely required to accurate aging (Grissino-Mayer 2003; Stoffel & Bollschweiler 2008; Speer 2010).

Despite being possible to analyse samples in the field, especially the stumps left in the ground (McBride 1983), treating samples in the laboratory allows to distinguish individual tree rings more effectively. But, on the other hand, it involves transporting those samples. Regardless the type of protection (paper or plastic straws, plastic tubes, plastic cling film) sample packaging is needed not only to avoid fragmentation but also to maintain fragments in the correct position (Asherin & Mata 2001; Kipfmuller & Swetnam 2001; Grissino-Mayer 2003; Speer 2010).

Both cross sections and cores should be left to dry before sanding. In very humid climates it may be necessary to dry the samples 24 hours in an oven (at 60 °C), or one week in laboratory hood, or 20-25 seconds in microwaves at high power, to prevent formation of molds. Because these methods are likely to cause wood deformation, in more favorable environments it is preferable to left the samples to dry in the open air. The cross sections, if thin sliced, must be mounted on a wooden plate before drying to prevent breakage. In contrast, samples collected with the increment borer must dry caught between two grooved wooden slats, or tied over the entire length against the groove to avoid deformations. Cores must be very dry prior to glue them since during the drying process they shrink causing core fragmentation (Asherin & Mata 2001; Speer 2010). The cores should be mounted and glued, with wood glue, into a groove on wooden mounts, such as the pith and xylem cells became vertically aligned. To prevent warping or loss of fragments of broken core samples must be secured (adhesive tape, clamps or string) to the mount as the glue is drying (Asherin & Mata 2001; Kipfmuller & Swetnam 2001; Rozas 2003; Speer 2010). After drying, to make rings visible, some authors have suggested several techniques that included application of water, stain, dyes, powders, or wax on the core surface, as well as inoculation of decay fungi, cutting with razor, using shade effect, or even making thin (10-20 μm) slices dyed with safranin. However except in the case of tree-ring boundaries very difficult to see it was considered by the majority of the authors that sanding with progressive grits (from a coarse-grain level under 100, and going through a series of sandpaper up to 400 grit or even higher if needed) is the best process (McBride 1983; Yamaguchi & Brunstein 1991; Asherin & Mata 2001; Cherubini *et al.* 2003; Clark *et al.* 2008; DeRose & Gardner 2010; Speer 2010).

Throughout time new technologies and processes to study growth rings have evolved, and currently researchers and professionals can use high resolution systems prepared to analyse tree-rings. Either by using stereo microscope and software that allows to measure rings width (McBride 1983; Touchan & Hughes 1999; Worbes *et al.* 2003; Helama *et al.* 2004; Worbes 2004), or sophisticated computer-controlled systems that enable analysing tree ring parameters through wood density (Schinker *et al.* 2003), or by adjusting common equipment to cope with the same type of analysis (Gonçalves 2008).

Although more than one sample per tree may exist (to allow evaluation of the eccentricity of the pith, detection of locally missing rings, and to test the possibility of crossdating) only one sample should be measured, i.e. the one with none or less anomalies being closest to the pith (Speer *et al*. 2004; Clark *et al*. 2008). Samples with slight eccentricity have to be corrected to prevent age underestimation. The number of missing years in the core can be estimated visually, if they are not more than two, or by overlapping a transparent sheet of paper with concentric rings to estimate the number of missing years. When this number is superior to five years cores have to be excluded, because error is cumulative with the number of missing years (McCarthy *et al.* 1991; Clark & Hallgren 2004; Bollschweiler *et al*. 2007; Clark *et al*. 2008; Stoffel & Bollschweiler 2008).

Samples that are not taken at root level need a correction factor to amend the time that the tree takes to grow to sampling height (Clark & Hallgren 2004; Bollschweiler *et al.* 2007), although sometimes no correction was made because it was considered of secondary importance (Cherubini *et al*. 2003). McCarthy *et al.* (1991) described a method to find a correction value for each tree by dividing the sampling height by an annual apical growth rate (determined by dividing the height of the tree above the sampling point by the number of rings in the core). However, growth rates in early years are not the same as in the adult tree and using this method could entail some error. Thus, although being a less precise option, normally a single value for all species of an area it is widely used (Gutsell & Johson 2002). Cherubini *et al.* (2003) suggested the possibility of using two to five years as a single correction factor for the species in the Mediterranean environment when they are sampled at one meter height, Ogden (1981) proposed two years when sampling is made at ca. 40 cm above the ground, and Worbes *et al.* (2003) recommended the use of seven years correction applied value in temperate zones whenever the sampling is done at breast height.

In some fields of dendrochronological research it is not enough to determine the age of the tree. To enable some studies (e.g. dendroclimatology) is strictly necessary to use correlation methods for ring patterns comparison (crossdating). This technique allows to identify false rings and missing rings, to confirm annual periodicity of rings, and as well as to obtain long standard chronologies (Norton & Ogden 1987; Campelo *et al.* 2006; Gonçalves 2008). Crossdating methods range from manual technique (skeleton plotting) to more advanced technologies by using image analysis software. The first process, although being time consuming is still used by many dendrochronologists that preferred to visually check the rings. They identify marker rings and plot thin and thick rings on graph paper (skeleton plot), measuring the rings width on a moveable-stage stereoscope. The second method uses semi-automatic programs to make virtual skeleton plots and to crossdate (Speer 2010; Maxwell *et al.* 2011). In both methods, accuracy of measurements and crossdating has to be evaluated. Software COFECHA, developed by Holmes (1983), was and still is often used, although some other specific software was also employed (Xiong *et al.* 2000; Worbes 2004; Copenheaver *et al.* 2006; Liutsko 2008; Maxwell *et al.* 2011). Testing in advance the crossdating potential of trees from a certain plot can be made by comparing measures of two radii of a cross section or between two increment cores, obtained at the same height, to check if ring widths coincide. Chronologies obtained can be compared with precipitation and temperature records (monthly and seasonal) to confirm if rings are annual, although it is frequently assumed that in regions with temperate climate if crossdating is successfully achieved it is a clear indication of an annual periodicity (Xiong *et al.* 2000; Speer *et al.* 2004; Speer 2010).

3.1.2 Dendrochronological potential of Madeiran native trees: what is known up to present?

The knowledge about growth rates of native trees occurring in Madeira Island is rather poor and based on the maximum age of the forest after a post-disturbance recovery documented by historical records or photographs (Pupo-Correia 2007). To date, no studies have been accomplished to investigate native trees of Madeira Island using dendrochronology and for this reason there is no information about growth rates or a tree ring database

In what concerns the *Lauraceae* there was the idea that age determination is not possible since it was believed that these trees do not produce annual rings (Arévalo & Fernández-Palacios 2000), and research on this matter has not been very active. Likewise, only a few studies have been carried out on the evergreen laurophyllous and sclerophyllous trees which are adapted to Mediterranean climate and thereby little information is known about anatomical, physiological, and phenological responses to those climatic conditions (Cherubini *et al.* 2003).

Despite no dendrochronological data about native trees of Madeira Island having been published up to date, two dendrometrical approaches were carried out not so long ago. Nevertheless, the information contained therein does not satisfy the objectives of this research. One of those, although including measurements of large sized stink-laurel trees, they correspond to a few specimens growing near settlements, in gardens (Domingues *et al.* 2008). In the other one, although carried out in laurisilva patches, it does not include the dendrometric data that were used to determine dominant trees in forest inventory (Neves *et al.* 1996).

Some studies on the anatomy of Madeiran woody endemic shrubs such as *Echium nervosum* and *E. candicans* (Carlquist 1970a), and *Plantago arborescens* subsp. *maderensis* (sub *P. maderensis* Decne) (Carlquist 1970b) have shown that even in wide range of ecological conditions annual growth rings were produced as response to rainfall and dryness. Also, several studies which were undertaken with laurel trees can contribute with some hints. Cherubini *et al.* (2003) verified that Mediterranean adapted evergreen laurophyllous vegetation tend to produce double rings as response to winter cold stress and summer drought in the Mediterranean climate characterised by hot and very dry summers and very cold winters. Some other studies, involving anatomical analysis, were performed specifically with Macaronesian laurel species (Morales *et al.* 2002; Loutfy 2009) or as part of studies including several other species of *Lauraceae* (Stern 1954; Léon 2002; Tomazello-Filho *et al.* 2004; Schweingruber 2007). These studies showed a very homogeneous wood anatomy within these species, and except *Apollonias barbujana* that has diffuse-porous wood to slightly semi-ring porous (Loutfy 2009) the other three species possess diffuse-porous wood (Léon 2002; Morales *et al.* 2002; Schweingruber 2007; Loutfy 2009). All authors considered that the growth rings, almost entirely earlywood, are well defined with ring boundaries distinct and expressed by radial flat fibers that form a little width band of latewood. A common wood anatomical feature is paratracheal parenchyma that is normally associated with the interruption of annual growth. Although Ogden (1981) stated that the presence of these cells, that seem to be formed to act as barrier to the spread of pathogens, cannot be a guarantee of annual periodicity because they can develop during times of stress, Morales *et al.* (2002) in their work with *Laurus novocanariensis* [sub *Laurus azorica* (Seub.) Franco] considered them as formed at the cessation of seasonal growth and rather useful to identify the limits of annual increment.

The objectives that established the main lines of the work presented in this chapter are related to different aims that were presented in the general introduction (first chapter):

1. One objective related to the main aim of this thesis (to evaluate progressive change of the landscape in Madeira Island, by assessing spatial and temporal vegetation dynamics), i.e.:

1.1 to obtain information about the age of the trees located in stands depicted in re-photographed landscape.

2. Three objectives related to the second subsidiary goal (to explore dendrochronology and dendrometry as a useful tool for the interpretation of native forests dynamics), i.e:

2.1 to evaluate the suitability of native woody species for dendrochronological use;

2.2. to adjust regression models, in order to select alometric equations to estimate tree age based on variables easily measurable such as diameter and total height;

2.3. to get information about growth rates of Madeiran native trees.

3.2 Methods

The methods used in this research were conditioned by sampling sites peculiarities, the species under study, and the work aims. They resulted from adaptation of methodologies used or suggested by several authors (Gomes 1957; Ogden 1981; McBride 1983; Norton & Ogden 1987; McCarthy *et al.* 1991; Dwyer *et al.* 1995; Norton 1998; Worbes 1999; Asherin & Mata 2001; Kipfmuller & Swetnam 2001; Wilson & Hopfmuller 2001; Gutsell & Johson 2002; Grissino-Mayer 2003; Worbes *et al.* 2003; Clark & Hallgren 2004; Speer *et al.* 2004; Worbes 2004; Krause 2005; Rozas 2005; Copenheaver *et al.* 2006; Pierson 2007; Clark *et al.* 2008; Liutsko 2008; Stoffel & Bollschweiler 2008; Speer 2010).

3.2.1 Sampling: samples collection and preparation

For samples collection and preparation the subsequent procedures were followed:

(1) Site selection: the sampling plots were distributed throughout Madeira Island and selected according to historical photographs location. The samples were collected in these plots whenever it was the natural occurrence of the species and with minimum effect of human disturbance. Trees in sites with the same bioclimate located out of photographed landscape were also cored in order to obtain a broader and more representative sample (Figure 3.1).

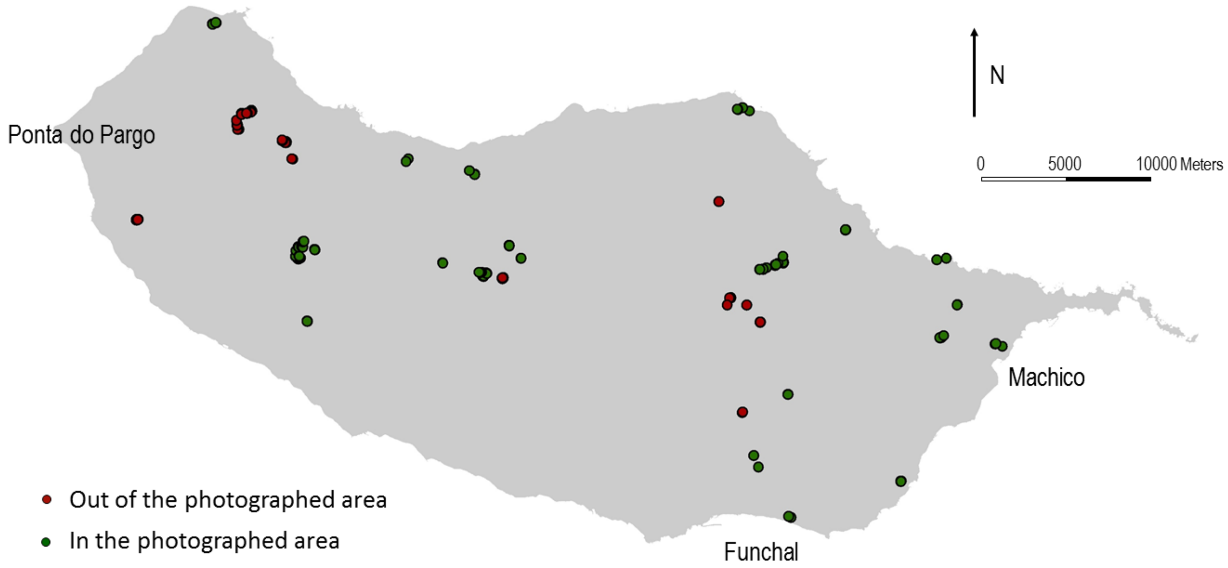

Figure 3.1 Location of the sampling plots.

(2) Tree selection: in each site the putative oldest tree was selected, in order to maximize the tree-ring chronology. Younger trees were also cored to cover larger range of diameters and heights. Trees within each site were chosen from healthy ones without traces of decay, large deformations or bark scars.

(3) Measuring tree attributes: diameter was measured at breast height (BH): 130 cm; or 50 cm with a diameter tape (Figure 3.2-c), depending on sampling location, and total tree height was measured with a relascope (Bitterlich's Spiegel Relascope), or with a hypsometer (Haglöf, Vertext IV) (Figure 3.2-d). Total height (h) of tilted trees was

determined by measuring the height (x) from the top of the tree to horizontal line at the base of the trunk and the angle (z) between the tree and that line, being h=x/sin z (Gomes 1957).

(4) Sampling procedure: tree cores were extracted with an increment borer of 5.15 mm in diameter and 400 mm long (Figure 3.2-a, b), and less frequently bigger increment borer (10 mm, 500 mm). Exceptionally were cross-sectioned trees with DBH (diameter at breast height) less than 6 cm in places with high density of young trees in the understory, and also wider trunks from dead trees, in order to evaluate if they produce reliably cyclic rings and did not have frequently major anomalies.

Figure 3.2: (a, b) coring process (borer 400 mm, 5.15 mm diameter), (c) measuring with diameter tape; (d) hypsometer (Haglöf, Vertext IV) used both for measuring tree height and angles needed to calculate total height of tilted trees.

(5) Sampling height and location on tree trunk: samples were cored at 50 cm or 130 cm height (BH), the latter when trees at 50 cm were too wide to reach the pith. Full cross-sections, from young trees that were sawn from the root collar, were sliced at 0-5 cm, 50 cm and 130 cm, in order to estimate the number of years that trees spent to reach 50 cm and 130 cm height. Despite sampling above the ground underestimate tree age requiring correction (age-height correction) coring at ground level (0-5 cm), as seen in introduction, apart from being more difficult, requiring special devices, it has a host of problems making it less suitable. Trees growing on slopes were cored perpendicularly to the contour to ensure that the pith was included in the sample or at least very close. Although several authors stressed that collecting cores should be performed parallel to the level curve to avoid reaction wood it also can impede pith interception due to eccentricity and thus disabling those samples. Because it was practically impossible to drill on the downslope side of trees located in very steep terrain many samples were cored uphill side, in spite of the fact that in this way they can intercept tension wood making ring counting much harder (Figure 3.2- a).

(6) Samples *per* tree: following the literature review, only one core per tree was normally extracted and not all trees in each population were cored to minimise injury. Even so, it was extracted a second core in situations when first did not pass through the centre and sometimes two cores were extracted at the same height, but on opposite directions, to evaluate the circuit uniformity and to prospect missing rings occurrence at the sampling height.

(7) Sample packaging and transportation: both cores and cross-sections were taken to the laboratory wrapped up in cling-film to avoid cracking and losing or moving fragments from the correct order, if they already existed. The wrapped cores were introduced into plastic tubes for further protection (Figure 3.3-a). All samples were identified by a reference number. The position of the core, inside the tube, was marked to enable the location of the bark that sometimes fell away from the wood.

(8) Field notes: field notes for each sample included species identification, community, GPS coordinates, diameter at sampling height (50cm or BH) and total tree height.

(9) Sample preparation: cross-sections were thickly sliced, planed, and left to air dry. Cores were placed and tied up with string to grooved wooden mounts to prevent deforming during the drying process. When completely dried they were glued with vertical alignment of the xylem cells (Figure 3.3-b). All samples were sanded (Figure 3.3-c) with progressively finer grades of sandpaper (100, 220, 320, 400 and 600 grit paper for a few samples that individual ring boundaries were not readily seen with coarser papers) attached to electric power finish sander.

Figure 3.3 (a) cores protected with cling-film and plastic tubes for transportation; (b) cores preparation (dry, mount, glue); (c) core of *Laurus novocanariensis* sanded with progressively finer sandpaper (100 to 400) permiting to see the rings (1-bark, 2-pith); (d) examination under stereo microscope Zeiss Stemi-SV 11 to analyse anatomical features, ring structure and to count rings.

3.2.2 Data analysis

For samples analysis the subsequent procedures were followed:

(1) Ring observation: the cores were observed under stereo-microscope (Zeiss Stemi-SV 11) to analyse anatomical features and ring structure (Figure 3.3-d), being the cutting surface re-wetted to enable distinguish blurred rings, whenever necessary. Cores were also analysed to prospect for unusual features (e.g. fire scars) which may indicate past disturbance events, and the time when they occurred. Samples with very diffuse rings, hard damage, decayed portions and as well very eccentric pith (more than 5 years estimated) were disposed, although measurements (height and diameter) were considered for statistical treatment (see point 3.2.2 - 5). The cross sections of the trunks of species under study were examined to evaluate circuit uniformity, and to look for tendency to form wedging rings.

(2) Data capture and measurements: samples were scanned with high resolution [(1200 ppi) HP4470c scannjet and Epson Stylus Photo RX620 (M)] and the images were imported into a measurement and image processing software (AxioVisionLE. Rel. 4.4). Rings were dated and counted from the outside towards the visible pith. The width of the five innermost rings of the complete cores (Figure 3.4-a) was measured from the centre of the visible pith following a perpendicular line to the ring boundary (to the nearest 0.01mm), in order to get a correction value for samples not cored to pith. In cross sections without anomalies the ring number was counted over one random radius. In cross sections with wedging rings, ring counting was made by matching rings along several radii around the circumference skipping sections were those rings were locally absent.

(3) Age correction (estimation of missing rings in off-centre cores): For the cores without visible pith it cannot be considered as centre the half arc length of innermost visible ring (Figure 3.4-b1), because this underestimates age. The position of the chronological centre was estimated and the distance between this point and the innermost visible arc was measured as radius of the circle (Figure 3.4-b2). The number of missing rings was estimated by dividing the length of the missing radius by a mean radial growth rate. This average value was based on the width, of the five innermost rings of the complete cores of the same species collected in the same area (see point 3.2.2-2).

(4) Age correction due to time taken to grow to sampling height: it was used a single value for all species: two years as a single correction factor for the species sampled at *ca*. 50 cm above the ground, and five years, to correct age of trees cored at breast height.

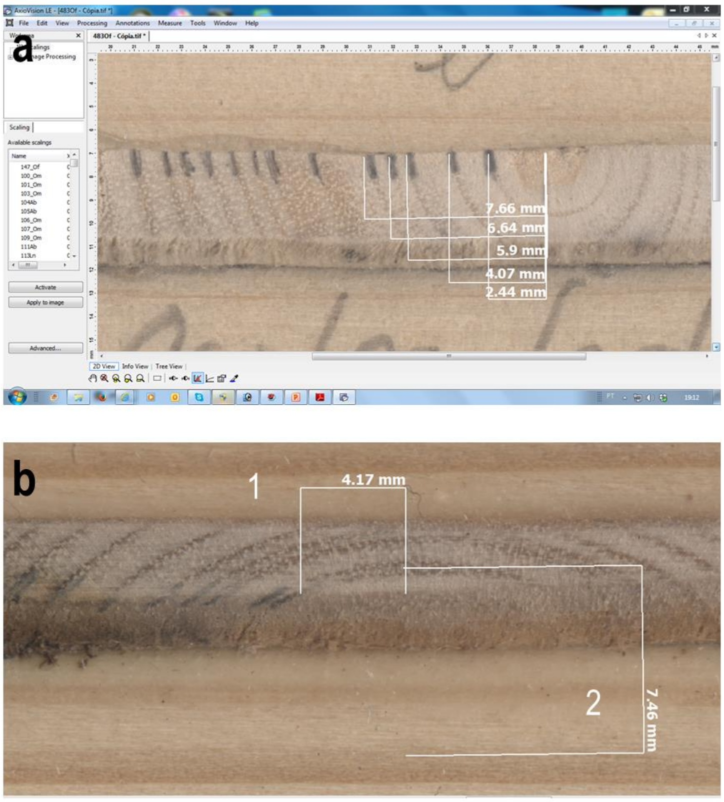

Figure 3.4 Age correction for cores with off-centre pith: (a) measurement of five innermost rings of samples with visible pith; (b-2) estimation of chronological centre, indicating the need to add four years to the amount counted (being in this case mean radial growth rate, for 5 innermost rings, 1.8 mm).

(5) Calculating correlations between stem diameter, total tree height and age: Tools provided by Microsoft Excel were used for calculations. Regression analysis was employed to estimate Total Height and Age, using Diameter at 50cm height or at 130cm (an easy access variable). For each species it was selected the model wich better combine: higher adjusted determination coefficient (R2adj), lower root mean squared (RMSE), which allows to analyse de goodness of fit and the residual value (Sit & Poulin-Costello 1994; Motulsky & Christopoulos 2003) a real asymptote (increasing to a certain value[1] and not to infinity), increasing throughout its domain, by using:

(i) Exponential: $Y = e\ (Ct + \alpha\ x) + \varepsilon$; (ii) Semi-exponential: $Y = Ct\ e\ (\alpha\ x) + \varepsilon$; (iii) Logarithmic: $Y = Ct\ x\ \alpha + \varepsilon$; (iv) Semi-logarithmic: $Y = Ct + \alpha\ \ln(x) + \varepsilon$; (v) Quadratic: $Y = Ct + \alpha\ X + \beta\ X2 + \varepsilon$; (vi) Combined Variable: $Y = Ct + \alpha\ X1 + \beta\ X2 + \theta\ X12\ X2 + \varepsilon$.

Where: Y – dependent variable, usually a variable from hard access (e.g. tree age); X1 and X2 – independent variables (predictive), usually a variable form easy access (e.g. diameter at breast height, total height of the tree); Ct – Constant; Α, β, θ - regression parameters; Ɛ - Residual value.

Diameter at 50 cm from the ground and total height were selected as an independent and dependent variable (using diameter as predictive variable in order to estimate age by using the previously presented equations. Only measurements associated with a known age were used to adjust the regression equations Age = f1 (D_50cm) or Age = f2 (Height) or Age = f3 (D_50cm; Height). The measurements (D_50cm and Total Height), from samples for which it was not possible to count the total number of rings (see 3.2.2-1), were used to adjust regression equations Height = f (D_50cm). After the stage of adjusting regression models, the ones with higher adjusted determination coefficient (R2adj) and lower root mean squared error (RMSE) were selected for further application.

(i) determination coefficient (R2);

$$R^2 = 1 - \frac{SSE}{SST_{corrected}} = 1 - \frac{\sum_1^n (y_i - \hat{y}_i)^2}{\sum_1^n (y_i - \bar{y})^2}$$

(ii) adjusted determination coefficient (R2adj);

$$R^2_{adj} = 1 - \frac{SSE * (n-1)}{SST_{corrected} * (n-p)} = 1 - \left\lfloor (1 - R^2) * \frac{n-1}{n-p} \right\rfloor$$

(iii) residual mean squares error (MSE);

$$MSE = \frac{SSE}{n-p} = \frac{\sum_1^n (y_{1-}\, \hat{y}_i)^2}{n-p} = \frac{\sum_1^n (e_i)^2}{n-p}$$

(iv) root mean squared error (RMSE)

$$RMSE = \sqrt{}MSE$$

Where: SSE – Regression Equation Sum Squared; SST – Total Sum Squared; n – number of samples; p – number of regression parameters.

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[1] Maximum height of *Apollonias barbujana, Laurus novocanariensis, Persea indica*, and *Vaccinium padifolium* was based on Press & Short (1994), and maximum height of *Clethra arborea*, *Erica arborea*, *E. platycodon* subsp. *maderincola, Ocotea foetens*, *Myrica faya*, and *Olea maderensis* that current height exceeded the one referenced, it was used maximum measurement value.

3.3 Results

As already mentioned the dendrochronological approach aimed in first place to obtain information about the age of trees located in some stands depicted in re-photographed landscape (Chapter 4) and to complete data that are needed to understand vegetation dynamics. Yet, it also attempted a preliminary evaluation of the suitability of some native woody species for dendrochronological research, to prospect the annual periodicity of growth rings, and to develop models to estimate tree age based on variables easily measurable such as diameter and total tree height. Thus, in this study were included native trees (*Apollonias barbujana* subsp. *barbujana*, *Laurus* novocanariensis, *Myrica faya, Ocotea foetens, Olea maderensis*, and *Persea* indica), and shrubs that frequently attain tree size (*Erica arborea*, *Erica platycodon* subsp. *maderincola*, and *Vaccinium padifolium*). In addition to native species were also cored some exotic trees (*Acacia mearnsii, Eucalyptus globulus, and Pinus pinaster*) mostly with the purpose of aging specimens seen in current landscape. Although their suitability for dendrochronological purpose was also evaluated, the data were intended to clarify doubts about their presence in the historical photograph, and thus were not included in extensive study as native trees.

3.3.1 Suitability of native trees of Madeira Island for dendrochronological purposes

The following section describes the rings characteristics that were observed in samples collected, and the several issues that have been detected during this analysis that can difficult ring identification (summarised in Table 3.1). For this analysis the total amount of samples collected was used, including those not containing the pith or having other major problem, which were not subsequently considered to age determination.

The native species that were analysed belong to the group of trees classified as *hardwoods* (designation attributed to angiosperm trees, in opposition to *softwoods*, related to gimnosperms). In seven of the ten *taxa* under study (*Apollonias barbujana, Clethra arborea, Laurus novocanariensis, Myrica faya, Ocotea foetens, Olea maderensis, Persea indica*, and *Vaccinium padifolium*) the difference in wall thickness of the cells creates the typical alternation light/dark that facilitates growth rings identification (Figure 3.5-Ab, Ca, Ln, Mf, Of, Om, Pi, and Vp). In *Apollonias barbujana, Laurus novocanariensis, Ocotea foetens, Persea indica,* and also in *Olea maderensis*, albeit not quite marked as in the previous one, each ring was easily recognised by its two parts: one wide and light coloured (earlywood) and the other narrow and dark (latewood). In addition, the boundaries are very distinct, with a very sharp transition between latewood and next year earlywood (Figure 3.6). Ring boundaries seen in the wood of *Clethra arborea*, *Myrica faya,* and *Vaccinium padifolium* are also quite clear but between light coloured band and dark band of the same calendar year as it is more uncommon (Figure 3.7).

The other two species, *Erica arborea* and *Erica platycodon* subsp. *maderincola* (Figure 3.5 and Figure 3.6-Ea, Ep), do not show a marked colour difference between the tracheids that are produced when growth resumes after a stoppage and cells produced later in the growing season. Even though, it is possible to distinguish growth rings. The vessels are largely concentrated in earlywood being this ring-porous structure accented by the occurrence of a few bit larger pores.

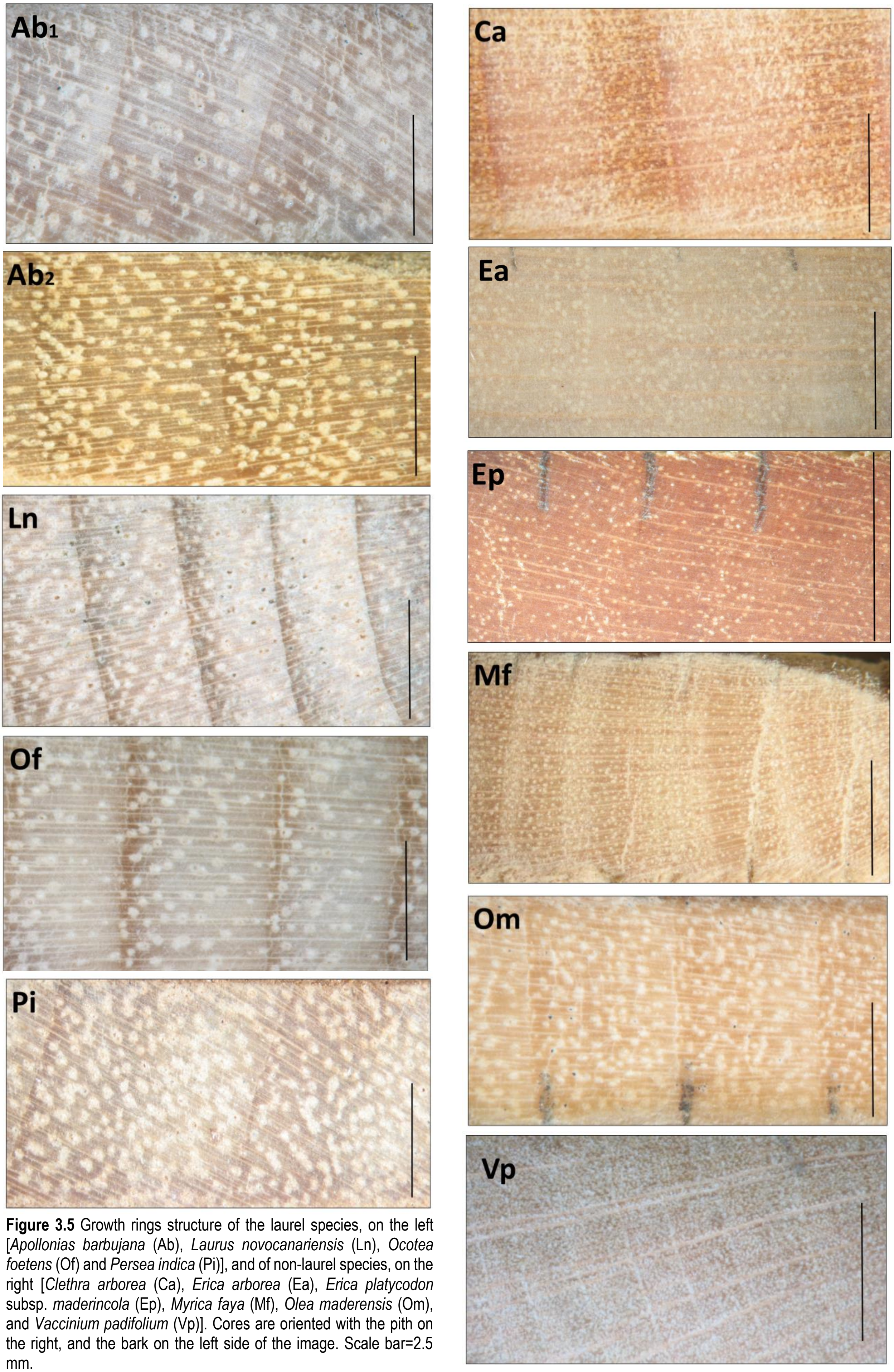

Figure 3.5 Growth rings structure of the laurel species, on the left [*Apollonias barbujana* (Ab), *Laurus novocanariensis* (Ln), *Ocotea foetens* (Of) and *Persea indica* (Pi)], and of non-laurel species, on the right [*Clethra arborea* (Ca), *Erica arborea* (Ea), *Erica platycodon* subsp. *maderincola* (Ep), *Myrica faya* (Mf), *Olea maderensis* (Om), and *Vaccinium padifolium* (Vp)]. Cores are oriented with the pith on the right, and the bark on the left side of the image. Scale bar=2.5 mm.

Table 3.1 Species and subspecies that were analysed in this sudy: some of their characteristics and issues.

Taxon	**Number of samples**	**Ecology** (Costa *et al***.** 2004)	**Growth rings**	**Minor issues**[a]	**Major issues**[b]
Apollonias barbujana	20	*Semele androgynae-Apollonio barbujanae sigmetum*	Clearly distinct rings, showing gradual change from early wood to late wood, which contrast to next growing season by well-marked boundaries.	Not found.	Not found.
Clethra arborea	67	*Clethro arboreae-Ocoteo foetentis sigmetum*	Clearly distinct rings, marked by well-marked boundaries when growth resumes after the summer stoppage, and alternation dark/light throughout annual increment.	Not found.	Not found.
Erica arborea	64	*Semele androgynae-Apollonio barbujanae sigmetum, Clethro arboreae-Ocoteo foetentis sigmetum,* *Polysticho falcinelli-Erico arboreae sigmetum*	Slightly distinct rings, marked by highest concentration of vessels in early wood portion of the ring.	Very old trees tend to present heartwood rotten, preventing ring counting.	Ring boundaries are often fuzzy. Low circuit uniformity, frequent false rings and locally missing rings.
Erica platycodon subsp. *maderincola*	131	*Semele androgynae-Apollonio barbujanae sigmetum, Clethro arboreae-Ocoteo foetentis sigmetum,* *Polysticho falcinelli-Erico arboreae sigmetum*	Slightly distinct rings, marked by highest concentration of vessels in early wood portion of the ring.	Very old trees tend to present heartwood rotten, preventing ring counting.	Ring boundaries are often fuzzy. Low circuit uniformity, frequent false rings and locally missing ring, stem torsions switch cells orientation along the core.
Laurus novocanariensis	157	*Semele androgynae-Apollonio barbujanae sigmetum, Clethro arboreae-Ocoteo foetentis sigmetum*	Clearly distinct rings, showing gradual change from early wood to late wood, which contrast to next growing season by well-marked boundaries.	Sporadic occurrence of false rings.	Not found.
Myrica faya	88	*Semele androgynae-Apollonio barbujanae sigmetum, Clethro arboreae-Ocoteo foetentis sigmetum*	Clearly distinct rings, marked by well-marked boundaries when growth resumes after the summer stoppage, and alternation dark/light throughout annual increment. .	Very old trees tend to present heartwood rotten, preventing ring counting.	Ring boundaries are often fuzzy. Low circuit uniformity, frequent false rings and locally missing rings.
Ocotea foetens	95	*Semele androgynae-Apollonio barbujanae sigmetum,* *Clethro arboreae-Ocoteo foetentis sigmetum*	Clearly distinct rings, showing gradual change from early wood to late wood, which contrast to next growing season by well-marked boundaries.	Sporadic occurrence of false rings. Very old trees occasionally present heartwood stained dark brown, or otherwise rotten, both preventing ring counting.	Not found.
Olea maderensis	14	*Mayteno umbellatae-Oleo maderensis sigmetum*	Clearly distinct rings, showing gradual change from early wood to late wood, which contrast to next growing season by well-marked boundaries.	Some boundaries can be fuzzy.	Not found.
Persea indica	36	*Clethro arboreae-Ocoteo foetentis sigmetum,* *Diplazio caudati-Perseetum indicae*	Clearly distinct rings, showing gradual change from early wood to late wood, which contrast to next growing season by well-marked boundaries.	Not found.	Not found.
Vaccinium padifolium	9	*Clethro arboreae-Ocoteo foetentis sigmetum*	Clearly distinct rings, marked by a ring formed by larger pores when growth resumes after the summer stoppage, and alternation dark/light throughout annual increment.	Not found	Not found

a - one-off cases within samples that were examined; b - common situation found within samples that were examined.

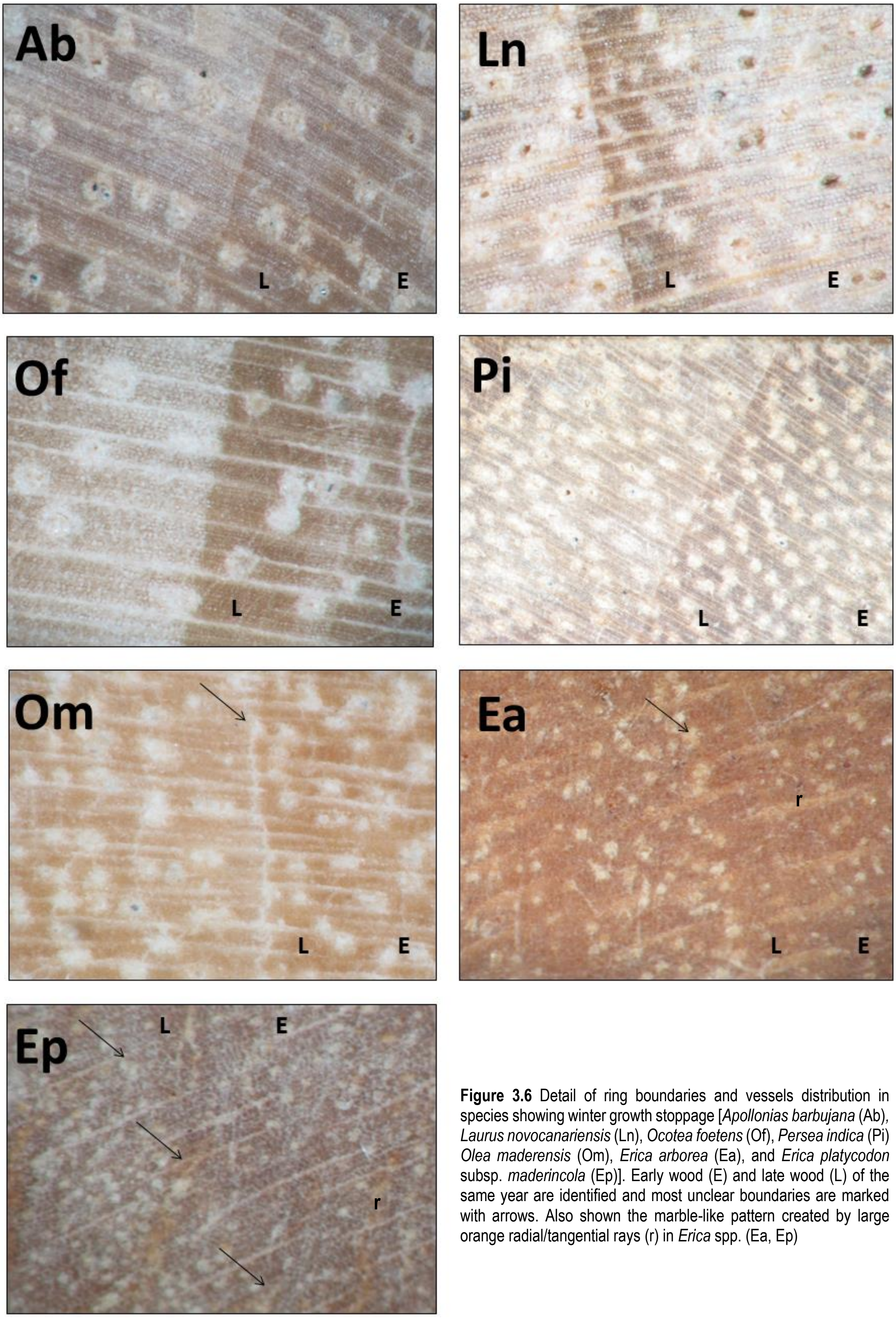

Figure 3.6 Detail of ring boundaries and vessels distribution in species showing winter growth stoppage [*Apollonias barbujana* (Ab), *Laurus novocanariensis* (Ln), *Ocotea foetens* (Of), *Persea indica* (Pi) *Olea maderensis* (Om), *Erica arborea* (Ea), and *Erica platycodon* subsp. *maderincola* (Ep)]. Early wood (E) and late wood (L) of the same year are identified and most unclear boundaries are marked with arrows. Also shown the marble-like pattern created by large orange radial/tangential rays (r) in *Erica* spp. (Ea, Ep)

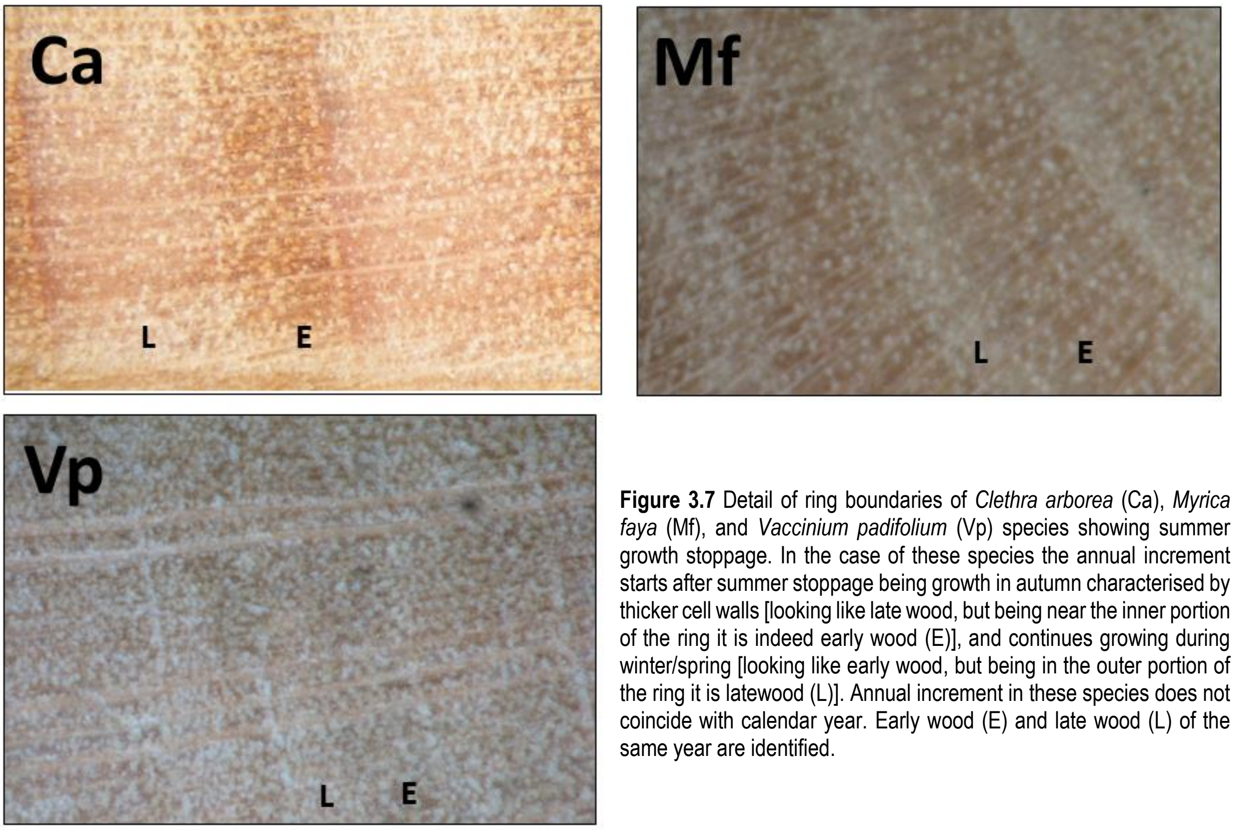

Figure 3.7 Detail of ring boundaries of *Clethra arborea* (Ca), *Myrica faya* (Mf), and *Vaccinium padifolium* (Vp) species showing summer growth stoppage. In the case of these species the annual increment starts after summer stoppage being growth in autumn characterised by thicker cell walls [looking like late wood, but being near the inner portion of the ring it is indeed early wood (E)], and continues growing during winter/spring [looking like early wood, but being in the outer portion of the ring it is latewood (L)]. Annual increment in these species does not coincide with calendar year. Early wood (E) and late wood (L) of the same year are identified.

With the exception of *Erica* spp. and *Vaccinium padifolium* all other species have vessels which are evenly sized and scattered throughout the growth ring (diffuse-porous woods). However in *Apollonias barbujana* some individuals showed pores slightly more concentrated in latewood portion of the ring, i.e. looking like semi-ring porous wood (Figure 3.5-Ab2), along with individuals showing diffuse-porous structure (Figure 3.5-Ab1).

Some anomalies that can hamper ring analysis were detected (Table 3.1). Samples of six tree species (*Apollonias barbujana, Clethra arborea, Laurus novocanariensis, Ocotea foetens, Olea maderensis,* and *Persea indica*) from the nine species observed have not shown recurrent anomalies, and only minor issues were found in a few situations. This was the case of a false ring seen in *Laurus novocanariensis* (Figure 3.8-Ln), and in *Ocotea foetens*, less clear boundaries, as it happen occasionally in *Olea maderensis,* and heart decay or occurrence of very dark *duramen*,

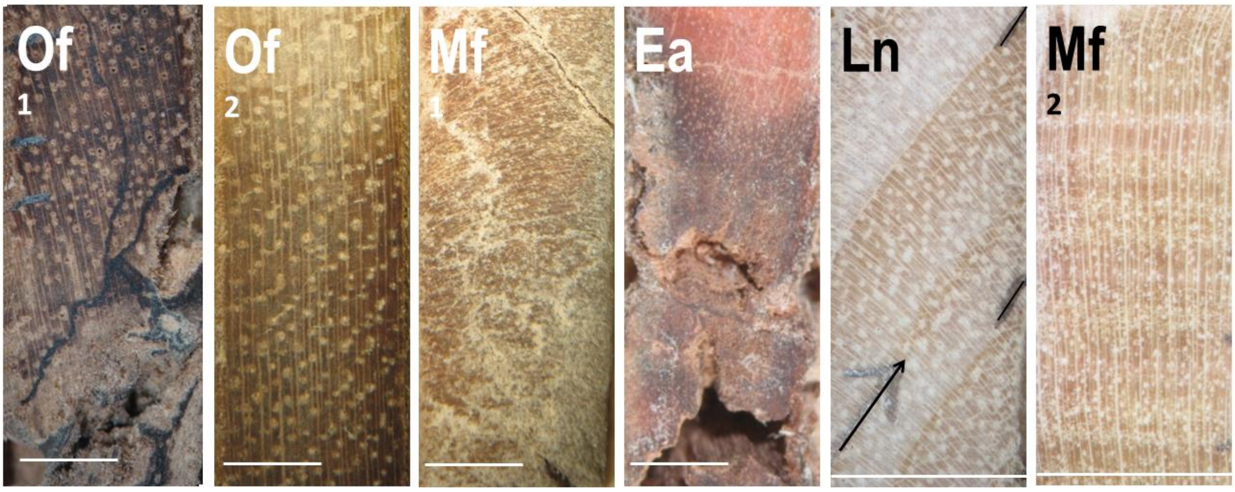

Figure 3.8 Some of the anomalies observed: core decay and dark brown heartwood in *Ocotea foetens* (Of1, Of2); rotten core in *Myrica faya* (Mf1), and *Erica arborea* (Ea); false ring in *Laurus novocanariensis* (Ln); and extremely fuzzy ring boundaries in *Myrica faya* (Mf2). Scale bar = 2.5 mm.

making rings identification more difficult, as seen in *Ocotea foetens* (Figure 3.8-Of1, Of2). The other three *taxa* (*Erica arborea, Erica platycodon* subsp. *maderincola* and *Myrica faya*) in addition to similar problems as mentioned above they have shown more complicated issues looking like frequent occurrences. The lack of alternation in colour between earlywood and latewood and wide radial/tangential rays in the two *Erica* spp., and also the fuzzy boundaries, as as it happen in *Myrica faya* (Figure 3.8-Mf2), makes it more difficult to identify growth rings in these species. Beside these traits, rotten heart (Figure 3.8-Mf1, Ea), false rings, wedging rings, and very eccentric pith, are also common issues that prevent a straight ring analysis. This is especially challenging in *Erica platycodon* subsp. *maderincola* that due huge torsions during growth is the one that contain more anomalies (Figure 3.9). This type of growth also affects the position of xylem cells that become no longer in cross-section view impeding growth rings visualisation (Figure 3.9-1, 2).

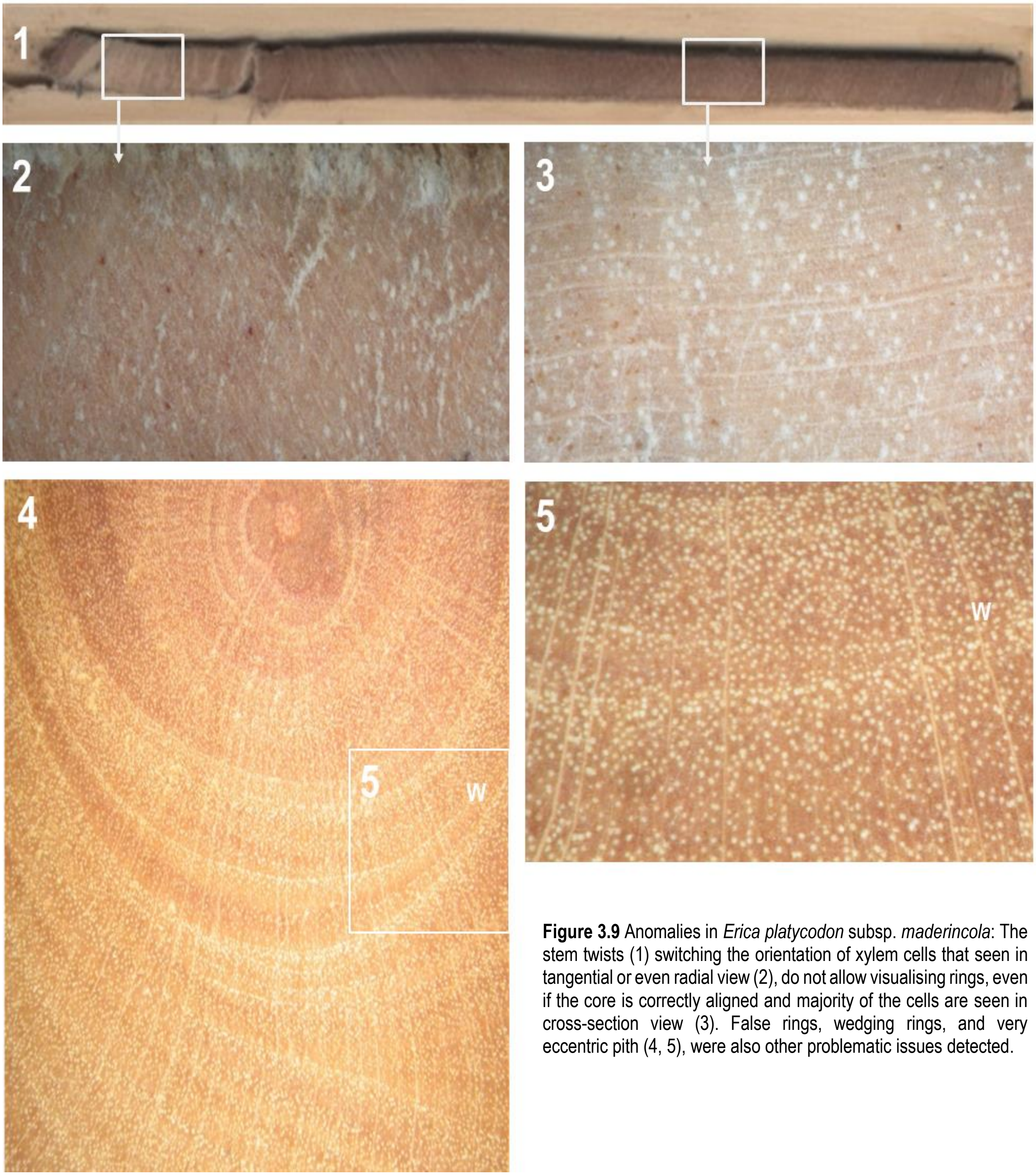

Figure 3.9 Anomalies in *Erica platycodon* subsp. *maderincola*: The stem twists (1) switching the orientation of xylem cells that seen in tangential or even radial view (2), do not allow visualising rings, even if the core is correctly aligned and majority of the cells are seen in cross-section view (3). False rings, wedging rings, and very eccentric pith (4, 5), were also other problematic issues detected.

Regardless the plant species it was observed that rings width is more or less constant along the core, declining with age to very narrow rings near the bark, in very old specimens (Figure 3.10-Of). Changes in this pattern can occur after a fire (Figure 3.10-Ln), as commonly happens after stressful events. Comparisons between two cores extracted on opposite sides of the trunk and several radii of full cross section have shown that even under pith eccentricity the number of rings remained roughly constant, except in *Erica* spp. and *Myrica faya.* In specimens with pith eccentricity ring width is variable being narrow where the pith is closer to the bark, as expected.

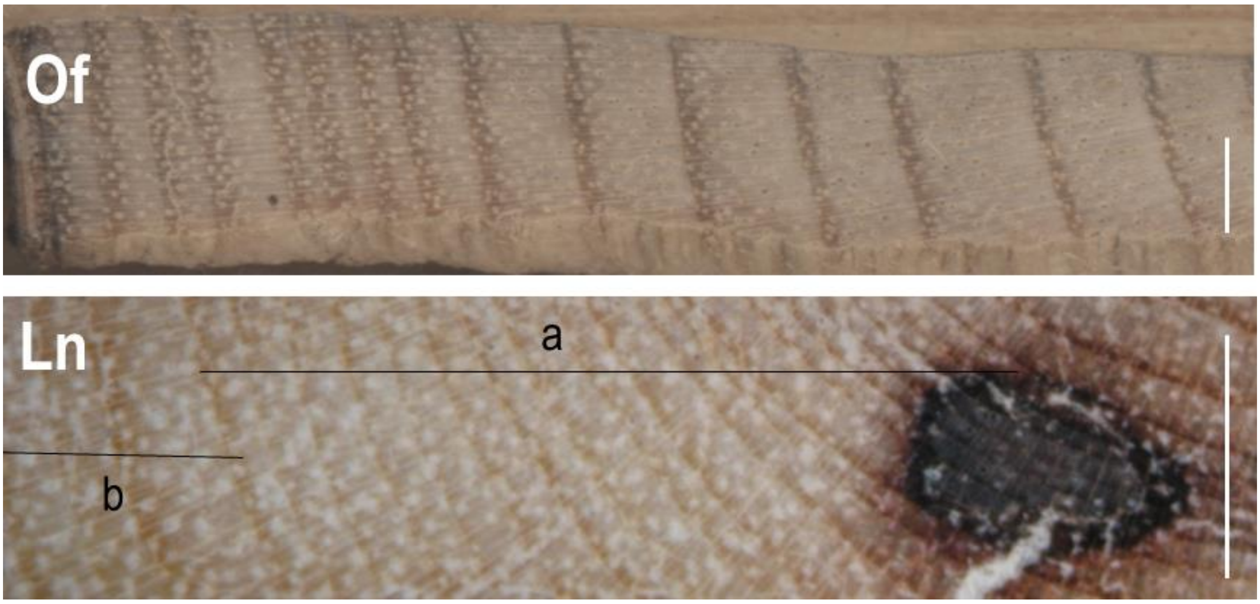

Figure 3.10 Rings width is more or less constant declining with age and becoming very narrow near the bark as seen here in *Ocotea foetens* (Of). In stressful years, such as after a fire, growth is suppressed and rings became narrow (a). They return to formative rates (b) after several years, as seen in this specimen of *Laurus novocanariensis* (Ln). Scale bar = 2.5 mm.

3.3.2 Suitability of exotic trees for dendrochronological purposes

In addition to native species the exotic trees most frequently found in the photographed landscape (*Acacia mearnsii, Eucalyptus globulus, Pinus pinaster,* and *Pittosporum undulatum*) were also cored. In relation to these species, it was only considered the fact that the growth rings (Figure 3.11) are clear enough to be counted and it was not carried out further research attempting to clarify annual regularity and cyclic increment of rings. Except for *Pittosporum undulatum*, other three species have very clear rings, marked by intense colour difference between earlywood and latewood. Concerning *P. undulatum* that in addition to insufficiently clear rings it has a very light colour wood, which does not easier ring counting, it was always necessary to resort to shadow or small bed of water to improve ring boundaries visualisation following suggestions of authors that also had to deal with this type of wood, although in other species (DeRose & Gardner 2010). Two samples of *Pinus pinaster* collected in a stand located on a hilltop have shown double rings throughout entire life of the tree, triggered by water stress in summer and low temperatures in winter (Figure 3.11-Pp2).

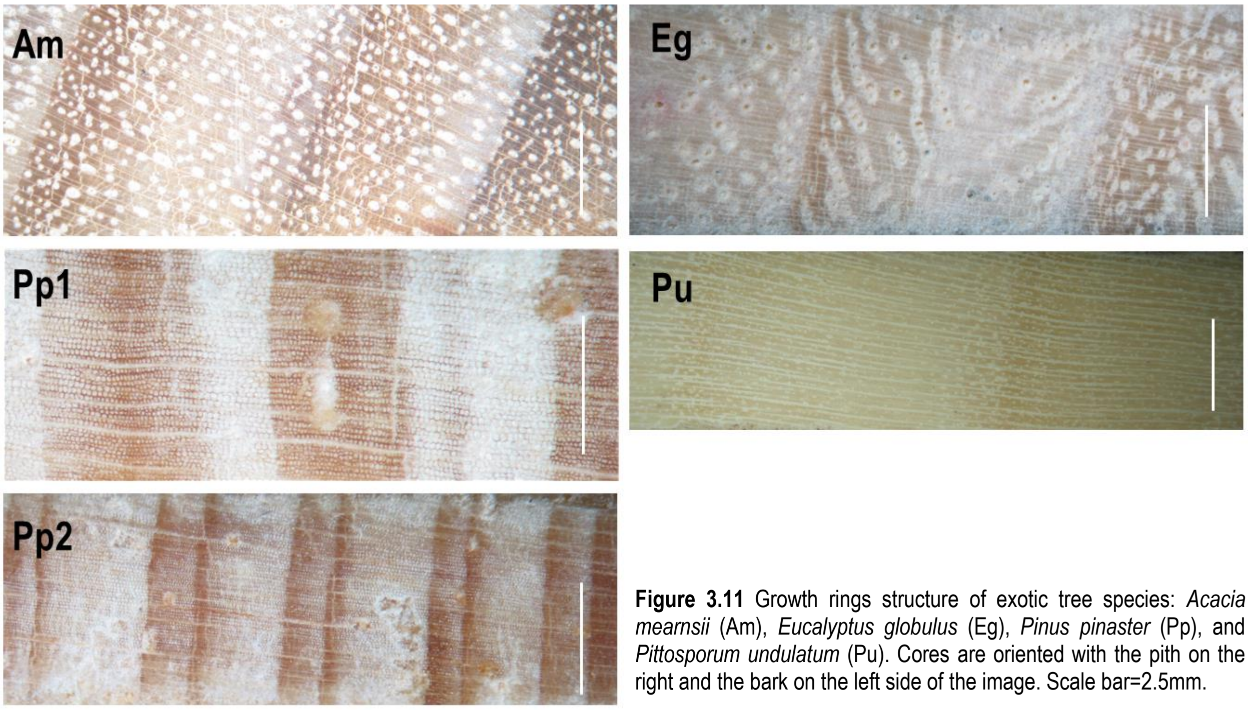

Figure 3.11 Growth rings structure of exotic tree species: *Acacia mearnsii* (Am), *Eucalyptus globulus* (Eg), *Pinus pinaster* (Pp), and *Pittosporum undulatum* (Pu). Cores are oriented with the pith on the right and the bark on the left side of the image. Scale bar=2.5mm.

3.3.3 Species collected across the study area

As previously stated samples were collected across the study area (Figure 3.1) geared in first place by historical photographs location (Table 3.2), and then to obtain a larger collection by collecting further samples out of that range. The number of samples of each tree species collected was mainly determined by the occurrence of trees meeting the conditions (see 3.2.1). Within the group of native species were collected 20 *Apollonias barbujana* subsp. *barbujana*, 53 *Clethra arborea*, 58 *Erica arborea*, 123 *Erica platycodon* subsp. *maderincola,* 147 *Laurus novocanariensis*, 81 *Myrica faya*, 92 *Ocotea foetens*, 14 *Olea maderensis*, 33 *Persea indica*, and 5 *Vaccinium padifollium.* Within the group of exotic tree species were collected 16 *Acacia mearnsii*, 6 *Eucalyptus globulus*, 9 *Pinus pinaster*, and 8 *Pittosporum undulatum*. The following maps show sampling locations of the species under study.

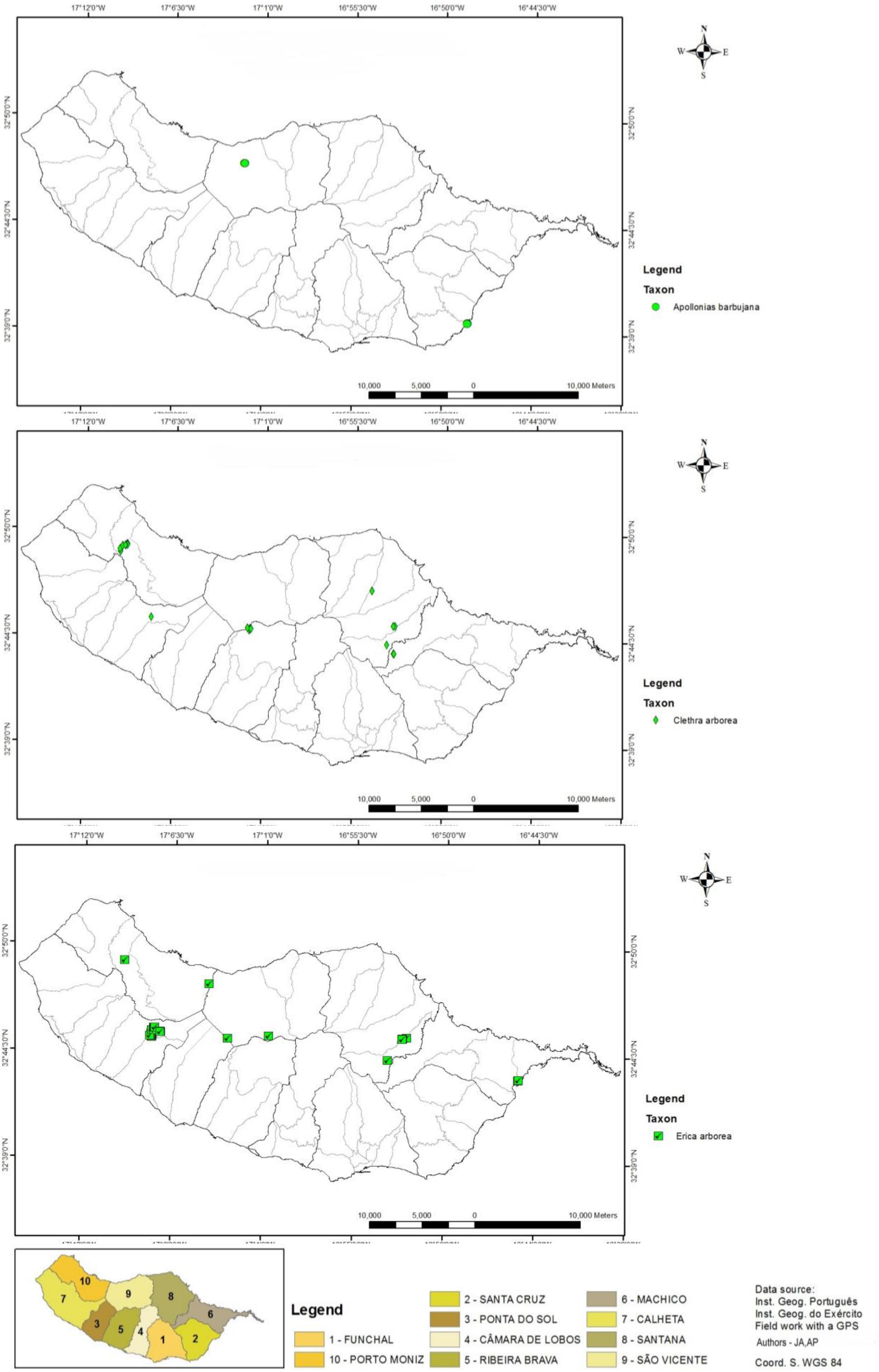

Figure 3.12 Distribution of species sampled (number of trees cored): *Apollonias barbujana* subsp. *barbujana* (20), *Clethra arborea* (53), *Erica arborea* (58).

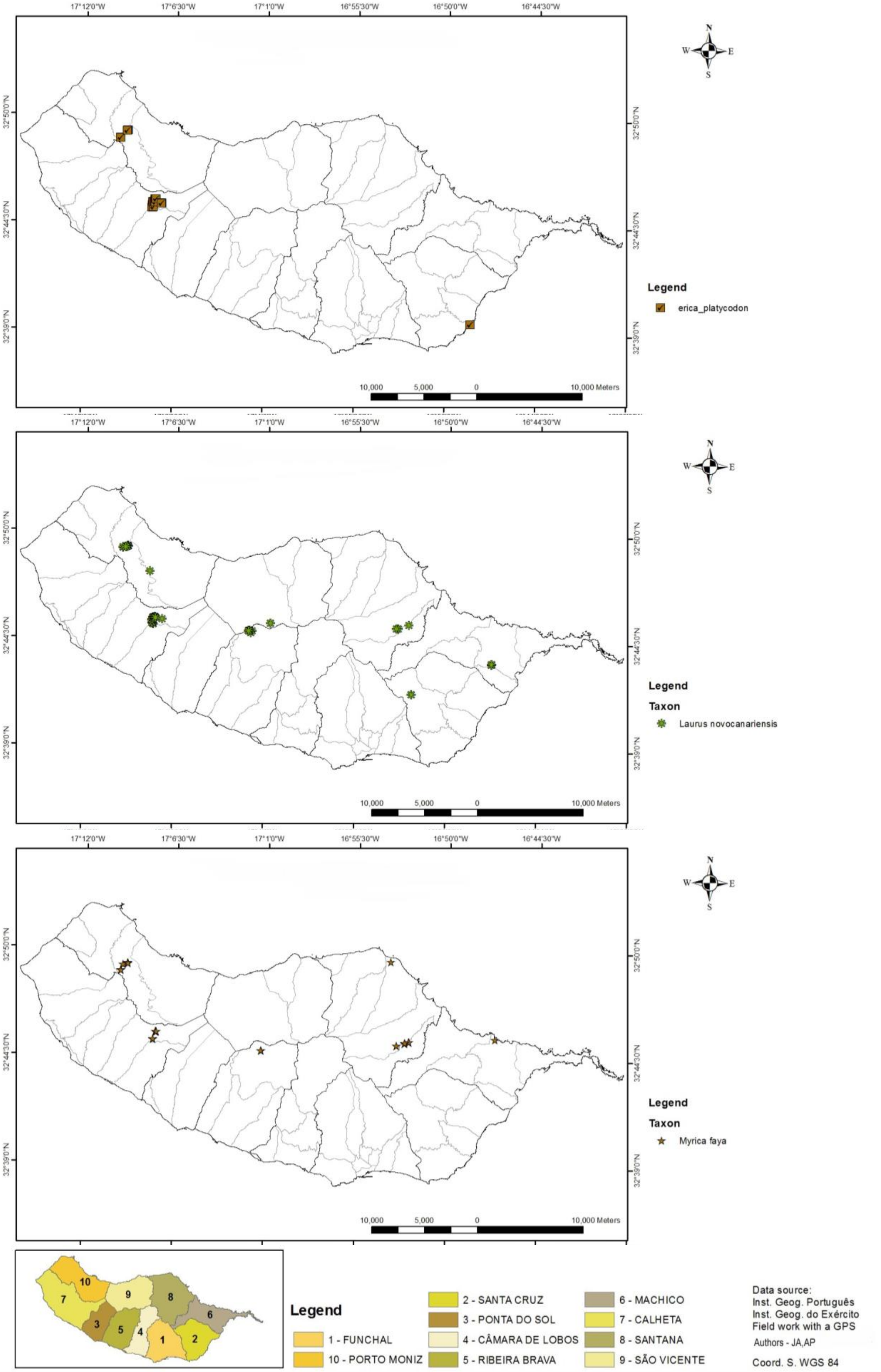

Figure 3.13 Distribution of species sampled (number of trees cored): *Erica platycodon* subsp. *maderincola* (123), *Laurus novocanariensis* (147) and *Myrica faya* (81).

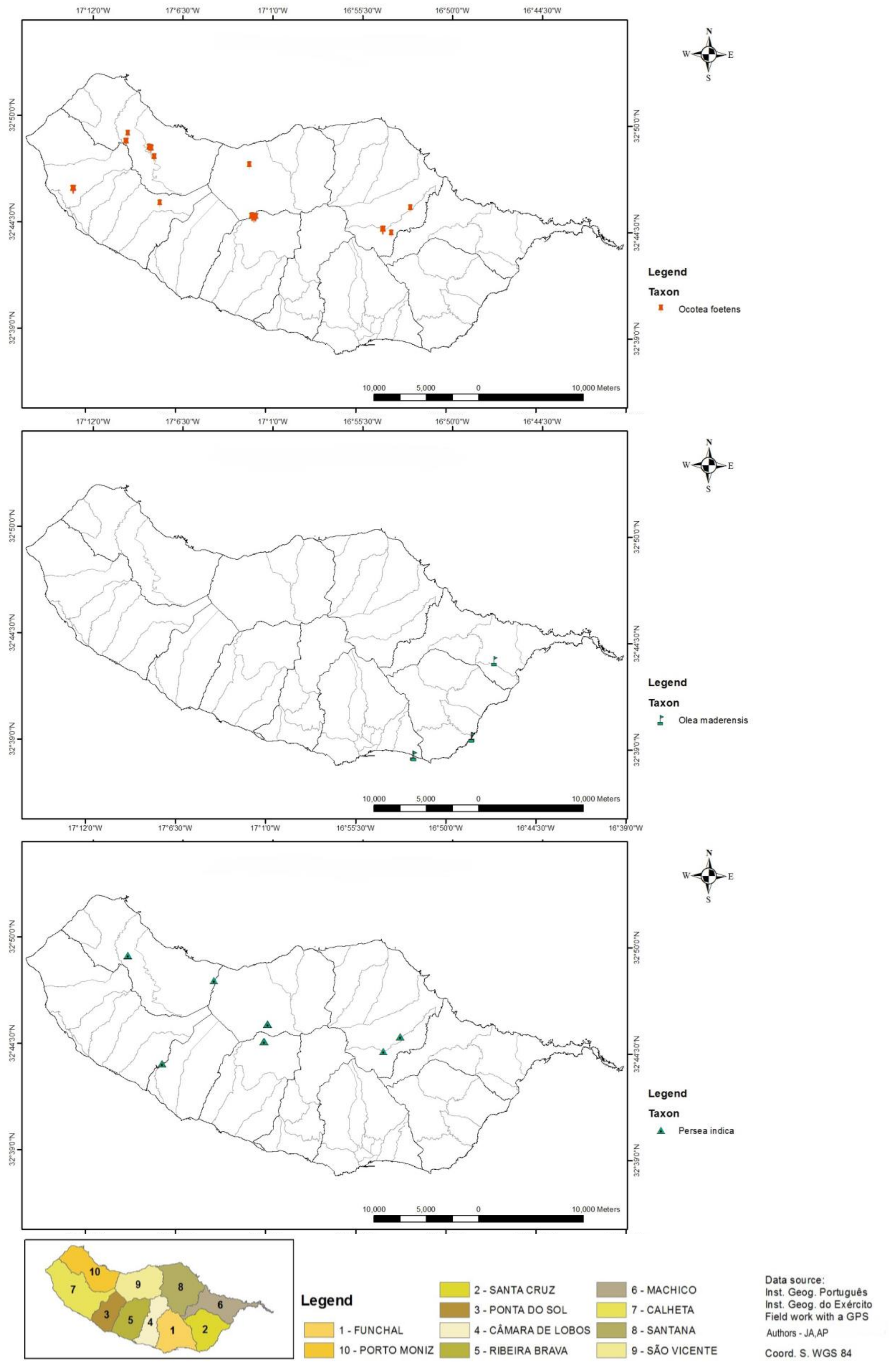

Figure 3.14 Distribution of species sampled (number of trees cored): *Ocotea foetens* (92), *Olea maderensis* (14), *Persea indica* (33).

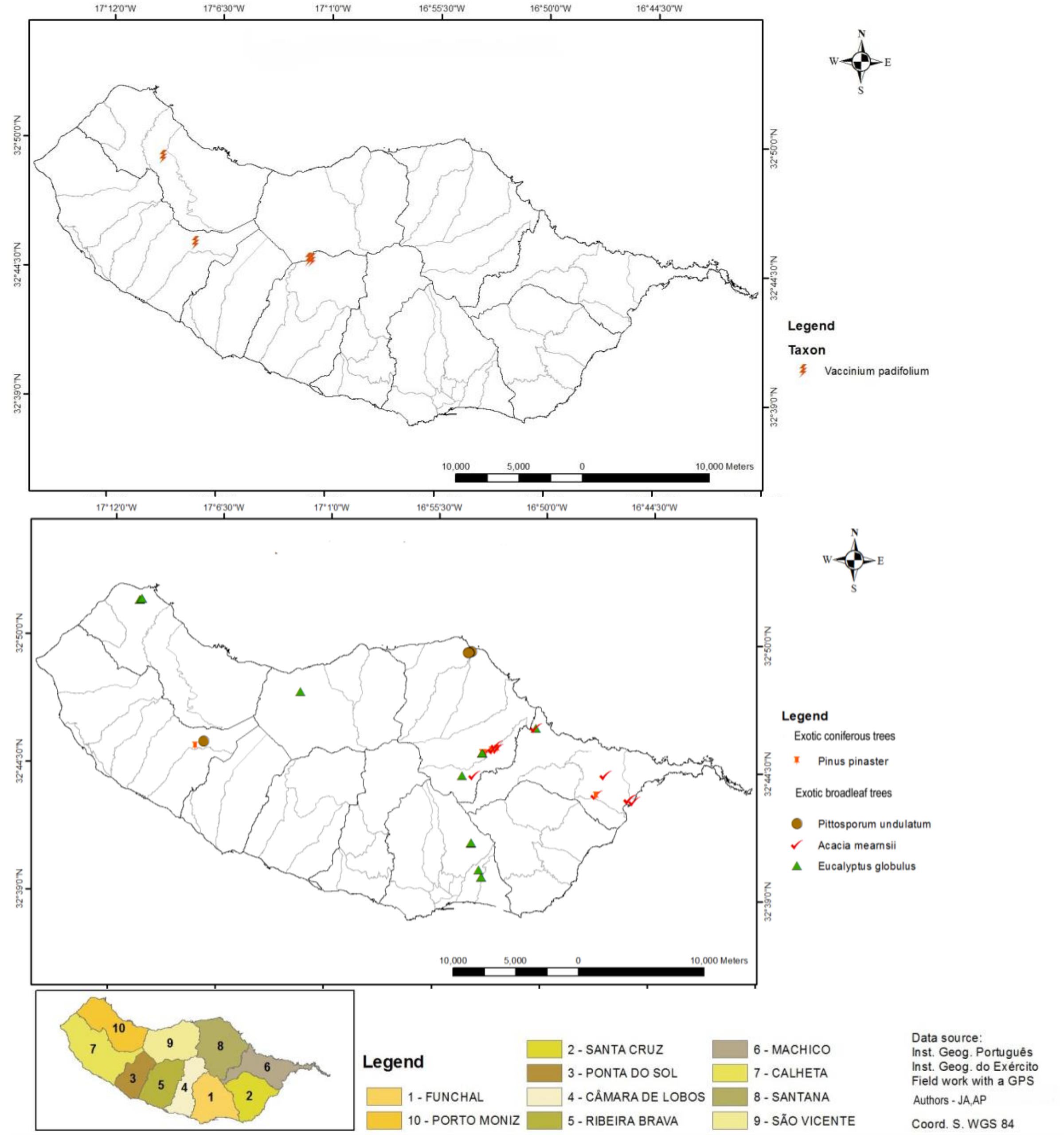

Figure 3.15 Distribution of species sampled (number of trees cored): *Vaccinium padifolium* (5); *Acacia mearnsii* (16), *Eucalyptus globulus* (6), *Pinus pinaster* (9), and *Pittosporum undulatum* (8).

3.3.4 Age of the trees across the study area

Age of trees across the photographed landscape was determined on the premise that every tree ring corresponds to a growth year i.e. it was assumed that native tree species, under study, were able to form annual increment rings. Native trees measured in woodlands seen in photographed landscapes (Table 3.2) ranged from 16 years (*Erica arborea*) to 119 years (*Erica platycodon* subsp. *maderincola),* both located in inland areas. Specimens that due to their age probably correspond to the same as those seen in historical landscape, were not found in coastal areas. In inland, species whose specimens may be the ones seen in old photographs belong to the first seral stage, like *E. platycodon* subsp *maderincola*, *E. arborea*, and *Myrica faya,* which becomes more abundant in a more mature phase of this successional stage, and also in young stink-laurel forest as *Laurus novocanariensis*. Individuals of trees that appear in later stages, like *Clethra arborea and Ocotea foetens*, exhibited ages well below. None of the exotic trees whose age was determined correspond to trees seen in historical landscape.

Table 3.2 Location and time intervals of photographs covering the area where samples were collected. Grey highlighted cells indicate trees that can correspond to the ones seen in historical landscape

Location	Time intervals- historical photos			*Taxon*	Terrain	Height	Age range	Trees
Pináculo, Funchal	]125-100]			*Olea maderensis*	hillside	273	49-61	2
Pico do Facho, Machico				*Erica arborea*	crest	365	31-35	2
Pico do Facho, Machico			]75-50]	*Acacia mearnsii*	hillside	159	39-42	2
Machico, head of the valley	]125-100]	]75-100]	]75-50]	*Acacia mearnsii*	hillside	224	32-35	2
Lombo Martel, Machico	]125-100]	]75-100]		*Laurus novocanariensis*	hillside	391	21-28	3
Lombo Martel, Machico	]125-100]	]75-100]		*Acacia mearnsii*	hillside	391	20	1
Lombo Martel, Machico	]125-100]	]75-100]		*Pinus pinaster*	hillside	391	59-62	3
Rabaçal, Ribeira da Janela	]125-100]			*Erica platycodon* subsp. *maderincola*	hillside	1056	45-52	5
Rabaçal, Ribeira da Janela	]125-100]			*Erica arborea*	hillside	1056	44-65	6
Rabaçal, Ribeira da Janela	]125-100]			*Laurus novocanariensis*	hillside	1056	38-41	7
Maiata, Porto da Cruz	]100-75]		]75-50]	*Myrica faya*	crest	379	28-38	2
Núcleo de barbusanos,São Vicente	]125-100]			*Apollonias barbujana* subsp. *barbujana*	foothill	78	19-47	7
Núcleo de barbusanos,São Vicente	]125-100]			*Ocotea foetens*	foothill	78	69	1
São Vicente, head of the valley	]125-100]			*Ocotea foetens*	hillside	865	51	1
São Vicente, head of the valley	]125-100]			*Laurus novocanariensis*	hillside	865	55	1
Porto Moniz			]75-50]	*Eucalyptus globulus*	crest	376	20-22	3
Cruzado, Cruzinhas do Faial	]125-100]		]75-50]	*Erica arborea*	crest	439	26-55	3
Cruzado, Cruzinhas do Faial	]125-100]		]75-50]	*Myrica faya*	crest	439	51-71	4
Cruzado, Cruzinhas do Faial	]125-100]		]75-50]	*Laurus novocanariensis*	crest	439	25	1
Cruzado, Cruzinhas do Faial	]125-100]		]75-50]	*Acacia mearnsii*	crest	439	22-25	3
Cruzado, Cruzinhas do Faial	]125-100]		]75-50]	*Pinus pinaster*	crest	439	67	1
Cruzinhas do Faial, hillock	]125-100]	]100-75]	]75-50]	*Myrica faya*	crest	430	74-80	2
Cruzinhas do Faial, hillock	]125-100]	]100-75]	]75-50]	*Erica arborea*	crest	430	23-47	6
Cruzinhas do Faial, hillock	]125-100]	]100-75]	]75-50]	*Pinus pinaster*	crest	430	47-52	2
Cruzinhas do Faial, Ribeira	]125-100]			*Laurus novocanariensis*	foothill	505	30	1
Cruzinhas do Faial, Ribeira	]125-100]			*Erica platycodon* subsp. *maderincola*	foothill	543	37	1
Cruzinhas do Faial, Ribeira	]125-100]			*Clethra arborea*	foothill	543	32	1
Cruzinhas do Faial, Ribeira	]125-100]			*Acacia mearnsii*	foothill	543	28-33	3
Ribeiro frio			]75-50]	*Ocotea foetens*	hillside	1000	76	1
Ribeiro frio			]75-50]	*Clethra arborea*	hillside	1000	30-32	2
Rabaçal, Ribeira da JanelaS1	]125-100]			*Laurus novocanariensis*	hillside	943	20-114	54
Rabaçal, Ribeira da JanelaS1	]125-100]			*Erica platycodon* subsp. *maderincola*	hillside	943	25-119	26
Rabaçal, Ribeira da JanelaS1	]125-100]			*Erica arborea*	hillside	955	64-103	6
Rabaçal, Ribeira da JanelaS1	]125-100]			*Ocotea foetens*	hillside	970	52	1
Rabaçal, Ribeira da JanelaS2	]125-100]			*Erica arborea*	hillside	850	35-63	6
Rabaçal, Ribeira da JanelaS2	]125-100]			*Myrica faya*	hillside	878	13-59	41
Rabaçal, Ribeira da JanelaS2	]125-100]			*Erica platycodon* subsp. *maderincola*	hillside	878	22-98	53
Rabaçal, Ribeira da JanelaS2	]125-100]			*Erica arborea*	hillside	878	16-111	23
São Jorge, stream mouth	]125-100]			*Myrica faya*	hillside	206	69	1
São Jorge, stream mouth	]125-100]			*Pittosporum undulatum*	hillside	206	21-46	8
Bica da Cana, Paul da Serra			]75-50]	*Erica arborea*	hillside	1555	43-62	2

3.3.5 Growth rates and age estimation of native trees

Approximately 600 samples of ten native woody *taxa* were aged, by ring counting, and measured (Table 3.3). Samples with very diffuse rings, hard damage, decayed portions and as well as very eccentric pith (more than 5 years estimated) were disposed, although their measurements (height and diameter) were considered for statistical treatment.

Table 3.3 Taxa of native phanerophyte that were aged and measured.

Taxon	Specimens aged	Specímens measured	Age range (years)	Height range (m)	Diameter range (cm)
Apollonias barbujana subsp. *barbujana*	14	20 (14 + 6)	15 - 47	2.5 - 14.9	2.6 - 33.5
Clethra arborea	53	53	18 - 63	1.8 - 17.0	3.7 - 42.2
Erica arborea	52	58 (52 + 6)	20 - 111	2.3 - 11.7	4 - 33.0
Erica platycodon subsp. *maderincola*	105	123 (105 +18)	22 - 93	3 - 10.7	4.2 - 53.8
Laurus novocanariensis	121	147 (121+ 26)	10 - 114	3 - 16.0	4.6 - 51.3 (0.50); 23.4-33.3 (1.30)
Myrica faya	69	81 (69 +12)	13 - 100	2.6 - 19.9	4 - 50.8
Ocotea foetens	64	92 (64+ 28)	15 - 142	2.5 - 41.3	2.5- 122.5 (0.50); 18.3 - 112.4 (1.30)
Olea maderensis	13	14 (13+1)	22 - 61	1.7 - 10.0	9.2 - 20.4
Persea indica	29	33 (29+4)	12 - 77	2.4 - 19.8	11.8- 88.0 (0.50); 1.7- 82.3 (1.30)
Vaccinium padifolium	5	5	25-40	3.9 – 4.8	3.5 – 8.6

As indicated in methods several mathematical models were analysed and for each specie it was selected the regression model to adjust the alometric equation (Table 3.4) that best estimates the age of the trees based on diameter, total tree height or a combination of the two biophysical variables.

Table 3.4 Equations to estimate age of the woody taxa in study (A=Age, H=Height, and D50=Diameter at 50 cm height).

Taxon	Eq_D50_A	R2adj	Eq_H_A	R2adj	Eq_D50_H_A	R2adj
Apollonias barbujana	$A = 0.0206\ D50^{2} + 0.3635\ D50 + 12.593$	0.7050	$A = 7.116\ H^{0,7063}$	0.4990	$A = 5.5568+0.6189*D\_50+1.6004*H$	0.6362
Clethra arborea	$A = 14.376*LN(D\_50)-2.3918$	0.7894	$A = 7.4612+2.3802*H+0.0076*H^{2}$	0.7449	$A = 12.68283+0.5582*D\_50+1.1348*H$	0.7064
Erica arborea	$A = 0.6085*D\_50^{1.5577}$	0.5979	$A = 9.4853*EXP(0.2574*H)$	0.4800	$A = 1.8345*D\_50+1.769484*H+0.0055*(D\_50^{2}*H)$	0.6360
Erica platycodon	$A = -0.0038*D\_50^{2}+1.6904*D\_50+22.845$	0.6616	$A = -0.1706*H^{2}+6.8575*H+7.4305$	0.2701	$A = 0.85438*D\_50+5.446121*H$	0.4441
Laurus novocanariensis	$A = 7.9263*D\_50^{0.6198}$	0.7198	$A = 2.8535*H^{1.2724}$	0.6987	$A =2.089462*D\_50+1.397429*H$	0.7821
Myrica faya	$A = 0.0037*D\_50^{2}+1.8258*D\_50+8.2891$	0.7290	$A = 0.307*H^{2}+0.6743*H+7.3465$	0.6780	$A = 6.0063+0.8397*D\_50+0.3992*H+0.0854*D\_50*H$	0.7370
Ocotea foetens	$A=0.0259*D\_50^{2}+1.0587*D\_50+19.85$	0.8907	$A=0.0204*H^{2}+2.5129*H+16.959$	0.6835	$A = 9.1227+2.0977*D\_50+0.6686*H$	0.8931
Olea madeirensis	$A =22.286*H^{0.3176}$	0.5389	$A = 10.448*EXP(0.0793*D\_50)$	0.2096	$A = 6.9071*(D50^{2}*H)^{0.2329}$	0.3323
Persea indica	$A = 0.0088\ D50^{2} – 0.0849\ D50+ 15.112$	0.3713	$A = 15.47\ Ln\ (H) + 6.4189$	0.4093	$A = 0.253904\ D\_50 + 1.992551\ H$	0.5404
Vaccinium padifolium	$A = 20.717ln(D\_50) - 0.2068$	0.8492	$A= 2.3427*EXP(0.6355*H)$	0.7930	$A =8.3529*(D\_50^{2}*H)^{0.2916}$	0.7330

Analysis of height-age correlation (Figure 3.16-a,b) showed that*:* (i) *Ocotea foetens* and *Persea indica*, have a similar growth rate (up to nine metres, ± 40 years), after which the rate of first one slows down, but whilst *P. indica* stops growing around 25 metres *O. foetens* grows up a height over forty metres (ii) *Laurus novocanariensis,* is the laurel tree with initial faster growing rate being surpassed by *Clethra arborea* (4m) and the other laurel trees [*A. barbujana* (5m), *O. foetens and P. indica* (8m)] (iii) *Clethra arborea* is the species showing highest growth rate between 6 and 16 metres, ± 40 years), being exceeded by species growing in the same bioclimate as *P. indica* and *O. foetens* which continued growing at regular rate; (iv) *Apolonias barbujana* has initialy lower growth rate than L. *novocanariensis,* but surpass it (around 5 metres height, ± 20 years), also growing faster than other two laurel trees (up to 16 metres, ± 40 years); (v) Myrica faya, has fast initial growth slowing down and being surpassed by *Apollonias barbujana* and *Clethra arborea* (5 metres, ± 20 years), and *Persea indica* and *Ocotea foetens* (10 metres, ± 35 years); (vi) *Vaccinium padifolium* is one of the first to reach 3 metres height, but after that has the lowest growing rate, being surpassed by all the other species; (vii) *Erica arborea* grows faster than *E. platycodon* subsp. *maderincola* up to 5 m, growing slower after reaching that height. Both are the ones with slower growing rate during their entire life.

Maximum height considered was based on Press & Short (1994) for *Apollonias barbujana, Laurus novocanariensis, Persea indica*, and *Vaccinium padifollium.* Maximum height of *Clethra arborea*, *Erica arborea*, *E. platycodon* subsp. *maderincola, Ocotea foetens*, *Myrica faya*, and *Olea maderensis* was based on measurement values obtained in present work, since they exceeded the referenced ones.

Analysis of Diameter (D50)-age correlation (Figure 3.16-c) showed that: (i) *Persea indica* is the species that grows faster in diameter over the entire life; (ii) *E. arborea* is the slowest growing taxa; (iii) For the majority of the taxa growing rate is initially faster, but later speeds down, as clearly seen in *E. arborea.*

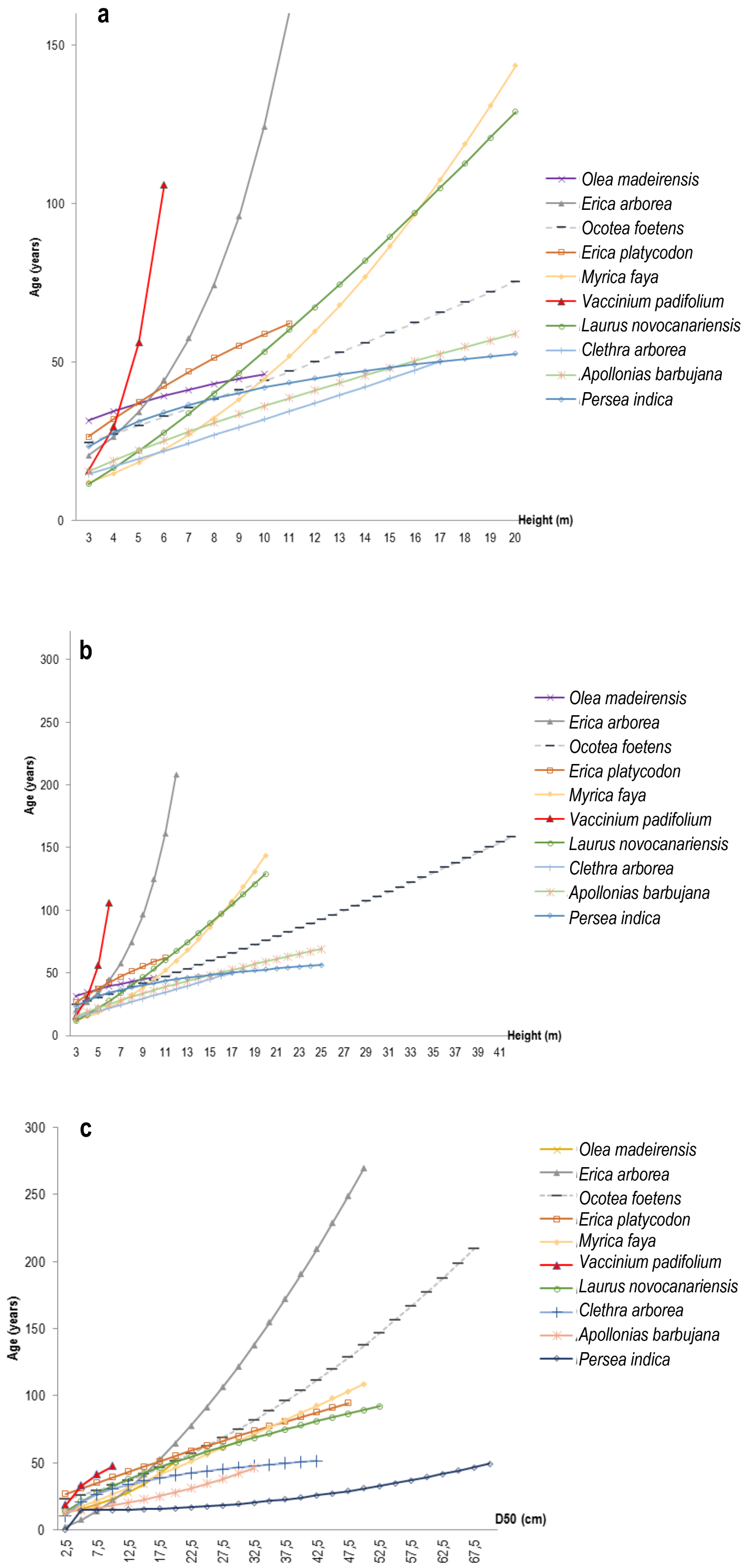

Figure 3.16 Age and growth rate estimation based on height for more common woody species of Madeiran forests up to 20 metres height (a) up to 41 metres height (b). Age and growth rate estimation based on diameter at 50 cm (c).

Combination of the two biophysical variable allowed to obtain better estimates of tree age, being selected the model with lowest RMSE. Age estimation by combination of diameter at 50 cm and total height for each *taxon* is shown in tables below (Tables 3.5-3.14): numbers in bold correspond to most likely values; cells grey highlighted correspond to age estimated using separately height and diameter. The age figures included in these tables diverge somewhat from the ones estimated using solely height and diameter as it was explained in methods. Charts for each species are shown in Appendix 1.

Apollonias barbujana subsp. *barbujana*

Table 3.5 Age estimation by combination of diameter at 50 cm and total height for *Apollonias barbujana* subsp. *barbujana*

	Height (m)	1	2	3	4	5	6	7	8	9	10	11	13	15	17	19	21	23	25
D_50 (cm)	Age (year)	7	12	15	19	22	25	28	31	34	36	39	44	48	53	57	61	65	69
1	13	**8**	**9**	**11**	13	14	16	17	19	21	22	24	27	30	33	37	40	43	46
3	14	**9**	**10**	**12**	**14**	15	17	18	20	22	23	25	28	31	34	38	41	44	47
5	15	**10**	**12**	**13**	**15**	**17**	18	20	21	23	25	26	29	33	36	39	42	45	49
8	16	**12**	**13**	**15**	**17**	**18**	**20**	**21**	23	25	26	28	31	34	37	41	44	47	50
10	18	13	**15**	**17**	**18**	**20**	**21**	**23**	25	26	28	29	33	36	39	42	45	49	52
13	20	15	**16**	**18**	**20**	**21**	**23**	**24**	**26**	**28**	29	31	34	37	41	44	47	50	53
15	23	16	18	**20**	**21**	**23**	**24**	**26**	**28**	**29**	**31**	**32**	**36**	39	42	45	48	52	55
18	25	18	20	**21**	**23**	**24**	**26**	**28**	**29**	**31**	**32**	**34**	**37**	**40**	**44**	**47**	50	53	56
20	28	20	21	23	**24**	**26**	**28**	**29**	**31**	**32**	**34**	**36**	**39**	**42**	**45**	**48**	52	55	58
23	31	21	23	24	**26**	**27**	**29**	**31**	**32**	**34**	**35**	**37**	**40**	**43**	**47**	**50**	**53**	56	59
25	35	23	24	26	27	29	**31**	**32**	**34**	**35**	**37**	**39**	**42**	**45**	**48**	**51**	**55**	58	61
28	38	24	26	27	29	31	32	34	35	37	**39**	**40**	**43**	**47**	**50**	**53**	**56**	**59**	**63**
30	42	26	27	29	31	32	34	35	37	39	40	42	45	**48**	**51**	**55**	**58**	**61**	**64**
33	46	27	29	30	32	34	35	37	38	40	42	43	46	**50**	**53**	**56**	**59**	**62**	**66**
35	51	29	30	32	34	35	37	38	40	42	43	45	48	51	54	**58**	**61**	**64**	**67**
38	55	30	32	34	35	37	38	40	42	43	45	46	50	53	56	59	**62**	**66**	**69**

Clethra arborea

Table 3.6 Age estimation by combination of diameter at 50 cm and total height for *Clethra arborea*

	Height (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
D_50 (cm)	Age (year)	10	12	15	17	20	22	24	27	29	32	35	37	40	42	45	47	50
2	3	**15**	**16**	**17**	18	19	20	21	23	24	25	26	27	28	29	31	32	33
3	11	**15**	**16**	**17**	**19**	20	21	22	23	24	25	27	28	29	30	31	32	33
5	21	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**25**	26	27	28	29	30	31	32	34	35
8	27	18	**19**	**20**	**21**	**23**	**24**	**25**	**26**	**27**	28	29	30	32	33	34	35	36
10	31	19	21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**30**	31	32	33	34	35	36	38
13	34	21	22	23	**24**	**25**	**26**	**28**	**29**	**30**	**31**	32	33	34	36	37	38	39
15	37	22	23	24	26	**27**	**28**	**29**	**30**	**31**	**32**	**34**	35	36	37	38	39	40
18	39	24	25	26	27	28	**29**	**30**	**32**	**33**	**34**	**35**	**36**	37	38	39	41	42
20	41	25	26	27	28	30	31	**32**	**33**	**34**	**35**	**36**	**37**	**39**	40	41	42	43
23	42	26	28	29	30	31	32	33	**34**	**35**	**37**	**38**	**39**	**40**	**41**	42	43	45
25	44	28	29	30	31	32	33	35	36	**37**	**38**	**39**	**40**	**41**	**43**	**44**	45	46
28	45	29	30	31	33	34	35	36	37	38	**39**	**41**	**42**	**43**	**44**	**45**	**46**	47
30	47	31	32	33	34	35	36	37	39	40	41	**42**	**43**	**44**	**45**	**46**	**48**	**49**
33	48	32	33	34	35	37	38	39	40	41	42	43	**44**	**46**	**47**	**48**	**49**	**50**
35	49	33	34	36	37	38	39	40	41	42	44	45	46	**47**	**48**	**49**	**50**	**52**
38	50	35	36	37	38	39	40	42	43	44	45	46	47	48	**50**	**51**	**52**	**53**
40	51	36	37	38	40	41	42	43	44	45	46	47	49	50	51	**52**	**53**	**54**
43	52	38	39	40	41	42	43	44	45	47	48	49	50	51	52	**53**	**55**	**56**

Erica arborea

Table 3.7 Age estimation by combination of diameter at 50 cm and total height for *Erica arborea*

	Height (m)	1	2	3	4	5	6	7	8	9	10
D_50 (cm)	Age (year)	12	16	21	27	34	44	57	74	96	124
3	3	**6**	**8**	**10**	12	14	15	17	19	21	23
5	7	**11**	**13**	**15**	**17**	19	21	23	24	26	28
8	14	**16**	**18**	**20**	**22**	**24**	26	28	30	33	35
10	22	21	**23**	**25**	**28**	**30**	**32**	**35**	37	39	42
13	31	26	28	**31**	**33**	**36**	**39**	**41**	44	47	49
15	41	31	34	37	**40**	**43**	**46**	**49**	**52**	55	58
18	53	36	39	43	46	**49**	**53**	**56**	**60**	**63**	67
20	65	41	45	49	53	57	**61**	**65**	**69**	**73**	**77**
23	78	46	50	55	60	64	69	**73**	**78**	**83**	**87**
25	92	51	56	62	67	72	77	83	**88**	**93**	**98**
28	106	56	62	68	74	80	86	92	**98**	**104**	**110**
30	122	62	69	75	82	89	96	103	**109**	**116**	**123**
33	138	67	75	83	90	98	106	113	**121**	**128**	**136**
35	155	73	81	90	99	107	116	124	**133**	**142**	**150**
38	172	78	88	98	107	117	126	136	**146**	**155**	**165**

Erica platycodon subsp. *maderincola*

Table 3.8 Age estimation by combination of diameter at 50 cm and total height for *Erica platycodon* subsp. *maderincola*

	Height (m)	1	2	3	4	5	6	7	8	9	10	11	12
D_50 (cm)	Age (year)	14	20	26	32	37	42	47	51	55	59	62	65
2,5	27	**8**	**13**	**18**	**24**	29	35	40	46	51	57	62	67
5,0	31	**10**	**15**	**21**	**26**	**32**	37	42	48	53	59	64	70
7,5	35	**12**	**17**	**23**	**28**	**34**	39	45	50	55	61	66	72
10,0	39	**14**	**19**	**25**	**30**	**36**	**41**	47	52	58	63	68	74
12,5	43	**16**	**22**	**27**	**32**	**38**	**43**	49	54	60	65	71	76
15,0	47	**18**	**24**	**29**	**35**	**40**	**45**	**51**	56	62	67	73	78
17,5	51	20	**26**	**31**	**37**	**42**	**48**	**53**	59	64	69	75	80
20,0	55	23	28	**33**	**39**	**44**	**50**	**55**	61	66	72	77	82
22,5	59	25	30	36	**41**	**46**	**52**	**57**	**63**	68	74	79	85
25,0	63	27	32	38	**43**	**49**	**54**	**59**	**65**	70	76	81	87
27,5	66	29	34	40	45	**51**	**56**	**62**	**67**	73	78	83	89
30,0	70	31	37	42	47	**53**	**58**	**64**	**69**	75	80	86	91
32,5	74	33	39	44	50	**55**	**60**	**66**	**71**	**77**	82	88	93
35,0	77	35	41	46	52	57	**63**	**68**	**73**	**79**	84	90	95
37,5	81	37	43	48	54	59	**65**	**70**	**76**	**81**	87	92	97
40,0	84	40	45	51	56	61	**67**	**72**	**78**	**83**	89	94	100
42,5	88	42	47	53	58	64	**69**	**74**	**80**	**85**	**91**	96	102
45,0	91	44	49	55	60	66	71	**77**	**82**	**87**	**93**	98	104
47,5	95	46	51	57	62	68	73	**79**	**84**	**90**	**95**	**100**	106
50,0	98	48	54	59	65	70	75	81	**86**	**92**	**97**	**103**	108
52,5	101	50	56	61	67	72	78	83	88	**94**	**99**	**105**	**110**
55,0	104	52	58	63	69	74	80	85	91	**96**	**101**	**107**	**112**

Laurus novocanariensis

Table 3.9 Age estimation by combination of diameter at 50 cm and total height for *Laurus novocanariensi*s

	Height (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
D_50(cm)	Age (year)	3	7	12	17	22	28	34	40	47	53	60	67	75	82	90	97	105	113	121	129
0,5	5	**2**	**4**	**5**	**7**	8	9	11	12	14	15	16	18	19	21	22	23	25	26	28	29
2,5	14	**7**	**8**	**9**	**11**	12	14	15	16	18	19	21	22	23	25	26	28	29	30	32	33
5,0	21	**12**	**13**	**15**	**16**	**17**	**19**	20	22	23	24	26	27	29	30	31	33	34	36	37	38
7,5	28	17	18	**20**	**21**	**23**	**24**	25	27	28	30	31	32	34	35	37	38	39	41	42	44
10,0	33	22	24	**25**	**26**	**28**	**29**	**31**	**32**	33	35	36	38	39	40	42	43	45	46	47	49
12,5	38	28	29	30	32	**33**	**35**	**36**	**37**	39	40	41	43	44	46	47	48	50	51	53	54
15,0	42	33	34	36	37	**38**	**40**	**41**	**43**	**44**	**45**	47	48	50	51	52	54	55	56	58	59
17,5	47	38	39	41	42	44	45	**46**	**48**	**49**	**51**	52	53	55	56	58	59	60	62	63	65
20,0	51	43	45	46	47	49	50	**52**	**53**	**54**	**56**	**57**	**59**	60	61	63	64	66	67	68	70
22,5	55	48	50	51	53	54	55	57	58	**60**	**61**	**62**	**64**	65	67	68	69	71	72	74	75
25,0	58	54	55	56	58	59	61	62	63	**65**	**66**	**68**	**69**	**70**	**72**	73	75	76	77	79	80
27,5	62	59	60	62	63	64	66	67	69	70	71	**73**	**74**	**76**	**77**	**78**	80	81	83	84	85
30,0	65	64	65	67	68	70	71	72	74	75	77	**78**	**79**	**81**	**82**	**84**	**85**	86	88	89	91
32,5	69	69	71	72	73	75	76	78	79	80	82	83	**85**	**86**	**87**	**89**	**90**	92	93	94	96
35,0	72	75	76	77	79	80	82	83	84	86	87	89	**90**	**91**	**93**	**94**	**95**	**97**	98	100	101
37,5	75	80	81	83	84	85	87	88	90	91	92	94	95	97	**98**	**99**	**101**	**102**	104	105	106
40,0	78	85	86	88	89	91	92	93	95	96	98	99	100	102	103	105	**106**	**107**	**109**	**110**	112
42,5	81	90	92	93	94	96	97	99	100	101	103	104	106	107	108	110	111	113	**114**	**115**	117
45,0	84	95	97	98	100	101	102	104	105	107	108	109	111	112	114	115	116	118	119	**121**	**122**
47,5	87	101	102	103	105	106	108	109	110	112	113	115	116	117	119	120	122	123	124	**126**	**127**
50,0	90	106	107	109	110	111	113	114	116	117	118	120	121	123	124	125	127	128	130	**131**	**132**

Myrica faya

Table 3.10 Age estimation by combination of diameter at 50 cm and total height for *Myrica faya*

	Height (m)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
D_50 (cm)	Age (year)	10	12	15	18	22	27	32	38	45	52	60	68	77	87	97	108	119	131	144
2,5	13	**9**	**10**	**11**	11	12	12	13	14	14	15	15	16	17	17	18	19	19	20	20
5,0	18	**12**	**13**	**14**	**14**	15	16	17	18	18	19	20	21	22	23	23	24	25	26	27
7,5	22	14	**15**	**16**	**18**	**19**	20	21	22	23	24	25	26	27	28	29	30	31	32	33
10,0	27	17	18	**19**	**21**	**22**	**23**	24	26	27	28	29	31	32	33	34	36	37	38	39
12,5	32	19	21	22	**24**	**25**	**27**	**28**	30	31	33	34	36	37	39	40	41	43	44	46
15,0	37	22	24	25	27	**29**	**30**	**32**	**34**	35	37	39	40	42	44	45	47	49	51	52
17,5	41	24	26	28	30	32	**34**	**36**	**38**	**40**	42	43	45	47	49	51	53	55	57	59
20,0	46	27	29	31	33	35	38	**40**	**42**	**44**	**46**	48	50	52	54	57	59	61	63	65
22,5	51	30	32	34	37	39	41	43	**46**	**48**	**50**	**53**	55	57	60	62	64	67	69	71
25,0	56	32	35	37	40	42	45	47	50	**52**	**55**	**57**	**60**	62	65	68	70	73	75	78
27,5	61	35	37	40	43	46	48	51	54	57	**59**	**62**	**65**	**68**	70	73	76	79	81	84
30,0	66	37	40	43	46	49	52	55	58	61	64	**67**	**70**	**73**	**76**	79	82	85	87	90
32,5	72	40	43	46	49	52	56	59	62	65	68	71	**75**	**78**	**81**	**84**	87	90	94	97
35,0	77	42	46	49	52	56	59	63	66	69	73	76	79	**83**	**86**	**90**	**93**	96	100	103
37,5	82	45	48	52	56	59	63	66	70	74	77	81	84	88	**92**	**95**	**99**	**102**	106	110
40,0	87	47	51	55	59	62	66	70	74	78	82	85	89	93	97	**101**	**104**	**108**	**112**	116
42,5	93	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	**110**	**114**	**118**	**122**
45,0	98	52	57	61	65	69	73	78	82	86	90	95	99	103	107	112	116	**120**	**124**	**129**
47,5	103	55	59	64	68	73	77	82	86	90	95	99	104	108	113	117	122	126	**131**	**135**
50,0	109	57	62	67	71	76	81	85	90	95	99	104	109	113	118	123	127	132	137	**141**

Ocotea foetens

Table 3.11 Age estimation by combination of diameter at 50 cm and total height for *Ocotea foetens*

	Height (m)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
D_50 (cm)	Age (year)	22	27	33	38	44	50	56	62	69	75	82	89	96	103	111	118	126	134	142	150	158
1	21	**13**	**14**	**15**	**17**	**18**	19	21	22	23	25	26	27	29	30	31	33	34	35	37	38	39
2,5	23	**16**	**17**	**18**	**20**	**21**	22	24	25	26	28	29	30	32	33	34	36	37	38	40	41	42
5,0	26	**21**	**22**	**24**	**25**	**26**	**28**	29	30	32	33	34	36	37	38	40	41	42	44	45	46	48
7,5	29	**26**	**28**	**29**	**30**	**32**	**33**	**34**	36	37	38	40	41	42	44	45	46	48	49	50	52	53
10,0	33	**31**	**33**	**34**	**35**	**37**	**38**	**39**	**41**	42	43	45	46	47	49	50	51	53	54	56	57	58
12,5	37	37	**38**	**39**	**41**	**42**	**43**	**45**	**46**	**47**	49	50	51	53	54	55	57	58	59	61	62	63
15,0	42	42	43	**45**	**46**	**47**	**49**	**50**	**51**	**53**	**54**	55	57	58	59	61	62	63	65	66	67	69
17,5	46	47	49	50	**51**	**53**	**54**	**55**	**57**	**58**	**59**	**61**	62	63	65	66	67	69	70	71	73	74
20,0	51	52	54	55	56	**58**	**59**	**60**	**62**	**63**	**64**	**66**	**67**	68	70	71	72	74	75	76	78	79
22,5	57	58	59	60	62	63	**64**	**66**	**67**	**68**	**70**	**71**	**72**	74	75	76	78	79	80	82	83	84
25,0	63	63	64	66	67	68	70	**71**	**72**	**74**	**75**	**76**	**78**	**79**	80	82	83	84	86	87	88	90
27,5	69	68	69	71	72	73	75	76	**78**	**79**	**80**	**82**	**83**	**84**	86	87	88	90	91	92	94	95
30,0	75	73	75	76	77	79	80	81	**83**	**84**	**85**	**87**	**88**	**89**	**91**	92	93	95	96	97	99	100
32,5	82	79	80	81	83	84	85	87	88	89	**91**	**92**	**93**	**95**	**96**	97	99	100	101	103	104	105
35,0	89	84	85	87	88	89	91	92	93	95	**96**	**97**	**99**	**100**	**101**	103	104	105	107	108	109	111
37,5	96	89	90	92	93	94	96	97	98	100	101	**102**	**104**	**105**	**107**	**108**	**109**	111	112	113	115	116
40,0	104	94	96	97	98	100	101	102	104	105	106	**108**	**109**	**110**	**112**	**113**	**114**	116	117	118	120	121
42,5	112	100	101	102	104	105	106	108	109	110	112	**113**	**114**	**116**	**117**	**118**	**120**	**121**	**122**	124	125	126
45,0	120	105	106	108	109	110	112	113	114	116	117	118	**120**	**121**	**122**	**124**	**125**	**126**	**128**	129	130	132
47,5	129	110	111	113	114	115	117	118	119	121	122	123	**125**	**126**	**127**	**129**	**130**	**131**	**133**	**134**	**136**	137
50,0	138	115	117	118	119	121	122	123	125	126	127	129	**130**	**131**	**133**	**134**	**135**	**137**	**138**	**139**	**141**	142
55,0	156	126	127	129	130	131	133	134	135	137	138	139	**141**	**142**	**143**	**145**	**146**	**147**	**149**	**150**	**151**	153
60,0	177	136	138	139	140	142	143	144	146	147	148	150	151	152	**154**	**155**	**156**	**158**	**159**	**160**	**162**	**163**
65,0	198	147	148	149	151	152	153	155	156	158	159	160	162	163	**164**	**166**	**167**	**168**	**170**	**171**	**172**	**174**
70,0	221	157	159	160	161	163	164	165	167	168	169	171	172	173	**175**	**176**	**177**	**179**	**180**	**181**	**183**	**184**
75,0	245	168	169	170	172	173	174	176	177	178	180	181	182	184	**185**	**187**	**188**	**189**	**191**	**192**	**193**	**195**
80,0	270	178	180	181	182	184	185	186	188	189	190	192	193	194	196	**197**	**198**	**200**	**201**	**202**	**204**	**205**
85,0	297	189	190	191	193	194	195	197	198	199	201	202	203	205	206	**207**	**209**	**210**	**211**	**213**	**214**	**216**
90,0	325	199	201	202	203	205	206	207	209	210	211	213	214	215	217	**218**	**219**	**221**	**222**	**223**	**225**	**226**
95,0	354	210	211	212	214	215	216	218	219	220	222	223	224	226	227	228	230	**231**	**232**	**234**	**235**	**236**
100,0	385	220	222	223	224	226	227	228	230	231	232	234	235	236	238	239	240	**242**	**243**	**244**	**246**	**247**
105,0	417	231	232	233	235	236	237	239	240	241	243	244	245	247	248	249	251	**252**	**253**	**255**	**256**	**257**
110,0	450	241	243	244	245	247	248	249	251	252	253	255	256	257	259	260	261	**263**	**264**	**265**	**267**	**268**

Olea maderensis

Table 3.12 Age estimation by combination of diameter at 50 cm and total height for *Olea maderensis*

	Height (m)	1	2	3	4	5	6	7	8	9	10
D_50 (cm)	Age (year)	22	28	32	35	37	39	41	43	45	46
2,5	13	**11**	**12**	**14**	15	15	16	17	17	18	18
5,0	16	**15**	**17**	**19**	**20**	**21**	22	23	24	24	25
7,5	19	**18**	**21**	**23**	**24**	**26**	**27**	28	29	29	30
10,0	23	20	**24**	**26**	**28**	**29**	**31**	**32**	**33**	34	35
12,5	28	22	**26**	**29**	**31**	**33**	**34**	**35**	**36**	37	38
15,0	34	24	29	**31**	**34**	**35**	**37**	**38**	**40**	**41**	**42**
17,5	42	26	31	**34**	**36**	**38**	**40**	**41**	**43**	**44**	**45**
20,0	51	28	33	36	39	**41**	**42**	**44**	**45**	**47**	**48**
22,5	62	29	35	38	41	**43**	**45**	**46**	**48**	**49**	**50**
25,0	76	31	36	40	43	45	47	**49**	**50**	**52**	**53**

Persea indica

Table 3.13 Age estimation by combination of diameter at 50 cm and total height for *Persea indica*

	Height (m)	2	4	6	8	10	12	14	16	18	20	22
D_50 (cm)	Age (year)	17	28	34	39	42	45	47	49	51	53	54
2,5	15	**5**	**9**	13	17	21	25	29	33	37	40	44
5,0	15	**5**	**9**	13	17	21	25	29	33	37	41	45
7,5	15	6	**10**	**14**	18	22	26	30	34	38	42	46
10,0	15	7	**11**	**14**	18	22	26	30	34	38	42	46
12,5	15	7	**11**	**15**	19	23	27	31	35	39	43	47
15,0	16	8	12	**16**	**20**	24	28	32	36	40	44	48
17,5	16	8	12	**16**	**20**	24	28	32	36	40	44	48
20,0	17	9	13	**17**	**21**	**25**	29	33	37	41	45	49
22,5	18	10	14	**18**	**22**	**26**	30	34	38	42	46	50
25,0	18	10	14	**18**	**22**	**26**	30	34	38	42	46	50
27,5	19	11	15	19	**23**	**27**	**31**	35	39	43	47	51
30,0	20	12	16	20	**24**	**28**	**32**	36	39	43	47	51
32,5	22	12	16	20	**24**	**28**	**32**	36	40	44	48	52
35,0	23	13	17	21	**25**	**29**	**33**	**37**	41	45	49	53
37,5	24	14	17	21	25	**29**	**33**	**37**	41	45	49	53
40,0	26	14	18	22	26	**30**	**34**	**38**	42	46	50	54
42,5	27	15	19	23	27	**31**	**35**	**39**	**43**	47	51	55
45,0	29	15	19	23	27	**31**	**35**	**39**	**43**	47	51	55
47,5	31	16	20	24	28	32	**36**	**40**	**44**	48	52	56
50,0	33	17	21	25	29	33	**37**	**41**	**45**	49	53	57
55,0	37	18	22	26	30	34	**38**	**42**	**46**	**50**	54	58
60,0	42	19	23	27	31	35	**39**	**43**	**47**	**51**	55	59
65,0	47	20	24	28	32	36	40	**44**	**48**	**52**	56	60
70,0	52	22	26	30	34	38	42	**46**	**50**	**54**	58	62
75,0	58	23	27	31	35	39	43	47	**51**	**55**	**59**	**63**
80,0	65	24	28	32	36	40	44	48	52	**56**	**60**	**64**
85,0	71	26	30	34	38	42	45	49	53	**57**	**61**	**65**

Vaccinium padifollium

Table 3.14 Age estimation by combination of diameter at 50 cm and total height for *Vaccinium padifolium*

	Height (m)	1	2	3	4	5
D_50 (cm)	Age (year)	4	8	16	30	56
1,1	2	**9**	**11**	12	13	14
2,5	19	**14**	**17**	**20**	21	23
5	33	21	**26**	**29**	**32**	34
7,5	42	27	33	**37**	**41**	**43**
10	47	32	39	44	**48**	**51**

3.4 Discussion

The dendrochronological suitability of a species depends on having clearly defined growth rings with annual regularity or at least reliable cyclic increment (Speer *et al.* 2004; Tomazello-Filho *et al.* 2004). In temperate zones the seasonality of climate regulates tree growth cycles. During the active period, between spring and autumn, the vascular cambium connecting the secondary xylem (wood) and the secondary phloem (inner bark) produces additional xylem and phloem. Because cell slows down its activity the lumen becomes smaller than the one produced during spring and summer time, until it stops during the dormancy period. Thus, one distinct increment ring is formed each year allowing the age assessment and establishment of chronologies (Schweingruber 2007; Stoffel & Bollschweiler 2008).

As previously referred there was the idea that tree age determination by means of rings-counting in *Lauraceae* family could not be possible since it was often believed that these trees do not produce distinctive annual rings (Arévalo & Fernández-Palacios 2000). The explanation can be related to the fact that being evergreen plants they do not have a clear dormancy period as deciduous trees, and being considered a relic of the Palaeotropical geoflora (Axelrod 1975; Mai 1989; Capelo *et al.* 2004; Fernández-Palacios 2009; Barrón *et al.* 2010) their dendrochronological potential could have been neglected as has happened with tropical and subtropical trees largely avoided in dendrochrononogical studies (Villalba *et al.* 1985; Worbes *et al.* 2003; Speer *et al.* 2004) given the difficulty on ring analysis (Tomazello-Filho *et al.* 2004; Speer 2010). However the research which has been carried out in last decades (Ogden 1981; Grau *et al.* 2003; Worbes *et al.* 2003; Martinelli 2004; Speer *et al.* 2004; Coelho 2011) have shown that even in tropical forests, where many trees do not have discernible growth rings due to a continuous growing process or form rings that do not have periodicity, in areas where the regional climate regime shows seasonality same trees are able to form annual increment rings. Furthermore climate seasonality is not the only cause of periodic cambial stop. It can occur for other reasons as leaf flushing or fruit production (Ogden 1981). The recent interest in tropical dendrochronology can contribute with methodologies to study and understand the cambial activity that occurs in response to the variability of the Mediterranean climate and in the transition zones to temperate and tropical climates, whose boundaries are indistinct and can vary from year to year (Cherubini *et al.* 2003).

In addition to above mentioned difficulties, another point normally hampers the use of hardwood species for dendrochronological research. Generally hardwood species have not ring boundaries as clear as softwoods, due to smaller size xylem cells resulting in little difference between earlywood and latewood. In addition, hardwoods frequently have even-sized and randomly distributed vessels which do not form easily recognisable bands. However, in the woody species belonging to Madeiran native flora, which were analysed, the rings are satisfactorily distinct. Among the four laurel species the differences in colour and size of the wood formed early in a year (broad and light coloured) and the wood subsequently produced (generally narrow and dark coloured) makes possible to distinguish rings which are often visible to the naked eye. The zonation is accentuated by the abrupt contrast that delineate the rings which, according to anatomical studies (Léon 2002; Morales *et al.* 2002; Loutfy 2009; Schweingruber *et al.* 2011), is expressed by radial flat latewood fibers. Because these species have diffuse-porous woods, with the exception of *Apollonias barbujana* that occasionally show rings defined by uneven porosity, this appearance is the only way to distinguish individual rings. Some discrepancies were found between observations and the features described in the bibliography reviewed which can be justified by the fact that the specimens used in those studies were from Canary archipelago, and not from Madeira Island. One of those differences refers to *Persea indica* which has shown clear growth rings, also sustained by Loutfy (2009) and Léon (2002), but that was considered by Schweingruber *et al.* (2011) as not having distinct growth rings. Another difference was related to the fact that *Apollonias barbujana* is classified in those studies as diffuse to slightly semi-ring porous wood. This intermediate state is characterised, in bibliography, by the presence of bigger and more concentrated pores at the beginning of each ring (Speer 2010), that is quite the opposite to the distribution observed (Figure 3.5-Ab2) in which pores are slightly more concentrated in narrow and darker portion of the ring that precedes the sharp transition to next ring.

Regarding the other species which equally are diffuse-porous woods (*Clethra arborea, Olea maderensis* and *Myrica faya*) it is also the discrete seasonal pattern created by conspicuous contrast between earlywood and latewood that allows ring identification. However, contrary to *C. arborea,* which invariably shows a marked boundary, in *O. maderensis* and *M. faya* the transition is not always sharply defined being often quite fuzzy. Until now, no anatomical studies of the xylem of *C. arborea* and *O. maderensis* were undertaken, and thus is not known whether this delineation is made by radial compressed fibers, as it happens in laurel species, or by bands of marginal parenchyma that is the other anatomical feature by which annual growth rings are outlined (Lopez *et al.* 2012). In relation to *M. faya*, this species was included in the anatomical study on Myricacea family performed by Carlquist (2002). In this study it was verified that most of species within this family show more or less perceptible rings, due to radially narrowed tracheids, except for some species including *M. faya.* Despite not being always possible to clearly distinguish individual rings (Figure 3.8-Mf2), or to figure out if they are false rings, it is as a matter of fact that rings exist. In fact, in the majority of the samples observed the rings are actually clear enough to be counted (Figure 3.5 and Figure 3.7), contrarily to *M. faya* specimens grown in Hawaii (Carlquist 2002), where the species was introduced from Madeira and Azores in the late nineteenth century (Gardener & Hodges 1993).

Finally, the three remaining *taxa* which have uneven vessels either in size or in distribution across the entire growth ring. Firstly, *Vaccinium padifolium* can be quite useful for dendrochronological uses due to its ring-porous structure characterised by a single hoop of large earlywood vessels that turns the annual increment very clear. Even though the contrast between earlywood and latewood is not so marked as it is in laurel species, not only because of the light colour of its wood but also due to large radial rays interwovening with ring boundaries, it is more useful than *Erica* spp. Contrarily *E. arborea* and *E. platycodon* subsp. *maderincola*, are the most difficul and challenging species. As seen, although rings can be quite clear because earlywood vessels are slightly larger and more concentrate than those of latewood (ring-porous woods) (Figure 3.5 and Figure 3.6), on the other hand individual rings are sometimes difficult to distinguish, due to lack of colour change in xylem fibers and due to smudged ring outlines caused by wide radial/tangential rays that create a marble-like pattern. Furthermore, they are both prone to produce anomalous rings, especially *Erica platycodon* subsp. *maderincola.* A fairly common critical feature is ring wedging that can be easily seen in full cross section when rings fade out and merge with other rings (Figure 3.9-4, 5). These locally absent rings (wedging rings) are formed when radial growth stops or it is extremely slow in segments of the circumference of the stem, whilst it is very fast in others, due to natural tendency for stems to twist. Problems related to anomalous rings can be overcome by carefully examining complete cross sections, and tracing around the circuit. Cores, even with careful preparation and examination, do not offer sufficient guaranties of accurate age estimations. For problematic species, age determination should not be based exclusively on cores because tree-ring sequences along radii of the same cross section differ. In such cases, coring should always be supported by full cross sections and increasing the number of samples (Norton & Ogden 1992).

The other issues observed in several samples (rotten core, dark heartwood, and false rings) can be considered minor sources of error. Although adversely affecting the analysis of an individual core they were not frequently seen in all samples. Even though it is needed to pay attention to them to avoid misjudgment in aging a single tree and wrongly estimating the age of tree populations.

Another reason that can prevent using rings to determine tree age is the fact that the rings formed do not follow a regular pattern. As seen in results, it was assumed, *a priori*, that all these species have annual growth-rings. This assumption was supported by the fact that the climate shows seasonality. As it was seen in first chapter the climate of Madeira, which is greatly influenced by subtropical location and the type of orography (Pereira, 1989), shows a seasonal pattern identified as Mediterranean climate. It is characterised by hot and dry summers, and wet and mild winters, with low temperatures at high uplands, being autumn and spring frequently affected by heavy rain. Low rainfall during summer it is, however, compensated by fog precipitation that occurs mainly on windward areas, depending on the presence of native plant species as *Erica arborea* L. and *Erica platycodon.* In addition to the climatic factor, showing seasonality, some studies on the anatomy of Madeiran woody endemic shrubs have shown that they produce annual growth rings as response to rainfall and dryness (Carlquist 1970a, b), and some other studies involving Macaronesian laurel species (Morales *et al.* 2002; Loutfy 2009) and *Lauraceae* in general (Stern 1954; Léon 2002; Tomazello-Filho *et al.* 2004; Schweingruber 2007) indicated that the well-defined rings produced by this species can be accepted as having annual pattern.

Thus, having these woody plants shown distinct growth rings with repetitive pattern, suggesting a regular cambial stop, it was assumed in first instance that grow rings produced are annual. Although Cherubini *et al.* (2003) have mentioned the possibility of Mediterranean evergreen sclerophyllous and laurophylous species could suffer a double stop, triggered by water stress in summer and cold in winter, such pattern would have appear as a sequence of wide and narrow bands alternating between them (Norton & Ogden 1992) which does not fit in any of the patterns observed. In fact, because a couple of samples of *Pinus pinaster* located on a hilltop have exhibited this type of pattern (Figure 3.11-Pp2) it shows that it can happen in xeric locations. However, none of the native species have shown similar ring arrangement, even those collected in the same stand (Cruzinhas do Faial). Thus, all of them, regardless of their location, showed just one clear stoppage. However, whereas *Apollonias barbujana, Ocotea foetens, Olea maderensis, Persea indica*, *Erica arborea* and *Erica platycodon* subsp. *maderincola, and Laurus novocanariensis* show a pattern compatible to winter cambial activity stop (characterised by an interruption that happens after latewood production as seen in Figure 3.17-Ln), *Myrica faya*, *Vaccinium padifolium,* and *Clethra arborea* show the sharp growth stoppage compatible with a summer break off [characterised by an interruption that happens before darker wood (produced with less water availability) seen in Figure 3.17-Ca].

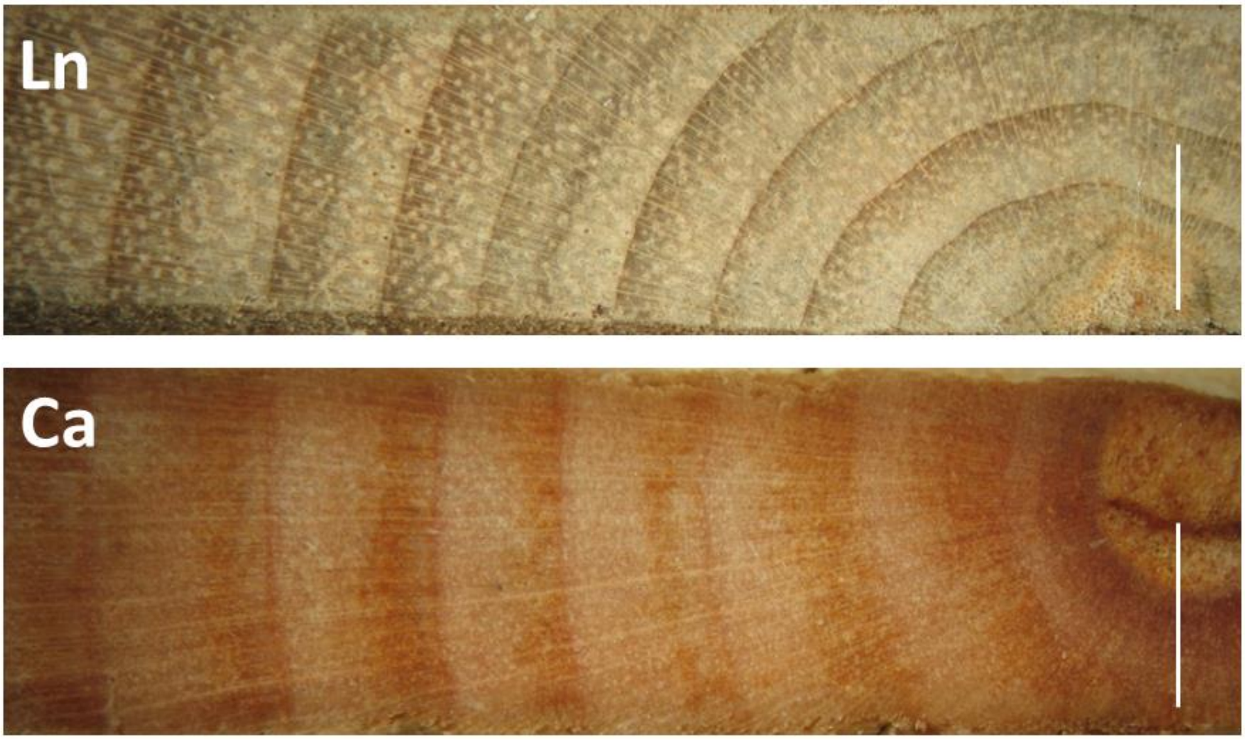

Figure 3.17 Sharp boundary compatible with winter stop, seen in *Laurus novocanariensis* (Ln), and summer stop, seen in *Clethra arborea* (Ca). Increment rings are here shown from the pith, leaving no doudt about earlywood and latewood position in each situation. Scale bar = 2.5 mm.

In this research although it was not relevant if it is a winter or summer stoppage, because it does not alter the annual nature of the increment rings it is an interesting matter that deserves further investigation in future works, especially because four of them (*Erica arborea*, *Erica platycodon* subsp. *maderincola*, *Laurus novocanariensis*, and *Myrica faya*) can be found in a wide range of bioclimate, showing same pattern whatever bioclimate they may be situated. According to Ogden (1981) it is important to pay attention to phenology and its relation with climate, because biological processes such as flowering, fruiting and new leaves production can also have impact on wood formation causing temporary cessation of radial growth. If those phenological events are periodic may be reflected in wood anatomy and generate clear annual (or any other periodicity) rings. Thus, if considering that cambial activity may stop during reproductive phenofases, the growth will resume before summer (with plenty water availability) for *A. barbujana* subsp. *barbujana, O. foetens, O. maderensis, P. indica*, *E. arborea* and *E. platycodon* subsp. *maderincola, and L. novocanariensis,* and after summer (with less water) in *Myrica faya*, *Vaccinium padifolium,* and *Clethra arborea* (Table 3.15), which coincide with the type of wood observed in each case.

Therefore, in view of the foregoing, the woody *taxa* possessing clearly distinct rings without recurrent anomalies and showing reliable cyclic increment, are potentially useful for dendrochronological studies, whereas the ones holding more frequently problematic issues (fuzzy ring boundaries, low circuit uniformity, false and locally missing rings, and rotten core) although likely usable should be employed more carefully (Table 3.16). Researches aiming to use dendrochronological data to date past events (e.g. to date disturbances) using these *taxa* should take into account that three of them do not fit into the calendar year (Table 3.16).

Table 3.15 Duration of reproductive phenophases[1] (grey highlighted) according to meteorological seasons and growth resumig after the annual stoppage in each situation (light yellow, before summer or early summer; light orange, after summer).

	Winter		Spring			Summer			Fall			Winter
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Apollonias barbujana subsp. *barbujana*		▨	▨	▨	▨	🟨						
Erica arborea		▨	▨	▨	▨	🟨						
Erica platycodon subsp. *maderincola*				▨	▨	▨	🟨					
Laurus novocanariensis	▨	▨	▨	🟨							▨	▨
Ocotea foetens	🟨						▨	▨	▨	▨	▨	▨
Olea maderensis			▨	▨	▨	🟨						
Persea indica	🟨							▨	▨	▨	▨	▨
Vaccinium padifolium					▨	▨	▨	▨	🟧			
Myrica faya				▨	▨	▨	▨	▨	▨	🟧		
Clethra arborea								▨	▨	▨	🟧	

Table 3.16 Classification according to their potential for dendrochronology (based on distinctiveness of growth zonation and issues related to ring count error) and correspondence to precise calendar year. Species grey highlighted are the ones which meet both conditions.

Taxon	**Dendrochronological usefulness**	**Match to calendar year**
Apollonias barbujana subsp. *barbujana*	Useful	yes
Clethra arborea	Useful	no
Erica arborea	Useful although problematic	yes
Erica platycodon subsp. *maderincola*	Useful although problematic	yes
Laurus novocanariensis	Useful	yes
Myrica faya	Useful although problematic	no
Ocotea foetens	Useful	yes
Olea maderensis	Useful	yes
Persea indica	Useful	yes
Vaccinium padifolium	Useful	no

Data collected were also used to get allometric correlations between stem diameter, total tree height and age, although the primary purpose of coring trees in stands seen in photographed landscape was to age them to complement the information gathered through repeated landscape photography. The results indicated that tree age and size measurements (diameter and total height) are quite well correlated and it is possible to use them to estimate age with considerable degree of accuracy (seeTable 3.4). This is important since it enables to estimate age of trees too large to reach the pith for which counting rings in the whole is not possible, or trees with historical and conservation importance which cannot be disturbed (White 1998). Although in this case it can be assumed that some error can exist because older and slower growing trees were omitted from this sampling since trees with advanced decay were avoided.

Samples were scatteredly collected within the natural range of each species, in order to incorporate variations and to detect possible differences. However, sampling does not include very distinct growth rates since trees in extreme environmental circumstances were avoided, and further efforts should be made to link data hitherto collected with environmental, physiological and phenological data to improve knowledge about growth behavior (White 1998; Way & Oren 2010).

Total height, although providing age information it is difficult to measure, requiring special apparatus (e.g. hypsometer), it is affected by breakage of branches, and does not increase once optimum crown size is reached. Diameter can be individually used because it is a non-reversible measure and increases each year throughout all the

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[1] Reproductive phenophases were based on Press & Short (1994), Silva &Tavares (1993) and Oliveira *et al* (2002).

phases of the life until senescence of the tree (White 1998), and furthermore it can be easily reported. However because the thickness of the stem increases at different rates [a rapid growth up to optimum crown development, followed by more constant rate during middle age period, slowing down after senescence (see Figure 3.10) (White 1998)], combining diameter with additional measurements such as the total height of the tree, can provide more stringent estimates of age, especially until maximum crown size is reached. The more independent variables the regression model uses, the more accurate will be the dependent variable estimation, due to the range of possible combinations between independent variables (White 1998; Kalliovirta & Tokola 2005).

Total height further than contributing to improve age estimation based on combination of the two variables allows to analyse growth rates in the context of successional dynamics. For instance, taking as example stink-laurel temperate meso-forest series (Figure 3.18) and barbusano-tree micro-forest series (Figure 3.19) it was possible to see that growth rate of each species is in accordance with the successional model proposed by Capelo *et al.* (2004). Within the *Clethro arboreae-Ocoteo foetentis sigmetum*, *Vaccinium padifolium*, a species belonging to an early phase of the substitution stage *Vaccinio padifoli-Ericetum maderincola*, is one of the first to reach 3 metres height. It becomes then the slowest growing species, being surpassed around 25-30 years later by the heaths, that are the ones that take more time to reach that height (Figure 3.16-a). *Myrica faya* a tree present in the later phase of this stage and remaining in early phase of climax forest with *Laurus novocanariensis* became dominant trees in a forest shared with Erica spp after 50-60 years (Figure 3.16-b). These two abundant trees in the early phase of the climax stage have faster growing rates when are young but become slower and are surpassed by shade tolerant trees of latter successional stages. *Clethra arborea*, the one that grows faster takes around 20 years to exceed the height of *L. novocanariensis* and *M. faya* growing at the same time (Figure 3.16-c). A more mature phase of climax forest appears when *Persea indica* and *Ocotea foetens* surpass *Clethra arborea* (Figure 3.18-d), around 45-60 years after they have conditions to growth.Stink-laurel forest emerge as fully mature around 80 years, when *Ocotea foetens* becomes the tallest tree of the forest (Figure 3.18-e). Thus, considering only the *tempus* from substitution stage *Vaccino padifoli-Ericetum maderincolae* appearance it takes around 155 - 170 years to *Clethro arboreae-Ocoteetum foetentis* to become a truly mature forest.

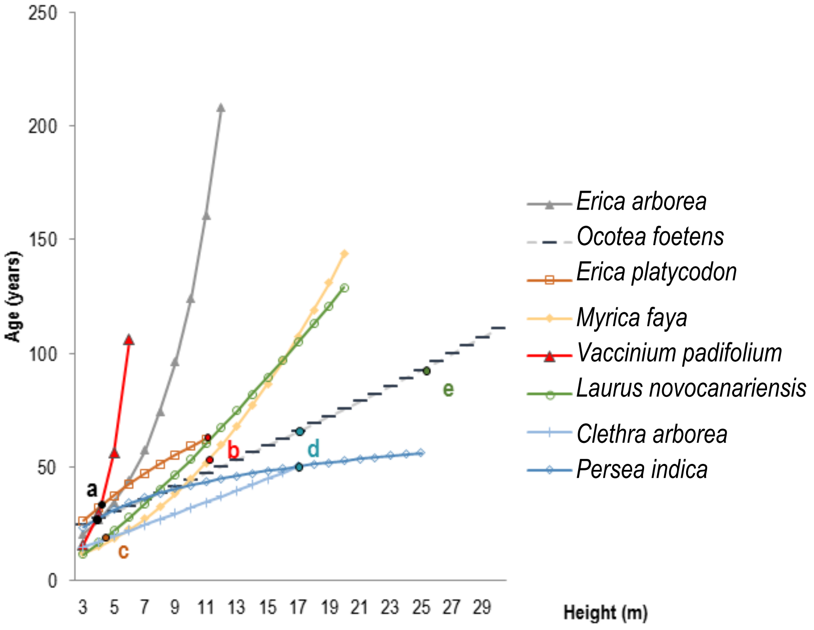

Figure 3.18 Growth rate of some woody species of *Clethro arboreae-Ocoteo foetentis sigmetum*. Points with relevance within the context of successional dynamics (a, b, c, d, and e) are marked.

Analysing growth rate of woody species of barbusano-tree micro-forest, it was verified it was verified that *Laurus novocanariensis* and *Myrica faya* take almost 50-60 years to surpass *Erica* sp (Figure 3.17-a), and create conditions to shade tolerant species as *Apollonias barbujana* that takes around 20-25 years surpasses growing rate of *Laurus novocanariensis* and *Myrica faya* (Figure 3.17-b), abundant trees in initial phase of this micro-forest, and around 55 years to become the tallest tree of the mature forest (Figure 3.19-c). Thus, *tempus* from from substitution stage *Globulario salicinae-Ericetum arboreae* appearance it takes around 105-115 years to *Semele androgynae-Apollonietum barbujanae* to reach the mature state.

This *tempus* is only a bit slower than the one found to mediterranean laurisilva of La Palma Island (Canary Islands). Surveys in clear-cut small areas of laurel forest pointed out to 15-25 years to reach the shade tolerant species stage of climax community, and around 60 years to reach favourable conditions to those species (Bermúdez *et al.* 2007).

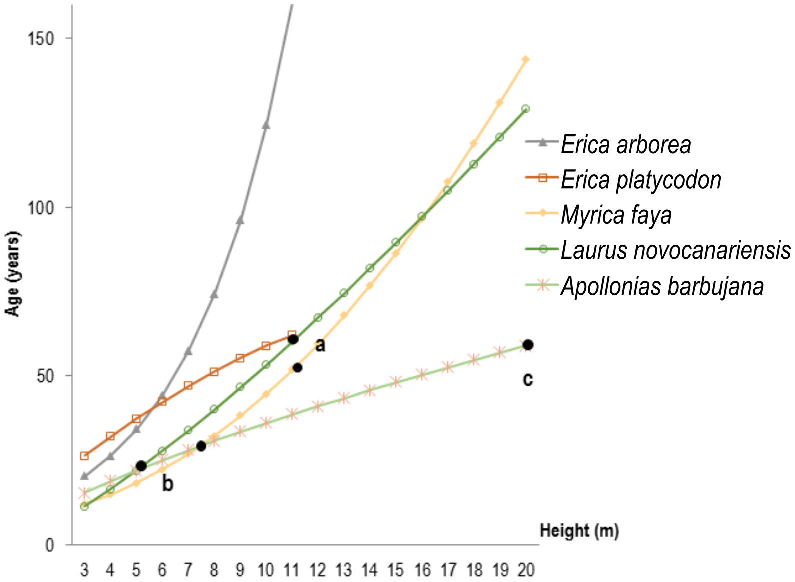

Figure 3.19 Growth rate of same woody species of *Semele androgynae-Apollonio barbujanae sigmetum.* Points with relevance within successional dynamics context (a, b) are marked.

It is also interesting to note that the three species showing summer stoppage do not coexist. *Vaccinium padifolium*, a species belonging to early phase of *Vaccinio padifoli-Ericetum maderincolae,* grows along with heaths that stop growing in winter, and tends to disappear giving rise to *Myrica faya* (*urzal-faial,* a formation dominate by *Myrica faya* and *Erica* spp. in the later stage of same association). *M. faya* that also remains in early phase of *Clethro arboreae-Ocoteetum foetentis,* grows together with heaths and *Laurus novocanariensis* which also stops growing in winter. It becomes replaced in intermediate phase of the forest by *Clethra arborea,* which grows together with laurel species (*L. novocanariensis, Ocotea foetens* and *Persea indica*) that cease cambial activity in winter time.

Assessing the age of trees across the photographed area (see 3.2) allowed to confirm that pressure on coastal native tree cover is greater than in inland, since specimens that due to their age may be the same as those seen in historical landscape were only found in the interior. Interpolation of the age measured showed that trees over coastal areas rarely exceeded 50-60 years, older trees achieving hundred years old are only found in western part of the Island, in slopes facing north (Figure 3.20).

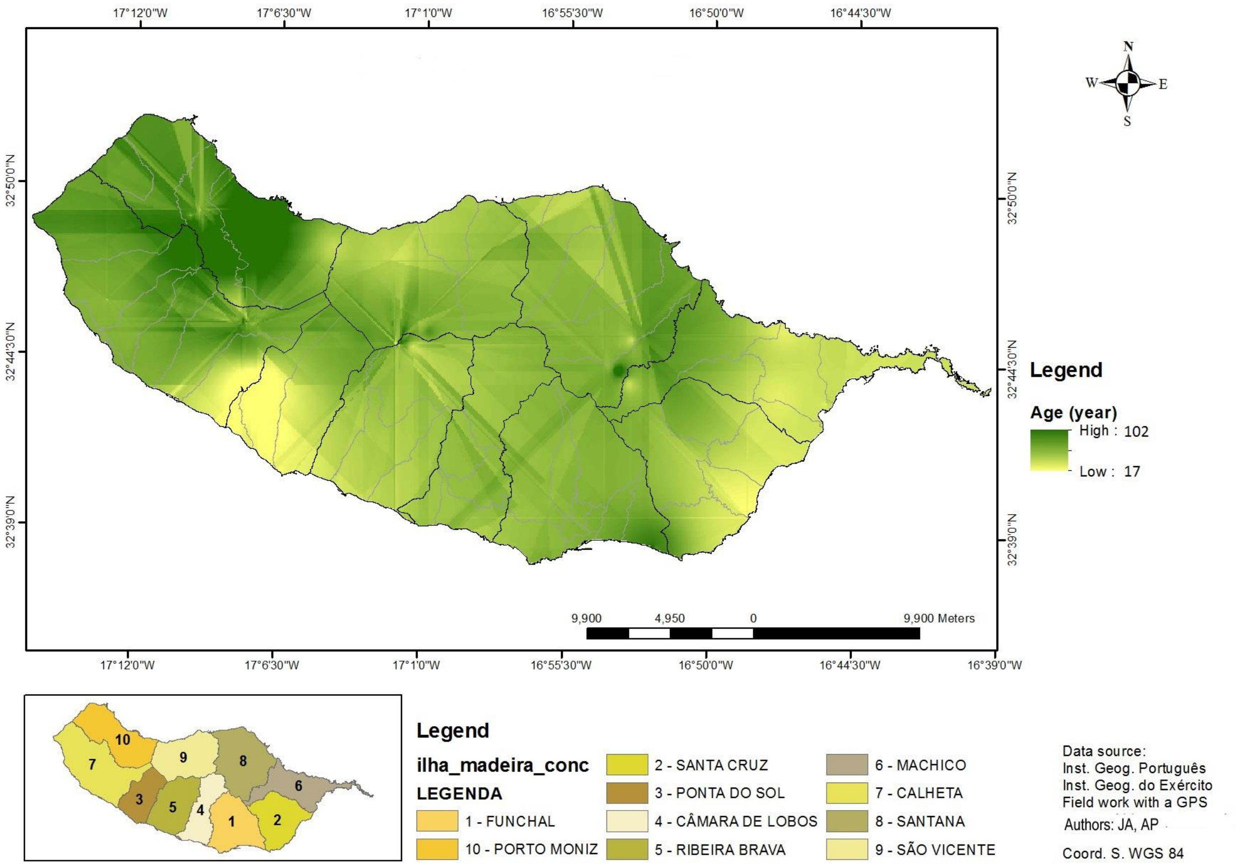

Figure 3.20 Interpolation of observed tree age by means of inverse wieghted method.

The fact that specimens belonging to initial seral stages and species present in young forest are the older, while species belonging to mature phases are much younger, and not seen in historical landscape, revealed that the forest currently occurring in the photographed area cannot be an old growth forest. Growth rates estimated, have pointed to stink laurel forest achieving the state of dynamic equilibrium almost eighty years after *Ocotea foetens*, main tree of this forest, have conditions to growth. This mean that in some spots of photographed area (for instance Rabaçal, Ribeira da Janela–S1) where oldest *Ocotea foetens* growing together with centennial laurels and heaths is around 50 years (see Table 3.2) it will take, without major disturbance, around 30 years to reach old-growth state. In some other spots, of same area, where a community of *urzal-faial* is currently found (S2), *Laurus novocanariensis* seedlings are starting to appear. Because there are no signs of *Ocotea foetens* yet the path to mature forest will be even longer. Since in same area centennial heaths are found this immature state can only be explained due to recurring disturbance. Indeed, fire scars seen in a few cores are the proof that fire was one of the recurrent disturbances that this forest was subjected not so long ago.

With regard to exotic trees none of the age which was determined correspond to trees seen in historical landscape. This fact shows that although current coverage corresponds to the same plant cover type they resulted from renewal of those forest stands either due to new plantations or, most probably, due to spontaneous renewal.

3.5 Conclusion

This evaluation has shown that species with distinct growth rings, little occurrence of anomalies, and annual pattern assigned to calendar year as *Apollonias barbujana* subsp. *barbujana*, *Laurus novocanariensis*, *Ocotea foetens, Olea maderensis,* and *Persea indica* can be considered as potentially useful for dendrochronological uses. *Clethra arborea* and *Vaccinium padifolium* not holding problematic issues are potentially useful for dendrochronological studies as well. However, because growing season does not correspond to calendar year they require further attention. Whilst others bearing more frequently problematic issues (fuzzy ring boundaries, low circuit uniformity, false and locally missing rings, and rotten core) as *Erica arborea, Erica platycodon* subsp. *maderincola, Myrica faya*, and this last one not matching to calendar year, although likely usable should be employed more carefully. Results indicated that it is possible to age the most common native phanerophytes of Madeiran forests only based in total height and diameter at 50 cm over bark, or combining these two biophysical measurements for a better age estimation. The dendrochronological tool here outlined, in addition to provide a baseline for future dendrocronological studies, can be considered, as it is now, an adequate proxy for understand disturbance and to reconstruct decadal forest dynamics.

The growth rates of the most common native woody species, determined by analysis of height-age correlation, were consistent with the successional model proposed by Capelo *et al* (2004), supporting the model itself as well. In addition they allowed to estimate *tempus* for the different phases of the late successional stages of *Semele androgynae-Apollonio barbujanae sigmetum* and *Clethro arboreae-Ocoteo foetentis sigmetum*. This analysis have shown that in the case of barbusano-tree forest series it takes around 60 years to reach a final stage, after *Apollonias barbujana* appearance, and around 105-115 from shrub stage. In the case of stink-laurel forest series the old-growth state emerge around 80 years after the appearance of *Ocotea foetens*, and approximately 170 years after overcoming first stages of forbs, grasses and low shrubs. Age assessment across photographed landscape revealed that only in inland the specimens seen in current and historical landscape are the same, and even in well conserved areas of native vegetation oldest specimens correspond to secondary vegetation indicating that no growth-old forest exist. To reach the final stage in the most advanced sites, if no huge disturbance holds back the succession, at least more 30 years will be needed. The assessment of growth rates also have shown that some species, as *Persea indica* has potential for forest production. Age assessment of exotic trees have shown that trees in current stands are not the same individuals pointing to replanting or spontaneous renewal.

Future research should be directed to: clarify rates of the initial growth of these species; conduct more detailed studies about the alternation between growth and rest periods, which seem to be not triggered by temperature and water stress; compare growth rates of species found in different bioclimates; extend dendrochronological studies to less common native trees; and to evaluate crossdating potential and built standard chronologies for each *taxa.*

4 Repeat Photography

> "Consider briefly the alternative of not using repeat photography. We would face decades of uncertainty while we waited for results from long-term monitoring and long-term experiments*,* (…)" (Pickard 2002, p. 414)

4.1 Repeat Photography: concept and applications

Repeat Photography, or re-photography, was defined as "... the practice of finding the site of a previous photograph, reoccupying the original camera position and making a new photograph of the same scene…" (Rogers *et al.* 1984, p. ix) although in a broader sense this concept concerns the production of photographs replicating the same view it is commonly applied to ground-based repeat photography or terrestrial photography (Hall 2001; Pickard 2002; Kull 2005; Burton *et al.* 2011).

There are two types of photography made at ground-level which are useful to document vegetation changes over time: site-specific repeat photography and landscape photography. The first is directed to a specific topic to be documented in detail (Hall 2001) such as obtaining information about phenological events (Crimmins & Crimmins 2008) or to monitoring vegetation transects (Hall 2001; Kull 2005; Hoffman & Toold 2010).The second aims to document change in landscape-scale areas, focusing the dynamic aspect of the landscape (Klett 2010; Webb *et al.* 2010a) and it includes both conventional landscape photography and the panoramic photography with a 360-degree view (Hall 2001).

The landscape repeat photography was pioneered by Sebastian Finsterwalder[1] in 1888-89 to estimate rates of glacial retreat in the Alps (Malde 1973; Webb 1996; Hall 2001; Webb *et al.* 2010a; Kaufmann 2012). Its value to the investigation of plant ecology was recognised early in the twenty century by Clements (1905), although its importance was highlighted only 50 years later with the publication of the classic *Changing Mile* (Hastings & Turner 1965), where the bases, rules and principles of repeat photography were established and, therefore considered a benchmark in the application of the technique to ecological studies (Malde 1973; Webb 1996; Pickard 2002; Turner *et al.* 2003; Kull 2005).

Over time, and especially after 1960, repeat photography became very popular in Europe and in the United States (Byers 1987), being applied in a variety of different disciplines such as geology, geography, architecture, anthropology and ecology (Gruell 2010; Webb *et al.* 2010a). In the field of geology, where the methodology has been firstly and widely implemented, it was specially used to evaluate physical processes where change is slow and less perceptible as: (1) ebb and flow of glaciers (Butler & DeChano 2001; Kull 2005); (2) erosion and accumulation of sediments; (3) interaction between vegetation and active geological processes (Malde 1973). In the latter field it was occasionally used to determine the magnitude and the frequency of catastrophic events as earthquakes, volcanoes,

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[1] Sebastian Finsterwalder (1862-1951) was the pioneer of repeat photography as temporal surveying technique. He was a German mathematician, Professor in Technical University of Munich, since 1891 to 1931, where he took over the chair of descriptive geometry from 1911 onwards. He developed measurement techniques to apply photogrammetry to landscape photography in mountains, and use it to map Alpine glaciers and to determine their flow velocity (Kaufmann 2012).

floods, landslides (Rogers *et al.* 1984), snow avalanches (Butler & DeChano 2001), not only to appraise the level of damage but also to document recovery after those hazards (Burton *et al.* 2011).

In plant ecology re-photography has been frequently applied to: (1) collect information about species and vegetation types; (2) evaluate changes in vegetation communities (Turner *et al.* 1998; McClaran 2003; Western 2010); (3) obtain data on the succession and long-term dynamics (Meagher & Houstan 1998; Hall 2001; Kull 2005; Moseley 2006; Hendrick & Copenheaver 2009b); (4) gather information about the demographic structure of long-lived plants (Hoffman *et al.* 2010); (5) estimate the growth of trees (Debussche *et al.* 1999; Bullock & Turner 2010), and (6) to observe phenological events (Crimmins & Crimmins 2008). It was also used to collect data on climate change (Hoffman *et al.* 2010) and to analyse impacts on environments with different degree of hemeroby as: (1) urban areas; (2) ecosystems being disturbed in the course of human activities as logging, burning, grazing, recreation; and (3) areas where the land-use has changed, specially related with agriculture abandonment (Byers 1987; Butler & DeChano 2001; McClaran 2003; Kull 2005; Moseley 2006; Hendrick & Copenheaver 2009b; Klett 2010).

Lately it has been recognised the potential of historical information for land management practices (Egan & Howell 2001). The observation of historical photographs, even if not intended to be used for repeat photography, provides an objective analysis of the conditions of the past (Munroe 2003; Bierman *et al.* 2005), and allows to fill gaps in areas for which there are no records or when information is not very precise (Debussche *et al.* 1999; Start & Handasyde 2002; Western 2010). Details contained in the photographs provide access to information regarding landscape organisation that, in some cases, is more complete than a written description (Turner *et al.* 1998; Lewis 2010). Repeat photography of historical landscape photographs can be used both to establish conservation and restoration programmes (Byers 1987; Meagher & Houstan 1998; Pickard 2002; Start & Handasyde 2002; Turner 2005a; Moseley 2006; Hendrick & Copenheaver 2009b; Veblen 2010) as well as to sensitise people and especially politicians who make decisions on conservation policies (Pickard 2002; Kull 2005; Crimmins & Crimmins 2008; Bierman 2010; Nyssen *et al.* 2010; Veblen 2010).

4.1.1 Guidelines on methods used in repeat photography

Since the work of Finsterwalder, in the late nineteenth century, to Hastings and Turner, in 1965, many other authors contributed over time with methodological guidelines (Webb *et al.* 2010a) that are summarised below under three broad headings: (1) Collecting and selecting images; (2) Re-photographing; (3) Analysing the images. The idea here was to gather together as many suggestions as possible about procedures[1] that were handed down by authors who used the technique and, in this way, to provide an overview of up-to-date information needed to develop a repeat photography project.

4.1.1.1 Collecting and selecting images

Whatever are the reasons to undertake a re-photography project the starting point it is always the search of photographs and their selection (Pickard 2002). The popularity of photography from the very beginning has provided a large amount of historical photographs that are available either in private collections or in public institutions archives

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[1] Hints to overcome limitations of the technique proposed by the authors reviewed were explored in Pupo-Correia *et al.* (2014) (appendix 4).

such as museums, libraries, universities and government agencies. Other sources as books, magazines, newspapers and websites have also been suggested, although the image quality is frequently lower and attending to copyright laws must be taken into acount (Pickard 2002; Kull 2005; Moseley 2006; Zier & Baker 2006; Boyer *et al.* 2010).

The format of original images ranged from printed photographs (Start & Handasyde 2002; Clark & Hardegree 2005; Zier & Baker 2006), postcards (Debussche *et al.* 1999; Dutoit *et al.* 2003), glass slides (Start & Handasyde 2002), negatives (Hall 2001) to digital images (Crimmins & Crimmins 2008). Regardless the original format and although retaining printed copies especially to be used in the field, most recent projects have opted to use images in a digital format. Not only for ease of storage (Hall 2001) but also to import them into image analysis software packages (Munroe 2003; Clark & Hardegree 2005; Levesque 2005; Hendrick & Copenheaver 2009b) and to the create databases and websites (Boyer *et al.* 2010; Carstensen *et al.* 2010; Klett 2010).

Not all photographs are suitable for a repeat photography project, being necessary to choose the proper ones among the available set (Hendrick & Copenheaver 2009b). The lack of quality was the first reason that led to the rejection of photographs in most of rephotography projects (Hall 2001; Munroe 2003; Zier & Baker 2006). The main cause is normally degradation over time (Hall 2001). Frequently, historical photographs were stored in improper conditions and have lost the sharpness needed to identify species, to notice disturbances, or even to achieve accurate pairing in the field. However, frequently characteristics of the image may have been affected by the original atmospheric conditions (Webb 1996; Debussche *et al.* 1999; Clark & Hardegree 2005; Kull 2005; Boyer *et al.* 2010). Poor photo quality can also be responsible for the loss of important information or for creating artifacts (i.e. a dark smudge on a distant mountain in the background can be a forest, a cloud shadow or a fire scar) misleading conclusions (Kull 2005). Although image-processing software can be used to restore to some degree damaged images, it is not possible to use them in this situation (Munroe 2003). Another criterion for selecting the photographs is the presence of peculiar landforms helpful to recognise the landscape and to find out the original camera position (Hall 2001; Moseley 2006; Zier & Baker 2006; Hendrick & Copenheaver 2009b).

The photograph age is also one aspect to consider because, depending on the objectives of the work, the selection has to focus on photographs included in a given time interval (Start & Handasyde 2002). The time lag between the original and the replica has been very variable. From periods lapsing over a century, in the field of historical ecology studies to assess long-term change and dynamics (Hart & Laycock 1996; Pickard 2002; Kay 2003; Munroe 2003; Bierman *et al.* 2005; Kull 2005; Moseley 2006), to shorter intervals ranging less than one year, when it was intended to evaluate short-term effects caused by disturbances or to verify seasonal patterns (Hall 2001; Munroe 2003; Kull 2005; Crimmins & Crimmins 2008; Turner *et al.* 2010). Furthermore, not knowing the exact date of the historical photograph may cause misinterpretation due to seasonal changes (Pickard 2002) and it can be troublesome especially if the project aim includes calculating rates (e.g. mortality rate, recruitment rate, rate of change) or determining the longevity of species (Webb 1996; Munroe 2003; Hoffman *et al.* 2010). It is, however, possible to estimate the age through historical research about the period of activity of the photographer, expeditions in which the photographs were made, and events related to details observed in the image (Veblen & Lorenz 1991; Rhemtulla *et al.* 2002; Munroe 2003; Boyer *et al.* 2010).

A collection of historical photographs always represents a spatial biased sample (Zier & Baker 2006; McClaran *et al.* 2010), except when the original photographic set aimed a systematic survey (Butler & DeChano 2001; Rhemtulla *et al.* 2002; Higgs 2003). Because early photographers were interested in a certain theme or a peculiar landform, views showing spectacular scenic landscapes are normally over-represented. Also, historical photographs were often taken along roads and easily accessible locations, probably due to the weight of historical photographic equipment, causing an over-representation of anthropogenic cover (Vale 2001; Rhemtulla *et al.* 2002; Kull 2005; Turner 2005b; Hendrick & Copenheaver 2009b). Furthermore, because original photographs were not randomly located and sometimes are showing small areas the sample would not be representative of the overall change (Debussche *et al.* 1999; Vale 2001; Pickard 2002; Rhemtulla *et al.* 2002; Start & Handasyde 2002; Kull 2005; Turner 2005a; Zier & Baker 2006; Hendrick & Copenheaver 2009b). Consequently, care must be taken: (1) to select a set of photographs spread over the study area (Rhemtulla *et al.* 2002; Zier & Baker 2006); (2) to choose just one photograph if an area is seen in more than one photograph with the same age (Debussche *et al.* 1999; Hendrick & Copenheaver 2009b), and (3) to examine the photographs to check if no systematic bias is favouring a specific landscape feature (Rhemtulla *et al.* 2002).

The scope of an investigation can also affect the choice of images. However, it should not be limited to those that describe the desired conditions otherwise it can put the credibility of the analysis in risk (Butler & DeChano 2001; Hendrick & Copenheaver 2009b)

4.1.1.2 Re-photographing

Finding the exact location, where the original photographer stood, is crucial if the aim is to quantify the change and make an accurate analysis (Malde 1973; Webb 1996; Debussche *et al.* 1999; Hall 2001; Munroe 2003; Clark & Hardegree 2005). Usually only historical collections that aimed topographical surveys or scientific expeditions contain precise information on camera position (Byers 1987; Butler & DeChano 2001; Rhemtulla *et al.* 2002; Hendrick & Copenheaver 2009b). Most frequently there is no such information because old photographs were not made to be repeated later (Malde 1973; Veblen & Lorenz 1991; Kay 2003; Munroe 2003; Kull 2005; Hanks *et al.* 2010; Lewis 2010). Although, old photographs were often taken in sites that are still popular sightseeing points (Webb 1996; Munroe 2003), finding the location can be a difficult and time-consuming step (Malde 1973; Veblen & Lorenz 1991; Hall 2001; Kull 2005; Hendrick & Copenheaver 2009b; Lewis 2010). Several hints were suggested, such as: (1) prospecting the image to find clues for a general location (e.g. geological features, direction of flow of a river, vegetation type) (Hall 2001; Hanks *et al.* 2010); (2) looking for books or magazines with travel descriptions dating from the time of historical photograph; (3) searching historical documents (Hall 2001; Kull 2005); (4) interacting with local residents asking for indication to find landforms or camera location (Hall 2001; Hendrick & Copenheaver 2009b; Hanks *et al.* 2010); (5) using Virtual Repeat Photography (VRP) to access a virtual landscape by manipulating digital elevation models (DEM) with GIS software or Google Earth to explore a virtual landscape to find out the location (Boyer *et al.* 2010; Hanks *et al.* 2010).

Likewise, relocating the camera in the exact site, after the general photo location is discovered, can be very easy, because frequently early photographers did not stray far from roads and paths. But, quite the reverse, it can be a challenging process and even an impossible task if there are no prominent landscape features (Veblen & Lorenz 1991; Munroe 2003; Kull 2005; Hanks *et al.* 2010; Lewis 2010). A common error is trying to frame the new photograph to the contour of the original causing deviation of the correct position (Pickard 2002). Some photographers developed methods to relocate the camera but in the main all of them were based on relative position of features seen in old photograph and present landscape (Pickard 2002; Munroe 2003; Klett 2010). Precise systems using mathematical calculations can be used, although they are very time-consuming (Boyer *et al.* 2010). Most authors followed the simple procedure, based on paralax principles, established by Malde (1973). Briefly, this method consists in aligning near and distant features in the centre of the field of view, to find the camera position, then moving along the central line until features in the periphery became tightly aligned, to determine the orientation of the camera axis, and finally comparing the relative distance between objects in the foreground and the background, to set up the height above ground. Hall (2001) suggested drawing lines directly on the printed photograph to facilitate comparison between distances and angles.

Verifying the correct position in field was a complicated task in first repeated photography projects. It became feasible by using Polaroid instant prints, and more recently by using digital cameras. With the development of the latter these became a quick way to compare the landscape and the original photograph, despite considered at the beginning as being poorly effective method (due to small LCD screen, barely visible in direct sunlight) (Pickard 2002). Thanks to the evolution of digital cameras, it is now possible to make the repeated photograph in digital format with high quality (Crimmins & Crimmins 2008), to review photographs once they have been taken in a quick and accurate way (Boyer *et al.* 2010) and also to make fine adjustments using the grid in the viewfinder or by uploading the historical photographs into the digital camera and toggling between photos to compare historical landscape with modern view (Carstensen *et al.* 2010).

To get accurate repeated photographs is also important to replicate the original environmental conditions, because different shadows can falsely indicate a different type of vegetation or a different density (Webb 1996; Hall 2001; Munroe 2003; Kull 2005; Klett 2010; Lewis 2010). Usually there is no record of those conditions, yet it is possible to infer the time of day based on the direction and length of shadows (Boyer *et al.* 2010), and time of year by the phenological state of the vegetation (Rhemtulla *et al.* 2002). Anyhow, taking the new photograph when sunlight is at high angle or the site is in full shade helps to avoid shadows that could lead to misinterpretations (Crimmins & Crimmins 2008). Severe atmospheric conditions affecting air quality and lighting conditions, as low clouds, ground hugging fog, rain or snow, prevent retaking the photograph. This is a problem that can only be solved by revisiting the site (Hall 2001; Hendrick & Copenheaver 2009b).

According to some photographers changing the format of the camera can cause serious problems in the coincidence of the photographs (Clark & Hardegree 2005; Kull 2005), however, as Rogers *et al.* (1984) stated and Hall (2001) experimentally showed, the camera format is not a critical issue. Regardless of the lens being used the photographs always match if they are taken from the same position and cropped to the same size. This was a very important outcome since original cameras, especially before 1930, are no longer available (Hall 2001). However, although not being necessary to use the original equipment (or lens with the same focal length) the large format of old photographs requires the use of wide-angle lens to photograph the same field of view otherwise landscape historical information on the image periphery will be lost (Kull 2005).

Sometimes landscape underwent remarkable transformations preventing to take the photo from the exact location either because it is impossible to recognise landforms (Hall 2001), the place for the retake is no longer accessible (e.g. erosion), or the original view is obscured by new constructions and vegetation growth in the foreground (Veblen & Lorenz 1991; Webb 1996; Hall 2001; Kull 2005; Zier & Baker 2006; Boyer *et al.* 2010; Lewis 2010). Although some authors have removed from the sample the photos in these situations (Debussche *et al.* 1999; Butler & DeChano 2001; Clark & Hardegree 2005) others have considered that if an alternative photo-point is located close to the original is possible to obtain a useful replicate, even if inadequate for a quantitative evaluation (Kull 2005; Zier & Baker 2006; Boyer *et al.* 2010). Also if the view is just partially obstructed, the photograph taken from the same point can be used to compare the visible portion of the landscape, in spite of losing part of the historical information (Veblen & Lorenz 1991).

An important point for repeat photography is that it should be repeatable to produce time series as a legacy to understand the forthcoming changes (McClaran 2003). Data concerning camera relocation must be well-documented to allow others to repeat the photograph in the future (Hall 2001), and field notes should include: (1) descriptions of landscape details (Hall 2001); (2) names of places and distance to main localities and access roads (Kull 2005); (3) a map locating the camera position and photo point; (4) height above ground (Hall 2001; Zier & Baker 2006); (5) photographs of the camera in position (Pupo-Correia 2007; Hoffman & Toold 2010); and (6) GPS coordinates (Munroe 2003; Kull 2005; Zier & Baker 2006; Pupo-Correia 2007; Hendrick & Copenheaver 2009b; Hoffman & Toold 2010). Camera location and photo point can be permanently marked (Malde 1973; Hoffman & Toold 2010) with wood fence posts or metal stakes, each one with advantages and disadvantages and different demands, being frequently used in monitoring programmes (Hall 2001). Other field notes to help the repetition should include date, time of the day, weather (Kull 2005), and if special gear is needed to reach the site (Hall 2001).

4.1.1.3 Analysing the images

The simplest approach for analysing images is a visual comparison attempting to detect significant differences, such as the relative location and extension of vegetation types. This qualitative analysis is very important especially to confirm and clarify vegetation types that existed in the past, to identify disturbances, patterns of change, problematic areas in need of specific intervention (Byers 1987), and particularly effective for environmental education (Pickard 2002). Even the projects that accomplished a quantitative assessment also performed a qualitative evaluation to analyse a larger number of photographs for which quantitative analysis was not feasible (Rhemtulla *et al.* 2002; Pupo-Correia 2007; Bierman 2010) or to analyse plans without the sharpness required to make accurate measurements (Butler & DeChano 2001). In this case, images analysis has been done either with photographs printed on paper, by putting photographs side-by-side (Turner *et al.* 1998; Debussche *et al.* 1999; Butler & DeChano 2001; Start & Handasyde 2002; Kull 2005; Moseley 2006) or displayed in computer monitor, by toggling between photos on the screen (Rhemtulla *et al.* 2002; Munroe 2003; Clark & Hardegree 2005; Kull 2005; Zier & Baker 2006; Crimmins & Crimmins 2008; Hendrick & Copenheaver 2009b).

Repeat landscape photography can be used to quantitatively analyse the change and vegetation dynamics and has been carried out by applying different methods, both simple and more complex, such as: (1) calculating the frequency of a certain attribute (Debussche *et al.* 1999; Bierman *et al.* 2005); (2) assigning categories (Zier & Baker 2006; Nyssen *et al.* 2010); (3) counting presence or absence of particular items (Vale 2001; Start & Handasyde 2002; Turner *et al.* 2003); (4) making measurements (Debussche *et al.* 1999; Munroe 2003; Hoffman *et al.* 2010); (5) superimposing grids on photographs (Hall 2001); and (6) using resampled images, and polygons or pixel classification, as employed in most recent projects (Rhemtulla *et al.* 2002; Clark & Hardegree 2005; Pupo-Correia 2007; Crimmins & Crimmins 2008; Hendrick & Copenheaver 2009b; Hoffman & Toold 2010; Klett 2010).

Measurements have been made by overlapping graduated rulers (Hoffman *et al.* 2010) and grids (Munroe 2003) directly onto the image or by transferring data from photographs to topographic maps (Butler & DeChano 2001). Frequency of cover-type conversions has been quantified by delineating polygons (Munroe 2003) or by pixels sampling, performed both by manually classifying clusters of pixels (Rhemtulla *et al.* 2002; Pupo-Correia 2007; Hendrick & Copenheaver 2009b) as well as automated pixel counting (Clark & Hardegree 2005; Crimmins & Crimmins 2008). The latter, although useful when the number of images is high (Crimmins & Crimmins 2008) it is of little effective due to low quality of historical photographs and scale variability (Clark & Hardegree 2005).

Scale variability of ground-based imagery beyond preventing planimetric surveying also tends to overvalue the type of vegetation established in the foreground (Rhemtulla *et al.* 2002; Hardegree & Clark, 2005). Although Rhemtulla *et al.* (2002) stressed that if a type of vegetation is not obviously favored over another there is no need to compensate the scale, some authors presented methods in order to reduce the bias. Debussche *et al.* (1999) divided the photograph into three parts (foreground, middle ground and background) and Clark & Hardegree (2005) sampled pixels distributed over image rows assuming that all the points of each row have the same distance to the camera and therefore the same scale. However, these procedures were considered by these authors as not being completely effective in complex terrain.

Another issue related with oblique angle is the impossibility of analysing areas hidden by terrain and vegetation, restricting the assessment of all geographical area. Furthermore, the change in these features can modify portions visible from one image to another making it impossible to compare them. Collecting data in these previously hidden areas can help to better characterise the landscape photographed, even though being impossible to use this information for landscape change quantification. Some authors have suggested to use aerial photographs or even oblique photographs, obtained at a higher level (McClaran *et al.* 2010), or to make field observations (Moseley 2006; Zier & Baker 2006). If alteration reveals new areas, they can either be used since not having historical information they are useless to evaluate change, (Webb 1996; Debussche *et al.* 1999; Clark & Hardegree 2005; McClaran *et al.* 2010).

Photograph pairs have to show landscape features located in the same image coordinates to allow comparision. However, even if taken from the exact same point they never match exactly (Hall 2001; Munroe 2003; Clark & Hardegree 2005; Kull 2005; Zier & Baker 2006). By using digital images and editing software (e.g. Adobe Photoshop) images were made semi-transparent, laid one over the other, matched and cropped with the same size (Munroe 2003; Kull 2005; Zier & Baker 2006; Hendrick & Copenheaver 2009b). However, studies aiming a more accurate comparison used remote sensing programs and image registration algorithms to spatially register the new photograph to the historical one (Manier & Laven 2002; Rhemtulla *et al.* 2002; Clark & Hardegree 2005).

The two co-registered images allow quantifying change, but only as it is represented in landscape pictured i.e. this process measures image surface coverage and the changes between the two images and does not quantify the cover type conversions within the actual landscape (Rhemtulla *et al.* 2002; Munroe 2003; Clark & Hardegree 2005). However, Butler & DeChano (2001) were able to obtain a value of the change that actually occurred in forest cover by determining the scale of panoramic photographs and transferring the areas delineated in landscape photographs into the topographic map. Furthermore, according to Rhemtulla *et al.* (2002) new perspectives are opening up due to the development techniques incorporating more complex algorithms to automatise the transformation of ground-based photographs into planar views.

Repeat photography data can be complemented with data from other techniques used in historical ecology such as: (1) dendrochronology (Veblen & Lorenz 1991; Bowman 2002; Kay 2003; Elliot & Baker 2004; Turner 2005b); (2) pollen analysis (Bowman 2002); (3) long-term monitoring (Turner 2005b). Inferring the nature and causes of the change can be supported by additional information from aerial photography (Rhemtulla *et al.* 2002; Levesque 2005), field notes on vegetation types and disturbance (Veblen & Lorenz 1991; Zier & Baker 2006) records of land management history, species autoecology and geomorphological and climatic data (Pickard 2002; Dutoit *et al.* 2003; Turner *et al.* 2003; Elliot & Baker 2004).

Certain issues which affect the reliability of results are overcome by using adequate selection strategies. However, some procedures during analysis also minimise bias as: (1) grouping photographs according to vegetation type (Zier & Baker 2006); (2) aggregating results by zones, when some areas are over represented. This procedure gives equal analytical weight to each subregion, thus reducing biases linked to over-representation (Kull 2005); (3) analysing the background, away from the main interest of the original photographer (Debussche et al. 1999); (4) dividing a view in multiple units or contrarily gathering different views to form a single unit (Kay 2003; Kull 2005; Zier & Baker 2006; Bullock & Turner 2010; Klett 2010); (5) transferring results into maps to determine areas with equal regional trend; (6i) using graphical representations to illustrate the state of vegetation over time (Kull 2005).

One major handicap hampering historical photography analysis can be the difficulty in identifying plant species (Pickard 2002; Start & Handasyde 2002; Hoffman & Toold 2010). Some other troublesome issues were also referred, as evaluation of: (1) composition and structure inside the forest stand (Moseley 2006); (2) density of the forest due to indistinct crown closure (Rhemtulla *et al.* 2002); 2002), (3) changes in communities of herbaceous species (Kay 2003). Although many authors have mentioned these limitations few solutions were proposed. Moseley (2006) suggested intensive fieldwork to overcome failures but this is not possible for old photographs since the time elapsed prevent confirming in field the species seen in the historical photograph. Contrarily to aerial photography, which has developed plenty bibliography aiming species recognition (e.g. Sayn-Wittgenstein 1978), this was not a matter of concern of ground-based photography. Possibly, because plants are seen in their characteristic appearance due to the horizontal perspective view, they are recognised more easily (Malde 1973; Kull 2005). Anyhow, if vegetation types persist in present landscape it is always possible to assume similar classes to currently seen in the repeated photograph (Clark & Hardegree 2005).

4.1.2 Repeat landscape photography: advantages in the context of landscape of Madeira Island

As previously highlighted, repeat landscape photography technique made possible to analyse relative vegetation cover and to assess change and vegetation dynamics although not giving the same type of quantitative data as other standard methods such as aerial photography and satellite based imagery. But, even if it cannot replace those methods in vegetation research, it can be of much use in collecting information when there are no other records or when information is not very clearly specified (Debussche *et al.* 1999; Start & Handasyde 2002; Western 2010). And, in some circumstances, it has advantages over those methods (Malde 1973), as it is the case of Madeiran landscape (Pupo-Correia *et al.* in press-b). The oblique perspective of landscape photography makes easier to recognise landforms, being possible to locate the landscape depicted in historical photographs and to establish the photo point because peculiar terrain features are seen in habitual form. Moreover, it also facilitates seeing vegetation on vertical escarpments as it was stressed by several authors (e.g. Malde 1973; Kull 2005; Gruell 2010; McClaran *et al.* 2010), wich is of particular relevance because being Madeira Island dissected by deep ravines (see point 1.1) the details on those cliffs are not sufficiently well resolved in aerial photography (Figure 4.1). This can be of particular importance in places with high level of hemeroby where areas seen in vertical imagery are greatly covered by exotic vegetation whereas native vegetation is virtually restricted to steep cliffs (Capelo *et al.* 2004). Also, in addition to enable seeing the vegetation on vertical escarpments, because they are seen as it allows to recognise plant species in old photographs, with high level of accuracy, with no need for specific training as for aerial photography interpretation (Sayn-Wittgenstein 1978).

Figure 4.1 Same cliff seen in aerial imagery (Orthophotomap IGP 2007) and ground-based photography (MS, AP 2011)

Furthermore, it allows to reach a much older record of the landscape. As previously state, the aerial photography, that was invented in the mid nineteenth century, was only improved upon around 1930 (Rhemtulla *et al.* 2002; Kull 2005) and although it has become very common in the 40s the cover with aerial imagery was only made many years later, even in the most developed countries (Debussche *et al.* 1999). Satellite imagery, for its part, have been solely implemented in 1972 (Kull 2005). Therefore, the remote sensing methods evaluate the change during a time period that may be too short in ecological terms. On the contrary, ground-based photography that became very popular in the late nineteenth century, allows to analyse much larger intervals, and they are often the sole source to gather data over a period when major changes happened (Debussche *et al.* 1999; Pickard 2002; Rhemtulla *et al.* 2002; Kay 2003; Clark & Hardegree 2005; Kull 2005; Gruell 2010). In relation to Madeiran landscape, because the earliest aerial photography of Madeira territory was taken in the 1960s those ground based pictures are the unique photographic record of landscape prior to that date (Pupo-Correia 2007). Particularly insofar as those photographs taken since late nineteenth century are a source of information over a period of agriculture and forest over-exploitation, when a great number of exotic plants were introduced (Menezes de Sequeira *et al.* 2007), and covering periods of land abandonment due to emigration cycles [1] (Corrêa 1927; Góis 1977; Pereira 2011).

Finally, even though not constituting a specific advantage for the peculiarities of Madeiran landscape, being ground-based photography a low-technology tool it is less costly and clearly more favourable when level funding is low (Kull 2005; Gruell 2010). Being possible to take photographs more often, had enabled that in the past a plethora of photographs showing the same landscape were taken, which consequently allows to document a wider variety of conditions and, to get a better understanding of the landscape evolution by providing information of interim changes.

4.1.3 Objectives

The objectives that established the main lines of the work presented in this chapter aimed to provide answers to some key questions mentioned in the general introduction[2] being, therefore, related to the main aim of this thesis that was to evaluate progressive change of the landscape in Madeira Island, by assessing spatial and temporal vegetation dynamics, i.e.:

(1) to get adequate number of photograph pairs to ensure a meaningful statistical sample, by increasing the number of repeated photographs as well as implementing analytical methodologies to find the answers to the questions set out;

(2) to extend the quantitative analysis to photos distributed over shorter time intervals (75 and 50), striving for a better understand of time patterns.

4.2 Methods

The methodology that was used to achieve, prepare and analyse the photo pairs [original photo (Old) and repeat photograph (New)] was mainly based on approaches and techniques suggested by authors referenced in 4.1.1, with amendments and adjustments that were found to be able to tackle the issues addressed within that point, and also the study area specificities (Pupo-Correia *et al.* 2014). They are set out below following same order as in introduction of this chapter: (4.1.1.1) Collecting and selecting images; (4.1.1.2) Re-photographing; (4.1.1.3) Analysing the images.

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[1] Since the nineteenth century that different events resulted in emigration flows. On this subject have been pointed out several crises that affected main agricultural productions [e.g. vineyards devastation by powdery mildew in 1852, and by phylloxera in 1872 (Corrêa 1927) which lead mass emigration of winegrowers]. These crises affected all sectors, but greatly agricultural domain which undergone significant changes due to land abandonment or switch to other crop type or (Góis 1977). Another cause of emigration flow were the problems associated with overpopulation and the limited resources forcing people to leave in search of better conditions, also with repercussions on rural landscape (Corrêa 1927, Natividade 1953).

[2] (1) what changes occurred over forsaken agricultural fields? (2) did native vegetation recovered following a gradual and continuous process over last hundred years or otherwise suffered a cyclical effect over time, alternating between destruction and restoration at shorter intervals? (3) did the recovery of native vegetation followed the successional model proposed by Capelo *et al*. (2004)?)? (4) what was the behaviour of exotic plants introduced throughout time?

4.2.1 Collecting and selecting images

The historical photographs taken from the late 1800's and first half of the 20th century were gathered mainly from two local public institutions [Madeira Regional Archive (ARM) and Forest Service archive (DRF)]; two private collections [A. Conceição (HCC), A. Nóbrega (AN)], and some were also downloaded from web sites[1] and purchased from antique dealers[2], constituting a private collection allocated to this project (AP). The historical photographs, collected as digital images or paper prints which were subsequently digitised with an HP *scanjet* 4470c scanner into 8-bit grey-scale images in TIFF format providing a collection of 1193 potentially useful landscape photographs, which was initiated in 2004 and used in former research (Pupo-Correia 2007, p.46), and enhanced in the ensuing years.

Figure 4.2 Historical photograph of mountains surrounding Curral das Freiras village, by the end of 19th century (by unknown photographer, AN Collection).

Unlike other repeated photography projects, which solely used photographs in horizontal orientation, in this research photographs with vertical dimension were also selected since many of the photographs depicting Madeiran landscape have this format (Figure 4.2) due to hilly terrain. Only photographs depicting areas of natural landscape, and rural landscape were chosen, being brushed aside the ones showing exclusively urban-industrial landscape. A further relevant issue taken into account, during photographs search was the recognition of the view in order to enable the location of the landscape. However it was also collected a large number of photographs of unrecognised places showing high landscape value, in expectation of being located later on.

From this first group were removed photographs capturing only close-up of vegetation, undated photographs or without any clue to enlighten about the age[3], and photographs with poor quality, either due degradation over time or

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[1] e. g. www.madeiraarchipelago.com, a royalty free stock web site with photos of Madeira Island (MA).

[2] Antique fairs and www.ebay.com.

[3]. Not knowing the exact age of the historical photographs it is an obstacle to their use. Only HCC and DRF collections had accurate information about the date they were made, the former because photographs were taken by a single photographer during the 1950s (Gabriel Cardoso), and the latter because they were taken when the local Division of National Forest Service (*Circunscrição Florestal do Funchal*) was being set up in early 1950s. Dating photographs included in all other collections, which being from very diverse sources besides showing a large temporal variation were undated, it was possible because some of early photographers signed their work. Although the identity of the photographer was the primary source of age information further historical research about some details seen in historical landscape also allowed photographs dating (Pupo-Correia *et al*, 2014) (appendix 4).

original lighting conditions (Figure 4.3-a) or even because they were hand-coloured as it was usual in the late 19th and early 20th centuries (Figure 4.3-b), both situations enabling species and vegetation identification.

Figure 4.3 Examples of shelved photographs due reduced quality. Photographs of Curral das Freiras (a, b), taken in early 20th century [by unknown photographers, AP Collection].

The historical photographs gathered to be allocated to this project came from a wide range of sources, and were made with different purposes[1]. In so far as the original photographs were not taken systematically or randomly, quite the contrary, most of the photographs meant to record the scenery seen from popular sightseeing points or were taken in easily accessible sites, which could lead to over or under-representation of specific vegetation communities or overestimation of anthropogenic cover, the subsequent selection was targeted to get a set distributed across elevation gradients, vegetation types, and throughout the entire study area (Figure 4.9), and photographs with about same age showing very large overlapped sections were taken away, as measure to avoid bias like it was noted by several authors (Rhemtulla *et al.* 2002; Kull 2005; Zier & Baker 2006; Bullock & Turner 2010).

The photographs in this collection were stored in a database (Microsoft Access) specially developed for this purpose, also containing relevant information about the photograph and landscape depicted.

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[1] Except the photographs from Forest Services archives, which aimed forest surveys (CFF 1952-1959) where vegetation was the main focus, most of the photographs were made to retain another sort of memories. Some were made just for artistic flair, others to record important events and family outings but, above all, a great amount of those photographs were taken due to early tourism industry, both by tourists themselves and by local photographers to sell them as souvenir (Pupo-Correia 2011) (appendix 3)

4.2.2 Re-photographing

The replicas of historical photographs were acquired from the same point and camera axis orientation (Figure 4.4) as the original images [large format, high resolution (TIFF quality) with two cameras: Nikon D200 equipped with AF-S Nikkor 18-70 mm lens, and Cannon EOS 60D equipped with EF-S 17-85 IS VS11 lens]. The wide-angle lens was used not only to prevent loss of historical information from the image periphery of old photographs, normally made in large format, but also to cover a larger field of view and to avoid losing information during trimming operations (see point 4.2.3-4).

Figure 4.4 (a) Old photograph showing Lugar de Baixo, south coast, in mid 1950s (by Gabriel Cardoso, HCC Collection). Relocation at the point where the original photographer stood, 2011 (AP, ZF).

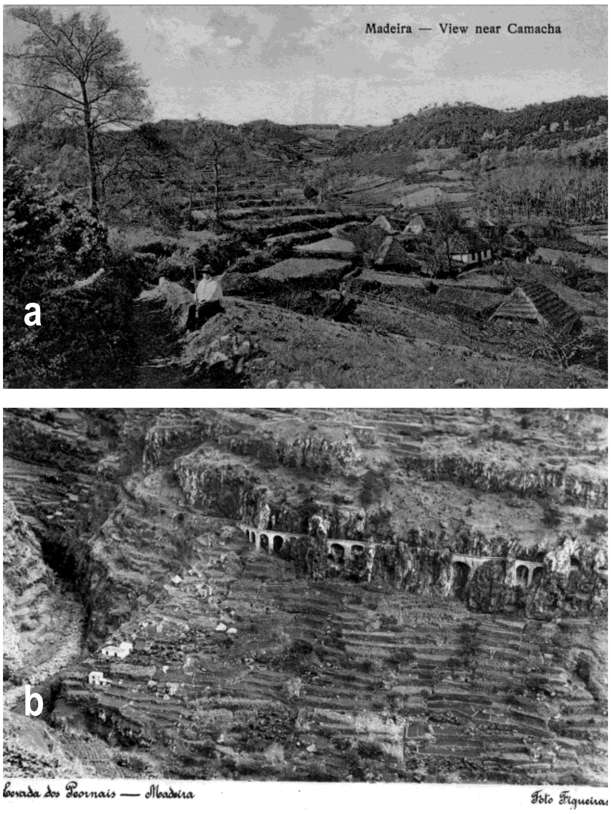


Figure 4.5 (a) Old postcard depicting a view near the village of Camacha in early 20th century [by unknown photographer (AP Collection)], and (b) photograph of Levada dos Piornais, near Funchal, mid 1930s, taken to be sold as souvenir (by Figueiras photographers, AP Collection).

Finding the general location of the landscape photographed and the point where the original photographer stood was achieved by following some of the helpful hints of former authors, and it was largely facilitated by the knowledge of the region. The majority of photographs that was possible to locate were taken for touristic purpose (Figure 4.5) and those that did not have indication of the locality often depicted views that still are popular sightseeing places nowadays, which made this step much easier.

For placing the camera in the exact position and height above ground was used a coarse “cross-hair” grid drawn on a printed copy to compare the view and to line up features, on the right and on the left, and in the foreground and background. Image orientation was established by the intersection of the lines that cross the fiducial marks [a simplification of the aerial photography method to identify the principal point (Lillesand & Kiefer 1994)]. To obtain maximum stability a tripod was used, but when impractical photos were taken hand-held. To verify if the position was correct the features observed in the printed photograph and in the digital image were compared, and to solve the concerns expressed by previous authors, under bright sunlight was added a shade and brightness levels of the LCD were adjusted.

Whenever it was impossible to repeat photographs from the exact location [the place for the retake was no longer accessible or the original view was hidden by constructions/vegetation that grew in the foreground (Figure 4.6)] those photographs were removed from the set, except when the original view was only partly hidden allowing a sectional analysis.

Sometimes, after locating the site, weather conditions [e.g. fog (Figure 4.7)] prevented retaking the photograph, making necessary to revisit the site on a different day. While it was possible to infer time of day and season for the vast majority of situations, and thus replicating light and shadows, photographing at noon or during overcast days blunted this issue.

Part of field notes within the context of this work were collected and set down with the view to allow using these repeated photographs in future projects, and therefore they included: name of location; description and a sketch of path and site; GPS coordinates; date; time of day, and to this record was added a photograph showing the exact position where the camera should be placed to retake the photograph. This information, along with captured images, was stored in the database previously referred.

Figure 4.6 (a) Historical photograph showing the landscape near Camacha village, mid 1930s (by Figueiras photographers, AP Collection). (b) Vegetation that grew in the foreground prevented re-photographing the landscape.

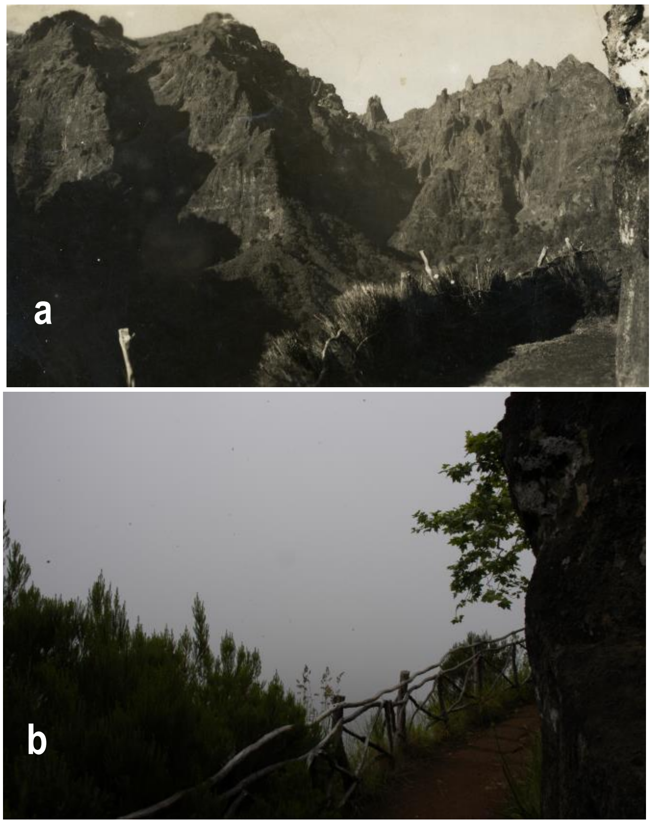


Figure 4.7 (a) View from Balcões sightseeing point, in Ribeiro Frio, at the beginning of the 20th century (by Perestrellos Photographers, ARM Collection). (b) Bad weather conditions resulting in postponement of photograph retake.

4.2.3 Analysing the images

Because this research aimed to quantitatively evaluate historical landscape changes and to analyse vegetation successional trends, some procedures were oriented to allow quantification and also to minimise bias. As it was previously raised, although ground-based photography is widely recognised as a useful tool for land cover vegetation analysis, the oblique angle hinder the direct application of methods that were developed to standard remote sensing imagery, such as aerial photography, being necessary to adjust those methodologies and developing some others:

4.2.3.1 To deal with problems related with the low oblique angle (see 4.1.1.3) plans presenting an extreme difference in distance to the camera were considered as distinct sample units, in order to minimise the consequences of scale variability (Figure 4.8); and areas hidden by landforms or high vegetation were not considered for analysis. Even when alteration in the foreground revealed new areas they were overlooked and only parts seen in both images were appraised.

4.2.3.2 To overcome limitations related to historical photographs the photos were grouped in three sets of photographs (Table 4.1 and Figure 4.9) spanning different time interval ([100-125[, [75-100[, [50-75[years old), in order to minimised the lack of uniformity in date and time frame within the collection, and folowing Kull (2005) suggestion photographs were grouped by sub-regions, in order to reduce bias linked to over-representation. There were considered three sub-regions: South coast, Inland, North coast (Table 4.1). In view of peculiarities of Madeira Island relief it was considered as “inland” the areas on the top of the mountains and locations of photographs, that were considered by Silva & Menezes (1946a, b, c) as “localities of the interior”.

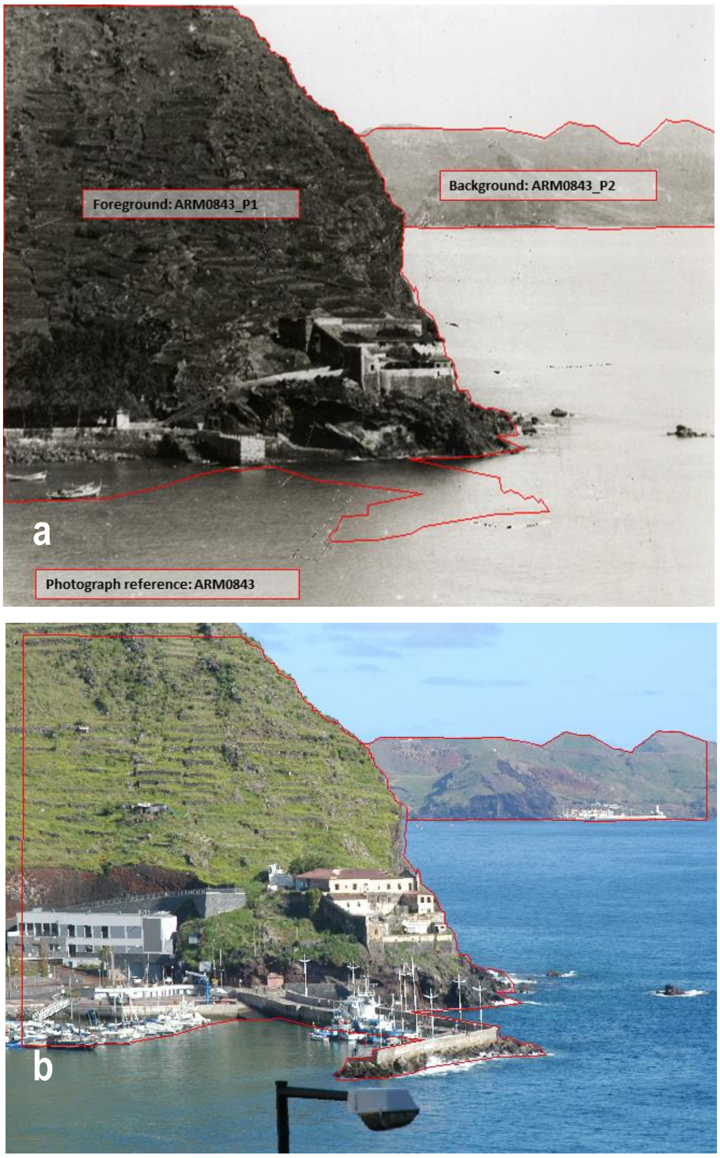
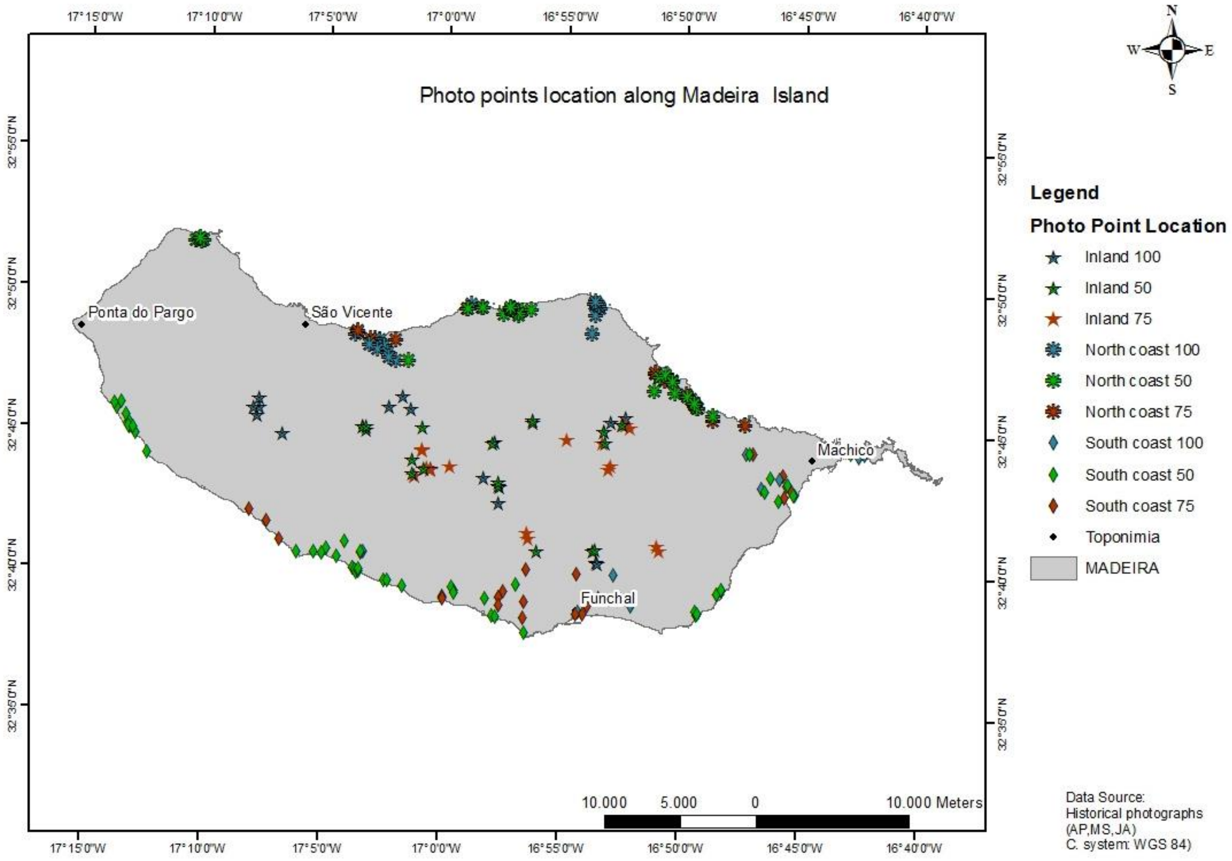


Figure 4.8 Machico (foreground) and Caniçal (background) in (a) late 19th century (by unknown photographer, ARM Collection), and in 2006 (AP, JP). Red line delimits the plan to be sampled.

Table 4.1 Samples grouped according time intervals ([100-125[, [75-100[, [50-75[), and sub-regions (South coast, Inland, North coast).

	Age brackets			
Sub-region	[100-125[	[75-100[	[50-75[	Total
South coast	**11**	**25**	**46**	82
Inland	**21**	**17**	**20**	58
North coast	**24**	**13**	**24**	62
Total	56	55	90	202



Data Source:
Historical photographs
(AP,MS,JA)
C. system: WGS 84)

Figure 4.9. Location of historical photographs across the study area.

4.2.3.3 To identify species and vegetation classes were followed some suggestions made by aerial photo interpreters: Tree species were identified based on crown shapes and branching habits [Figure 4.10 (a_1) *Pinus pinaster*], and smaller plants were also identified in the foreground based on size, texture, foliage pattern and sometimes the shape of the leaves [Figure 4.10 (b) *Rubus* sp., (c) *Pteridium aquilinum,* and (d) *Erica* sp.].

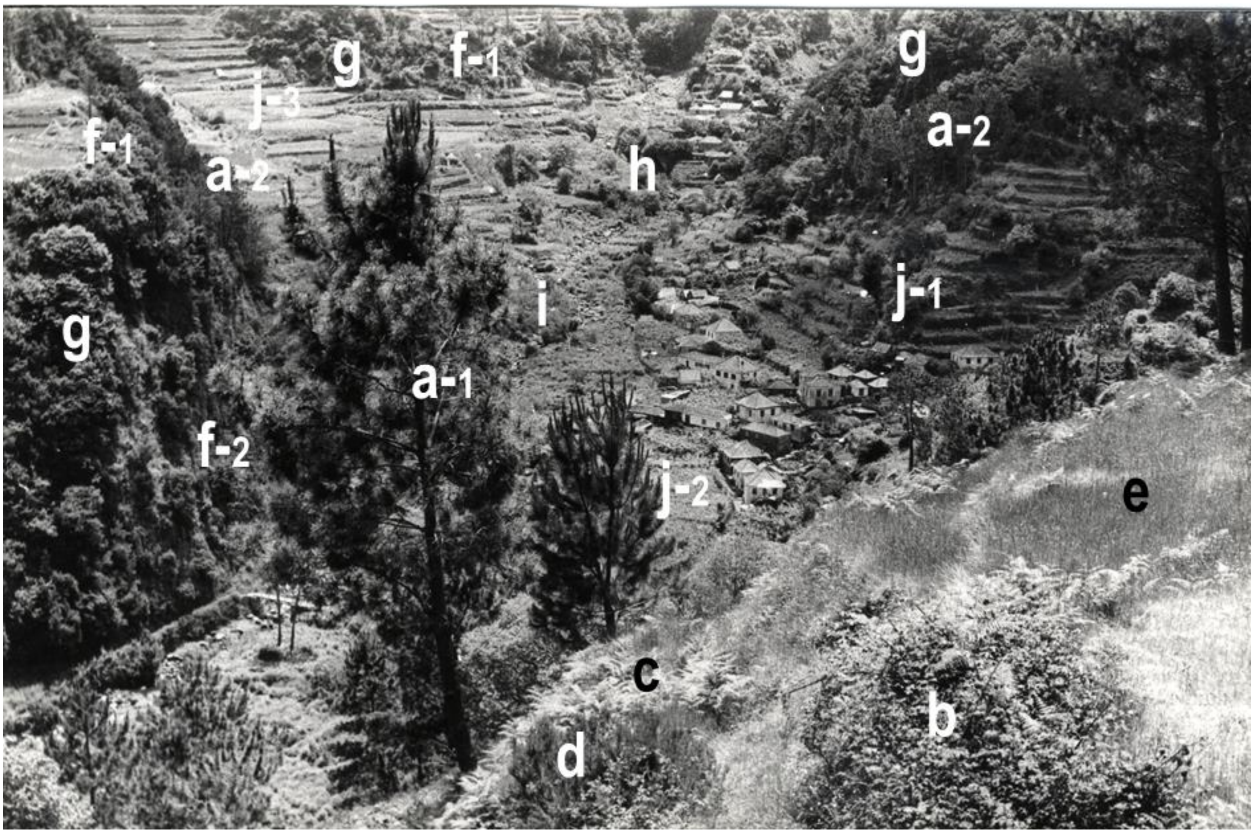


Figure 4.10 Inland by mid-20th century [by unknown photographer (ARM Collection)] showing: (a-1, a-2) *Pinus pinaster*; (b) *Rubus* sp; (c) *Pteridium aquilinum*, (d) *Erica* sp; (e) Plant community dominated by native annual forbs and grasses; (f) Plant community dominated by high–scrub and low-scrub species belonging to natural hedges and substitution stages of climatophylous series (f-1), or as permanent community in very steep cliffs (f-2); (g) Plant community dominated by tree species belonging to the forest stage of climatophylous series; (h) Plant community dominated by tree species belonging to the hygrophillic forests; (i) *Arundo donax*; (j) Agricultural terraces with (j-1) diverse agriculture, (j-2) vineyards, and (j-3) cereal crops.

As the scale decreases those features became useless and identification has to be based on spatial organisation, photographic tone and texture (Figure 4.10-a$_2$, f, g, h, i, and j). Identification of plant communities, in old photographs was based on visual similarity to the pattern of assemblages seen in new images. Species and communities recognition in the new photographs was facilitated by colour and supported by supplementary photographs taken with long focal length lens (Pupo-Correia *et al.* 2014) and field data (floristic inventories and phytosociologial relevés). *Taxa* identification was based on Press & Short (1994) and the identification of vegetation types followed the model proposed by Capelo *et al.* (2004).

4.2.3.4 To enable the quantitative assessment of vegetation change and dynamics, the photo pairs have to show landscape features placed in the same relative image coordinates to allow comparison (see 4.1.1). However, even if taken from the exact same point the photographs are not strictly identical and a better match is obtained by spatially registering the new photograph to the historical image (Figure 4.11).

The *New photograph* was co-referenced to *Old photograph* by using remote sensing and geographic information system technologies (ArcGIS 9.3). The new photograph was made semi-transparent, so the old one could be seen through, to look for common features to identify possible control points.

Figure 4.11 Resampling procedure: adjusting the replica to the historical image (same X Y image coordinates). Reis Magos, South coast, (a) by 1950s (by unknown photographer, DRF Collection); (b) Replica made in 2006 (MS, AP); (c) Old and Resampled-New images (overlapped).

It was used a *Georeferencing* tool to place landscape features in same relative coordinates in both images, with at least four control points (i.e. distinctive features seen in both photographs), in order to assign both photographs under a relative error (root mean square error) ≤ 0.05 pixel. This process causes spatial distortion, but because the repeated photographs were taken with larger field of view, there was no loss of information on the image periphery when clipping the new photograph by the size of the old photograph (Figure 4.12).

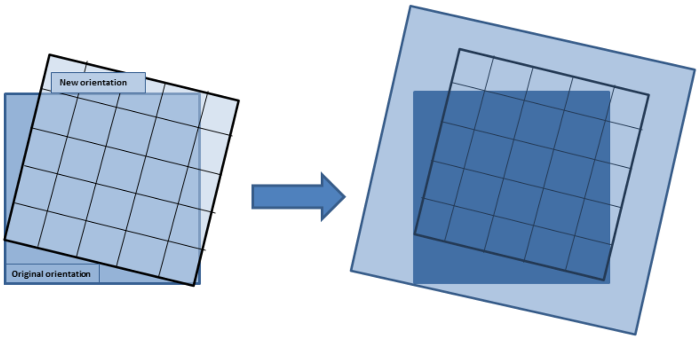
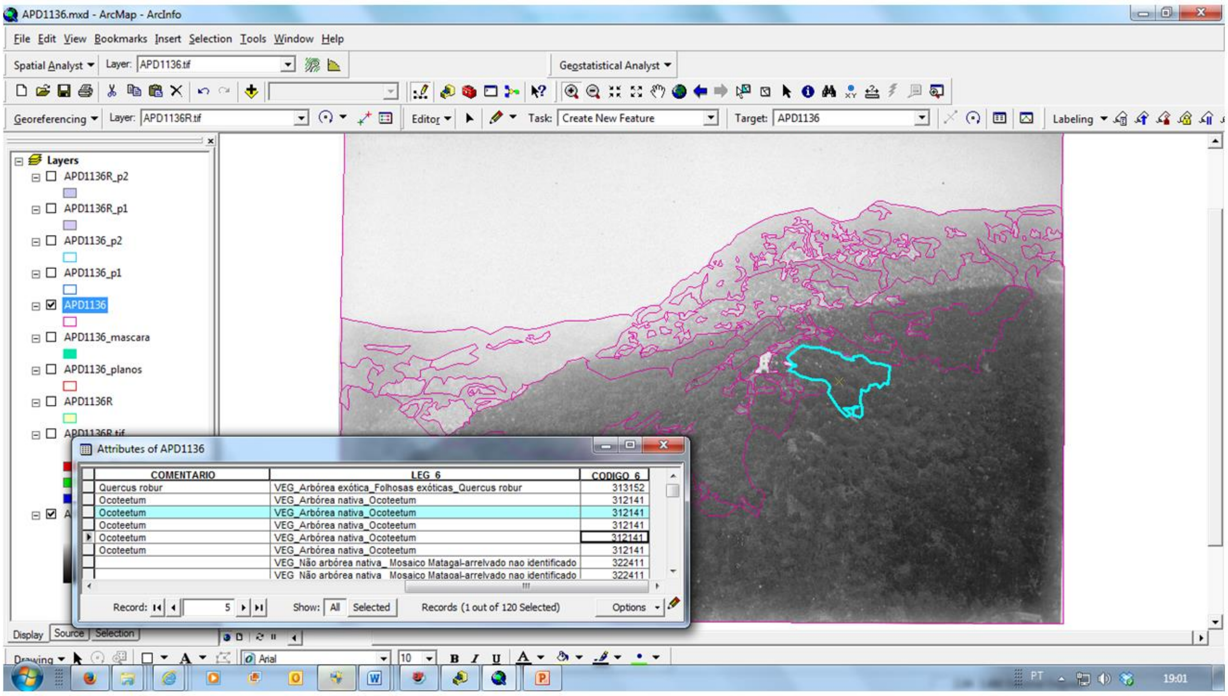


Figure 4.12 Diagram showing distortion of the new image during the procedure to register spatially this image to the old one (modified from Eastman 2001).

4.2.3.5 Same software (ArcGIS 9.3) was used to classify landscape features by creating vector files (*shapefiles*), with polygons representing distinct land coverage types (supervised classification). Relevant characteristics of the features were stored in *attribute tables* (text data fields containing a land cover code and a feature characterisation) (Figure 4.13). Landscape sections seen on different photos about the same age were classified in only one of them to avoid biased sampling.



COMENTARIO	LEG_6	CODIGO_6
Quercus robur	VEG_Arbórea exótica_Folhosas exóticas_Quercus robur	313152
Ocoteetum	VEG_Arbórea nativa_Ocoteetum	312141
Ocoteetum	VEG_Arbórea nativa_Ocoteetum	312141
Ocoteetum	VEG_Arbórea nativa_Ocoteetum	312141
Ocoteetum	VEG_Arbórea nativa_Ocoteetum	312141
Ocoteetum	VEG_Arbórea nativa_Ocoteetum	312141
	VEG_Não arbórea nativa_ Mosaico Matagal-arrelvado nao identificado	322411
	VEG_Não arbórea nativa_ Mosaico Matagal-arrelvado nao identificado	322411

Record: 5 Show: All Selected Records (1 out of 120 Selected) Options

Figure 4.13 Polygons creation for supervised classification of landscape features (screenshot showing procedure).

4.2.3.6 Despite the advantages of using a pre-defined classification system, because it was not possible to know *a priori* what classes would be found, mainly in old photographs, classification was made by describing all land cover features depicted in the photographed landscape. To cope with the resultant heterogeneous legend, after completing this phase, all attribute tables were analysed and converted into a classification system created to deal with the variety of classes found. Land cover classes definition is mandatory in cartography procedures and must be created according to rules easily understood by people using or analysing maps. The Land cover classification system as presented in Table 4.2 (for further detail see appendix 2) resulted from the adaptation of nomenclature of CORINE Land Cover (CLC), the European Union land cover project, running from 1990, in which classes are organised in three levels, from five general classes in level one, fifteen classes in level two, and so on in a crescendo of complexity and specificity (Caetano *et al.* 2009). Since it was needed a much more specific definition of land cover to cope with plant species that do not exist in European mainland, and to deal with the details inherent to the larger scale, it was created a land cover classification subjected to the specific features of Madeira Island vegetation. Thus a legend for three, four, five and six level was created, being classes in such system hierarchically arranged in order to describe different level of detail, from coarse differentiation to stricter levels of the classification. Some classes were not intentionally described in detail, and remained with the general level one denomination, for others was sought a more detailed distinction [e.g. Class three (*Vegetation*) for which it was made a differentiation within level six].

Table 4.2 Codes and designations of land cover classes, from level one to level six, which are related to the features of each of the six major cover classes identified. Designations light grey highlighted correspond to the 143 classes of the higher level of classification (sixth level).

Land Cover Classes

Code	Designation	General Description/codes included up to level six
First Level		
1	Construction	11; 111; 1111; 11111; 111111.
2	Agriculture	(second level).
3	Vegetation	(second level).
4	Bare ground	(second level).
5	Water	51; 511; 5111; 51111; 511111.
6	Non-sampled	61; 611; 6111; 61111; 611111.

Agriculture Cover Classes

Code	Designation	Codes included up to level six
Second Level		
21	Unidentified/varied agriculture	211; 2111; 21111; 211111.
22	Permanent cropland	(third level).
23	Seasonal cropland	(third level).
24	Set-aside land	(third level).
Third Level		
221	Orchards	2211; 22111; 221111.
222	Vineyards	2221; 22211; 222111.
223	Banana tree plantations	2231; 22311; 223111.
231	Vegetables crops	2311; 23111; 231111.
232	Cereals crops	2321; 23211; 232111.
233	Sugar cane plantations	2331; 23311; 233111.
241	Forsaken fields	2411; 24111; 241111.
242	Fallow agricultural land	2421; 24211; 242111.

Vegetation Cover Classes

Code	Designation	Codes included up to level six
Second Level		
31	Forest vegetation	(third level).
32	Non-forest vegetation	(third level).
33	Forest/ Non-forest vegetation mosaic	(third level).
34	Degraded vegetation	(third level)
Third Level		
311	Unidentified trees	3111; 31111; 311111.
312	Native trees	(fourth level).
313	Exotic trees	(fourth level).
314	Mixture of native and exotic trees	3141; 31411; 314111.
321	Unidentified shrubby vegetation	3211; 32111; 321111.
322	Native non-forest vegetation	(fourth level).
323	Exotic non-forest vegetation	(fourth level).
324	Mixture of native and exotic non-arboreal plants	3241; 32411; 324111.
331	Mosaic of climx community and substitution stages	(fourth level).
332	Mixture of native trees and exotic non-arboreal plants	(fourth level).
333	Mixture of exotic trees and native non-arboreal plants	(fourth level).
334	Mixture of exotic trees and exotic non-arboreal plants	(table fourth level).
335	Mixture of trees and non-arboreal plants (exotic and native)	3351; 33511; 335111.
341	Burnt vegetation	3411; 34111; 341111.
342	Landslide	3421; 34211; 342111.
343	Uncovered soil	(fourth level).

Fourth Level

3121	Climatophylous communities	(fifth level)
3122	Edaphohigrophylous communities	(fifth level)
3131	Hardwood forests	(fifth level)
3132	Softwood forests	(fifth level)
3133	Mixture of hardwood and softwood trees	31331; 313311.
3221	Native scrubland	(fifth level).
3222	Native grassland	(fifth level)
3223	Mixture of native shrubs and *Rubus* spp.	32231; 322311.
3224	Mosaic of native scrubland and grassland	(table fifth level).
3225	Rupicolous vegetation	(fifth level)
3226	Hygrophilic vegetation	(fifth level).
3227	Coastal vegetation	32271; 322711.
3231	Exotic shrubs	(fifth level).
3233	Exotic herbs	(fifth level).
3234	Mixture of exotic shrubs and herbs	(fifth level).
3235	*Arundo donax*	32351; 323511.
3311	Mosaic of natural vegetation assemblages (Unidentified communities)	33111; 333111.
3312	*Oleetum* and seral stages	(fifth level).
3313	*Apollonietum* and seral stages	(fifth level).
3314	*Ocoteetum* and seral stages	(fifth level).
3315	*Ericetum* and seral stages	(fifth level).
3321	Native trees and exotic shrubs	(fifth level).
3322	Native trees and exotic herbs	33221; 332211.
3331	Exotic trees and native shrubs	(fifth level).
3332	Exotic trees and native herbs	(fifth level).
3341	Exotic trees and exotic shrubs	(fifth level).
3342	Exotic trees and exotic herbs	(fifth level).
3431	Bare soil	34311; 343111.
3432	Soil with very sparse vegetation	34321; 343211.

Fifth Level

31211	*Mayteno umbellatae-Oleetum maderensis*	312111.
31212	*Helichryso melaleuci-Siderxyletum marmulanae*	312121.
31213	*Semele androgynae-Apollonietum barbujanae*	312131.
31214	*Clethro arboreae-Ocoteetum foetentis*	312141.
31215	*Polysticho falcinelli-Ericetum arboreae*	312141.
31221	*Rhamno glandulosi-Sambucetum lanceolati*	312211.
31222	*Diplazio caudati-Perseetum indicae*	312221.
31223	*Scrophulario hirtae-Salicetum canariensis*	312231.
31311	*Acacia* spp.	(sixth level).
31312	*Eucalyptus globulus*	313121.
31313	*Pittosporum undulatum*	313131.
31314	*Castanea sativa*	313141.
31315	*Quercus* spp.	(sixth level).
31317	*Salix babilonica*	313171
31318	*Phoenix canariensis*	313181
31319	Mixture of hardwood trees	313191.
31321	Softwood forests- *Pinus* spp.	(sixth level).)
32211	Scrubland seral stage	(sixth level).
32212	topographical climax	(sixth level)
32221	Perennial grassland seral stage	(sixth level).
32222	*Pteridium aquilinum*	322221.
32223	Annual grassland seral stage	(sixth level).
32224	Assemblage of non-seral herbaceous annual plants	322241.
32241	Mosaic of native scrubland and grassland (Unidentified communities)	322411
32242	Mosaic of scrubland and perennial grassland	(sixth level).

32243	Mosaic of scrubland and annual grassland	(sixth level).
32251	Unidentified rupicolous vegetation	322511
32252	*Sedo nudi-Aeonietum glutinosi*	322521
32253	*Sinapidendro gymnocalicis-Sedetum brissemoreti*	322531
32254	*Musschietum aureae*	322541
32261	Unidentified hygrophilic vegetation	322611
32262	Community with *Phragmites australis*	322621
32263	Community with *Juncus acutus*	322631
32264	*Deschampsietum argenteae*	322641
32311	High and low exotic bushes	(sixth level).
32312	Exotic climber-scrubs	(sixth level).
32331	Exotic Perennial herbs	(sixth level).
32332	Exotic annual herbs	(sixth level).
32341	Mixture of exotic shrubs	323411
32342	Mixture of exotic shrubs and herbs	323421
33121	*Oleetum* and scrub community	(sixth level).
33122	*Oleetum* and grassland community	(sixth level).
33131	*Apollonietum* and scrub community	(sixth level).
33132	*Apollonietum* and grassland community	(sixth level).
33141	*Ocoteetum* and scrub community	(sixth level).
33142	*Ocoteetum* and grassland community	(sixth level).
33151	*Ericetum* and scrub community	(sixth level).
33152	*Ericetum* and grassland community	(sixth level).
33211	Native trees and high and low exotic bushes	332111
33212	Native trees and exotic climber-scrubs	332121.
33311	Exotic trees and native shrubs	(sixth level).
33312	*Rubus* spp.	(sixth level).
33321	Exotic trees and native perennial herbs	(sixth level).
33322	Exotic trees and native annual herbs	(sixth level).
33411	Exotic trees and exotic shrubs	(sixth level).
33412	Exotic trees and exotic climber scrubs	(sixth level).
33421	Exotic trees and exotic perennial herbs	(sixth level).
33422	Exotic trees and exotic annual herbs	(sixth level).

Sixth Level

313111	*Acacia* mearnsii
313112	*Acacia* sp.
313151	*Quercus robur*
313152	*Quercus ilex*
313211	*Pinus pinaster*
313212	*Pinus* sp.
322111	*Euphorbietum piscatoriae*
322112	*Artemisio argenteae-Genistetum tenerae*
322113	*Myrtus communis–Hypericetum canariensis*
322114	*Globulario salicinae-Ericetum arboreae*
322115	*Vaccinio padifoli-Ericetum maderincolae*
322116	*Bystropogono puntacti-Telinetum maderensis*
322117	Community of *Erica maderincola*
322118	*Argyranthemo montanae-Ericetum maderensis*
322121	Community of *Euphorbia piscatoria*-Topographical climax
322122	*Vaccinio padifoli-Ericetum maderincolae-Topographical climax*
322211	*Cenchro ciliaris-Hyparrhenietum sinaicae*
322212	*Dactylo hylodes-Hyparrhenietum sinaicae*
322213	*Pericaulido auritae-Geranietum palmatae*
322215	*Vicio capreolatae-Odontietum hollianae*
322214	*Teucrio francoi-Origanetum virentis*
322231	*Galactito tomentosae-Brachypodietum distachyae*
322232	*Campanulo erini-Wahlenbergietum lobelioidis*

322233	*Leontodo longirostris-Ornithopetum perpusilli*
322421	*Euphorbietum/Hyparrhenietum*
322422	*Hypericetum/Hyparrhenietum*
322423	*Ericetum/Hyparrhenietum*
322424	*Ericetum/Geranietum*
322425	*Ericetum/Odontietum*
322426	*Ericetum/Origanetum*
322431	*Euphorbietum/Brachypodietum*
322432	*Euphorbietum/Wahlenbergietum*
322433	*Hypericetum/Wahlenbergietum*
322434	*Ericetum/Wahlenbergietum*
322435	*Ericetum/Ornithopetum*
323111	*Cytisus* spp.
323112	*Ulex* spp.
323113	*Opuntia tuna*
323114	*Solanum mauritianum*
323115	*Tamarix gallica*
323116	*Agave americana*
323117	*Nicotiana glauca*
323118	*Hedychium gardnerianum*
323119	*Ageratina adenophora*
323121	*Cardiospermum grandiflorum*
323122	*Podranea ricasoliana*
323123	*Passiflora molissima*
323311	*Brachiaria mutica*
323312	*Pennisetum purpureum*
323313	*Oxalis pes-caprae*
323314	*Agapanthus praecox*
323321	*Tropaeoleum majus*
331211	Oleetum/*Euphorbietum*
331212	Oleetum/*Genistetum*
331221	Oleetum/ *Hyparrhenietum*
331222	Oleetum/ *Brachypodietum*
331311	*Apollonietum/Ericetum*
331312	*Apollonietum/Hypericetum*
331321	*Apollonietum/Hyparrhenietum*
331322	*Apollonietum/Wahlenbergietum*
331411	*Ocoteetum/Ericetum*
331412	*Ocoteetum/Telinetum*
331421	*Ocoteetum/Geranietum*
331421	*Ocoteetum/Ornithopetum*
331511	*Ericetum/*Community of Erica maderincola
331512	*Ericetum/Comun. Erica plathycodon*
331521	*Ericetum/Odontietum*
331522	*Ericetum/Origanetum*
331523	*Ericetum* and grassland community – *Ericetum/Ornithopetum*
333111	Exotic trees and native shrubs - Hardwood trees/native shrubs
333112	Exotic trees and native shrubs - Softwood trees/ native shrubs
33312	Hardwood trees/ *Rubus* spp.
33312	Softwood trees/ *Rubus* spp.
333211	Hardwood trees/ native perennial herbs
333212	Softwood trees/ native perennial herbs
333221	Hardwood trees/ native annual herbs
333222	Softwood trees/ native annual herbs
334111	Hardwood trees/exotic shrubs
334112	Softwood trees/exotic shrubs

334121	Hardwood trees/exotic climber scrubs	
334122	Softwood trees/exotic climber scrubs	
334211	Exotic trees and exotic herbs - Hardwood trees/exotic herbs	
334222	Exotic trees and exotic herbs - Softwood trees/exotic herbs	

Bare ground Classes

Code	Designation	Codes included up to level six
Second Level		
41	Bare rocks	(third level)
42	Slag heaps	421; 4211; 42111; 421111.
43	Superficial deposits of non-cohesive natural materials	(third level).
Third Level		
411	Bedrock in escarpments and cliffs.	4111; 41111; 411111.
412	Bedrock in banks and bed of water streams	4121; 41211; 412111.
413	Bedrock in rock outcrops	4131; 41311; 413111.
431	Coarse-grained sediments	4311; 43111; 431111.
432	Finely-grained sediments	4321; 43211; 432111.

Water Classes

Code	**Designation**	**Codes included up to level six**
Second Level		
51	**Ice**	511; 5111; 51111; 511111.
52	**Water body surfaces**	521; 5211; 52111; 521111.

4.2.3.7 To quantify the alteration, shapefiles of the sampled areas of each photograph pair [classified according to level six (see Table 4.2)] were intersected (*Intersect tool*): In the new shapefile created old land cover areas were assigned to new land cover areas. This new shapefile enable to get information about features or portions of features that overlap, to calculate geometric relationships between them (*Calculate Geometry tool*) and to create a contingency table for statistical changes analysis. The area values that were calculated meant to quantify the changes in image cover and not to measure the real surface area.

4.2.3.8 To process data, attribute tables were exported to Microsoft Office Excel, being analysed through contingency tables (as Table 4.3). All the 202 tables were created using level six codes which made possible to downgrade levels for more detailed land cover analysis.

Table 4.3 Contingency table corresponding to APD1136_P1 (seen in Figure 4.13), showing changes that occurred in features between two dates (light grey highlighted cells over diagonal line show what has remained unchanged), the percentage of each class in historical (TtOld%) and current landscape (TtNew%), percentage of gains and losses within each class and overall change (dark grey highlighted cell).

	Old												
New	111111	312141	313112	313151	322115	322411	323111	331411	411111	TtNEW	TtNew%	Gain	Gain%	Gain_NEW
111111	0.0022	0.0043		0.0098	00.0015	00.0076			0.0023	0.0277	0.4097	0.0255	92.0578	3.3582
312141	0.0178	2.2843		0.0024	10.4416	10.1849			0.4813	5.4123	80.0470	3.1689	58.1108	107.6302
313112		0.0349			00.0161					0.0510	0.7543	0.0510	100	New entry
313151	0.0068	0.0871		0.0135	00.0318	00.0114			0.0083	0.1589	2.3501	0.1454	91.5041	518.2879
322115		0.0037			00.3944	00.1634			0.0242	0.5857	8.6624	0.2019	33.8588	-73.4813
322411										0.0000	0	0.9658		-100
323111		0.0565			00.0088					0.0653	0.	0.0653	100	New entry
331411		0.1037			00.1374	00.0773			0.0138	0.3322	4.913184	0.3325	100	New entry
411111		0.0152			00.0478	00.0137			0.0516	0.1283	1.897536	0.0773	59.9690	-80.4460
TtOLD	0.0268	2.5897	0.0000	0.0257	2.07940	10.4583	0.0000	0.0000	0.5815	6.7614				
TtOld%	0.3964	38.3012	0	0.3801	30.7540	21.5680	0	0	8.6003					
Loss	-0.0246	-0.3054	0.0000	-0.0122	-1.6850	-1.4583	0.0000	0.0000	-0.5299					
Loss%	-91.7910	-11.7929	Perish	-47.4708	-81.033	-100	Perish	Perish	-91.1264		59.38			

For the calculations the values of class 6 (features not sampled as ocean, sky, background, and unmatched areas between old and new photo) were removed. The data underwent different mathematical approaches:

(i) It was calculated the percentage of each class in historical (% Old=Σcolumn/overall change value x100) and current landscape (%New=Σline/overall change value x100); the percentage of gains [(TtNew-Agreement value (diagonal cell)/TtNewx100], in which TtNew=Σ line, the percentage of losses [(Agreement value (diagonal cell)-TtOld)/TtOldx100], in which TtOld= Σ column, and it was determined the overall change that occurred in landscape between two dates [Alteration=100-(Σdiagonal cells/Σ all cells x 100].

(ii) Global alteration values of the photographs that have been grouped into nine categories (Table 4.1) were used to calculate median value within each area and each time bracket. To analyse spatial and temporal variation was used median as measure of central tendency because it is the one that best retains the central location and is not strongly affected when the data distribution is skewed, as it is in this case.

(iii) Contingency tables of photograph pairs showing change value under 50% were analysed to identify the Land Cover Class with the highest level of agreement between past and present. Frequency of each one of those classes, within this set of slightly modified landscapes was assessed. Differences between north-south and lowland-highland were analysed in the photograph groups dispersed in each area.

(iv) To get information on the causes of change, contingency tables were analysed, and the class with highest transition value was considered as the main reason of alteration. Within the set it was determined the frequency of each class ascertained as major cause of landscape change. Because it is not enough to know which class was the main responsible for alteration but also to get information on direction of change, the variation that occurred between two dates was determined by calculating percentage of alteration between past and present (%variation= %New-%Old) of all features of each contingency table. The values achieved for each class (taking into account codes of sixth level) were added to obtain a single value for each of the following classes: *Construction* (first level, Code 1); *Agriculture* (first level, Code 2), *Unidentified vegetation* (third level, Code 311, 321); *Native trees* (third level, Code 312); *Native shrubs* (fourth level, Code 3221); *Native herbs* (fourth level, Code 3222), *Exotic vegetation* (third level, Code 313, 323, 334), *Mixture of exotic and native vegetation* (third level, Code 314, 324, 332, 333), *Degraded vegetation* (second level, Code 34), *Bare rock* (first level, Code 4). Within each group the mean value for those classes was calculated.

(v) Native vegetation dynamics across study area was assessed by using ArcGIS tools (*Geostatistical Analyst*). The interpolation process of data from third level of classification (Code_3) was performed by means of *Inverse Distance Weighting* (IDW^2) using eight *Sector Types*, eight neighbours, and at least four neighbours. Concerning late successional stage of native vegetation types [*Native trees class* (Code 312)] were drawn maps, using as reference in the ground the central area of the landscape depicted in the photographs, which was geographically referenced. Were defined five classes based on Gain_New value (TtNew-TtOld/ TtOld x 100) calculated in each contingency table (see table XI): Class 1 - Did not exist/Still not existing (values=0); Class 2 – Existed/Disappeared (values= -100, or multiples); Class 3 – Existed/Diminished (negative values ≠ 100, or multiples); Class 4 – Existed/Increased (positive value≠10000 or multiple); 5 - Did not exist/Appeared (correspond to new entries, it was attribute a fictional value=10000). Over these maps was overlapped a shapefile with information of binary nature: 1 - Existed (classes 2, 3 and 4), and 0 - Did not exist (classes 1 and 5) created with data from third lever classification (Code_3) about the occurrence in the past of early successional stages of native vegetation, i.e. *Native non-forest vegetation class* (Code 322).

(vi) To check out the behaviour of the exotic species it was determined the frequency of exotic species seen in historical landscape and in current landscape, to get information about most common species then and now. To get information about the change experienced by past exotic vegetation, it was determined a mean value of agreement between past and present, and a mean value for the transitions that occurred from exotic plants identified in old photographs[1]. For exotic plants[2] identified in current landscape the contigency tables were analysed to get information about the features over which they grew up.

(vii) Transitions that occurred over forsaken agricultural fields were analysed in order to get information about vegetation that developed over these disturbed areas. Forsaken fields with remnants of former crops and the changes to construction were not considered. It was calculated the percentage of vegetation classes (Exotic plants [codes 313, 323, 334], Mixture of native and exotic plants [codes 314, 324, 332, 333, 335], Native trees [code 312], Native shrubs [codes 3221, 331], Native herbs [codes 3222, 3224]) in current landscape that grew over past cultivated areas [e.g. % Exotic vegetation =Σ Code 313, 323, 334/ (Tt Code 2-diagonal Code 2) x 100]. It was determined the mean value within each photograph group (e.g. South coast; [50-75[), and a mean value for the sub-region. It was also determined the frequency of each exotic species, as well as the frequency of each native community that reestablished over former agricultural land.

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[1] *Agave Americana* (Code 323116), *Arundo donax* (323511), *Castanea sativa* (Code 313141), *Eucalyptus globulus* (Code 313121), *Opuntia tuna* (323113), *Pinus pinaster* (Code 313211), *Quercus robur* (Code 313151), *Salix babilonica* (Code 313171) and *Tamarix galica* (Code 313115).

[2] *Acacia mearnsii* (code 313111), *Acacia* sp. [(code 313112), mainly *A. melanoxylon* and *A. longifolia*)], *Eucalyptus globulus* (code 313121), *Pittosporum undulatum* (code 313131), *Castanea sativa* (code 313141), *Quercus robur* (code 313151), *Quercus ilex* (code 313152), *Phoenix canariensis* (code 313181), *Pinus pinaster* (code 313211), *Pinus* sp. (code 313212), *Cytisus* spp. [code 323111 (Cytisus scoparius and C. striatus)], *Ulex* spp. [code 323112 (*Ulex europaeus* subsp. *europaeus* and *Ulex minor*), *Opuntia tuna* (code 323113), *Solanum mauritianum* (code 323114), *Tamarix gallica* (code 323115), *Agave americana* (code 323116), *Nicotiana glauca* (code 323117), *Hedychium gardnerianum* (code 323118), *Ageratina adenophora* (code 323119), *Cardiospermum grandiflorum* (code 323121), *Podranea ricasoliana* (code 323122), *Passiflora molissima* (code 323123), *Brachiaria mutica* (code 323311), *Pennisetum purpureum* (code 323312), *Oxalis pes-caprae* (code 323313), *Agapanthus praecox* (code 323314), *Tropaeoleum majus* (code 32321), *Arundo donax* (code 323511).

4.3 Results

The visual record which constitutes the photographic collection confirmed the wide destruction of native vegetation and its replacement by exotic tropical plants, in lower lands, and pine trees higher up, above farmlands, in the late 19th century and early 20th century (Figure 4.14) as it was described in contemporaneous written historical documents (for further detail see chapter 1, point 1.2.2).

Figure 4.14 (a) Old photographs from early 20th century: south face lowlands (b) and uplands (by unknown photographer, ARM).

Once these were selected following criteria exposed in methodology, and retaken the feasible ones, it was established the photographs that had to be divided in different plans, in order to minimise scale variability. The visual comparison of the photograph pairs have shown great landscape change caused by urban growth, agriculture abandon and woodland cover increase, mainly with exotic tree species such as *Acacia mearnsii.*, *Eucalyptus globulus*, *Pinus pinaster*, and *Pittosporum undulatum.* It was also observed a broad spread of exotic shrubs and herbs such as *Ageratina adenophora*, *Arundo donax*, *Brachiaria mutica* (Forssk.) Stapf[1], *Pennisetum purpureum*, *Cardiospermum grandiflorum*, *Cytisus scoparius* [2], *Cytisus striatus* (Hill) Rothm.[3], *Opuntia tuna*, *Oxalis pes-caprae, Podranea ricasoliana*, and *Solanum mauritianum,* in areas where other features were seen in historical images.

The 202 contingency tables (see Table 4.3) that resulted from cross tabulation of each photograph pair allowed to obtain data about: (1) the level of agreement between cover types; (2) the transition between features, (3) percentage of image cover of each feature within the total image sampled, and (4) the overall change value. These values were processed and analysed as explained in methodology, and allowed to obtain the following body of facts.

4.3.1 Landscape alteration

It was found that overall change value ranged from a minimum of 9% to a maximum of 100% (Figure 4.15). The central tendency of change values seen in photograph pairs within the oldest photographs set were higher than values assessed for the more recent time series of south coast and north coast, i.e. median value found for south coast sets was: [50-75[= 71; [75-100[= 83; [100-125[= 85, and [50-75[= 73.5; [75-100[= 77; [100-125[= 77.5. Although same trend was observed between the sets [50-75[= 77; [75-100[= 90 of photographs located in inland, the trend towards the set [100-125[= 83 did not follow the same tendency, which is going to be discussed later. The change that landscape suffered over more than one hundred years was bigger in south coast, which in turn revealed the lowest value when the assessment focused on [50-75[set. North coast presented lowest alteration value for earliest dates and inland presented highest values for latest dates. Given that sets with older photos also include the change that happened more recently, it is possible to infer that the greatest alteration have happened between seventy-five to fifty years and present time (Figure 4.16). Photograph pairs within each set, showing a global landscape change (GLC, in figures captions) close to median value of each set were selected and shown in following pages (Figures 4.17-19).

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[1] Commonly known as para-grass, Angola grass, and locally as *capim, erva, erva-do-governo.*

[2] Commonly known as common bromm, Scotch broom, and locally as *giesta*

[3] Commonly known as Portuguese broom, and locally by *giesta,* not being made distinction from vernacular name of *C. scoparius.*

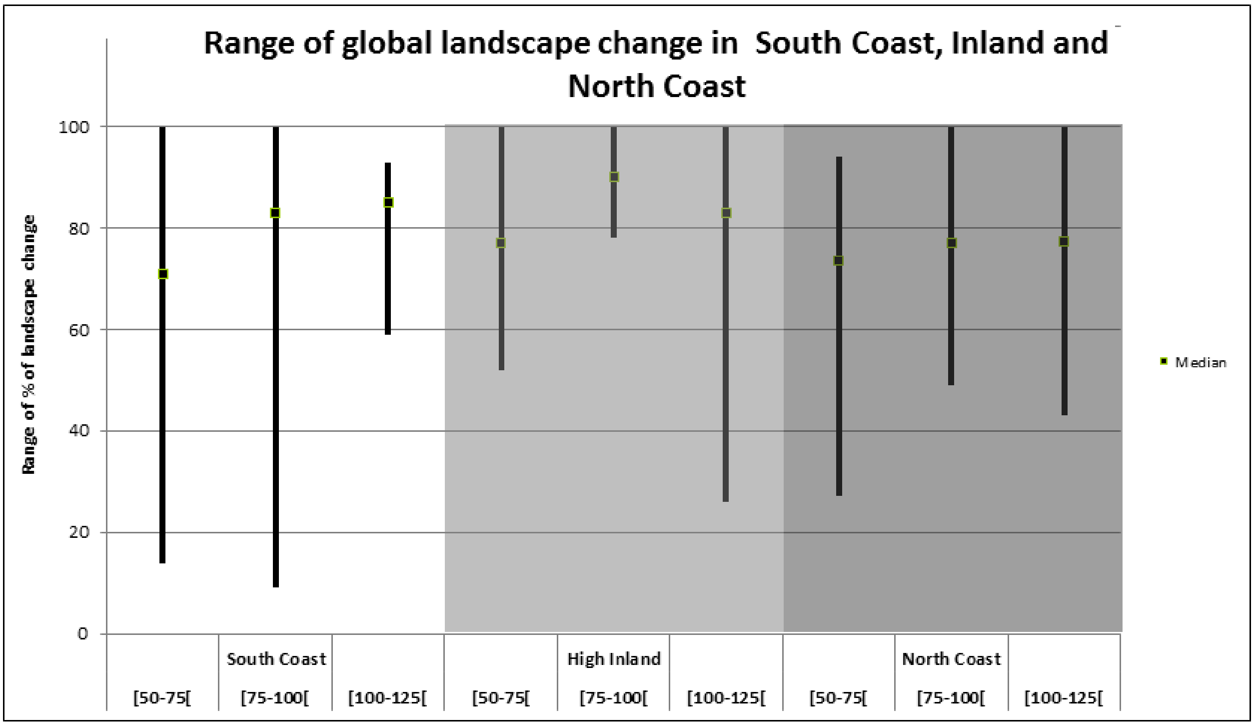


Figure 4.15 Range of overall change that occurred in each sub-region (South coast, Inland, North coast) in each time interval ([100-125[, [75-100[, [50-75[). The central tendency of change is expressed by the median value.

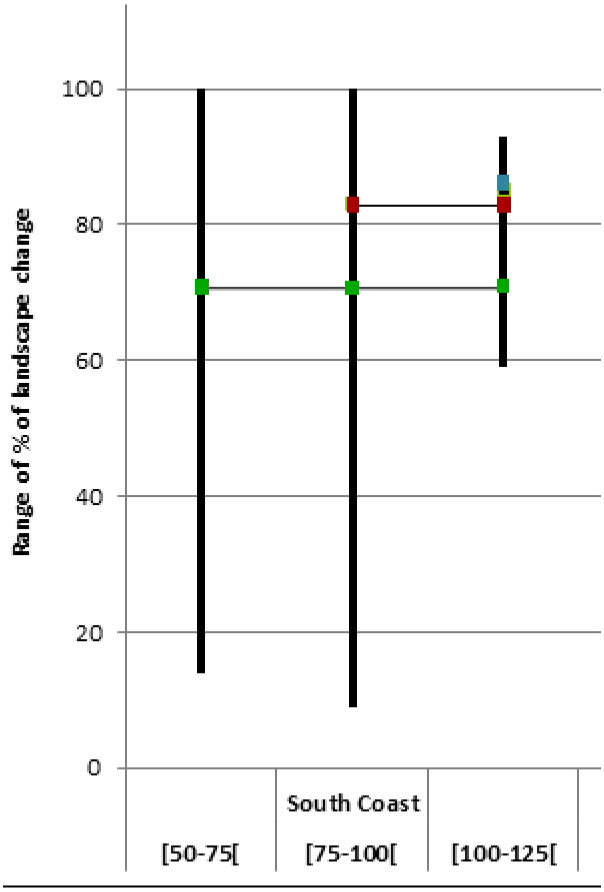


Figure 4.16 Global landscape change in south coast for the three time intervals, with median value found for each time bracket highlighted in different colours: [50-75[in green, [75-100[in red, and [100-125[in blue. Assuming that median value of alteration found for photograph pairs with latest historical images correspond to alteration that took place during the same period in pairs with older photographs it can inferred that the biggest change has happened over in last 75-50 years.

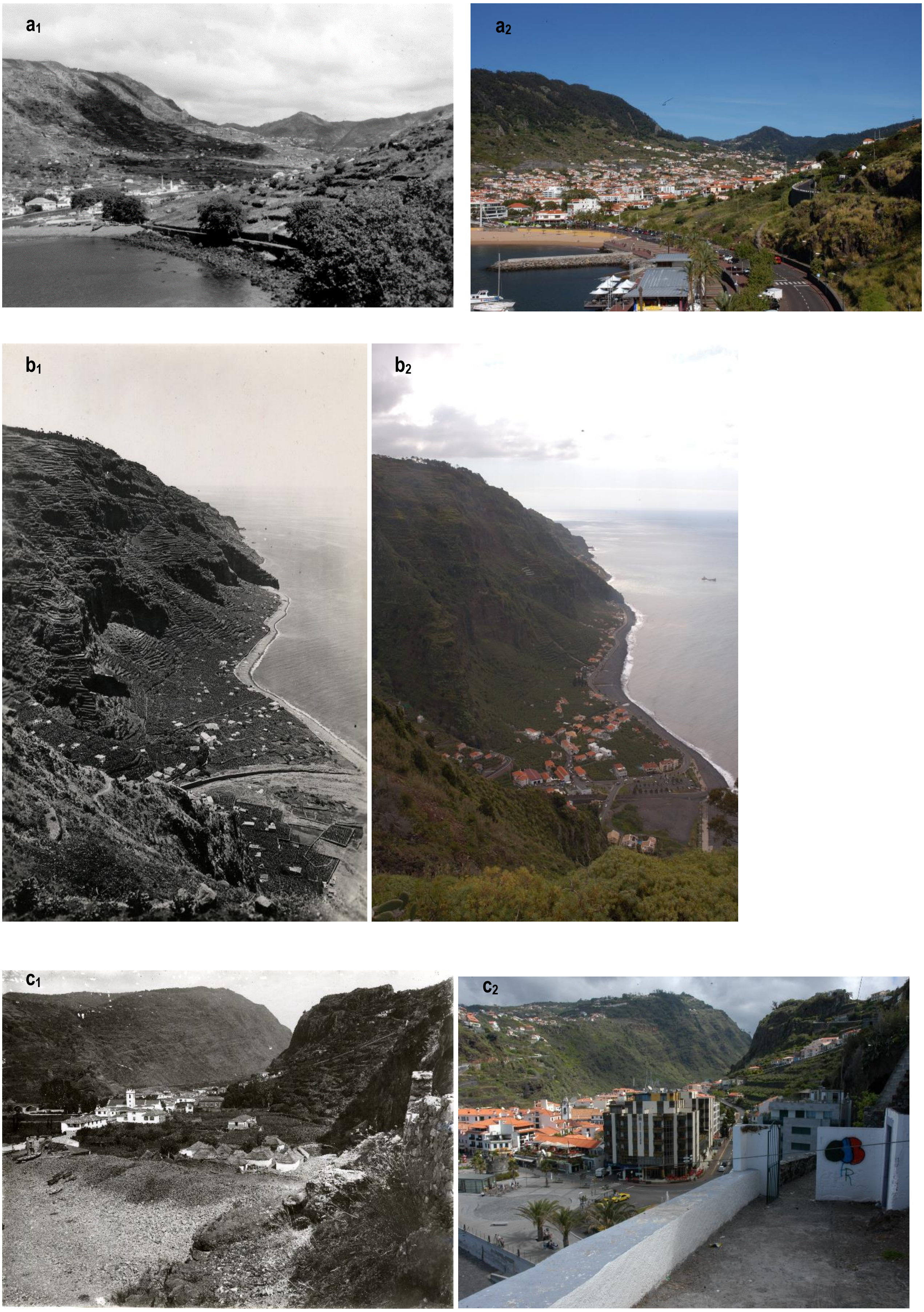


Figure 4.17 Historical and repeated photographs located in southern coast: (a_1) Bay and valley of Machico in 1950s (by unknown photographer, DRF), and (a_2) in 2012 (MS; AP), showing GLC = 68%; (b_1) Madalena, in early 1940s (by Figueiras photographers, ARM), and (b_2) in 2012 (MS, AP), showing GLC = 83%; and (c_1) Ribeira Brava, in late nineteenth-century (by unknown photographer, ARM), and (c_2) in 2006 (MS, AP), showing GLC = 87%.

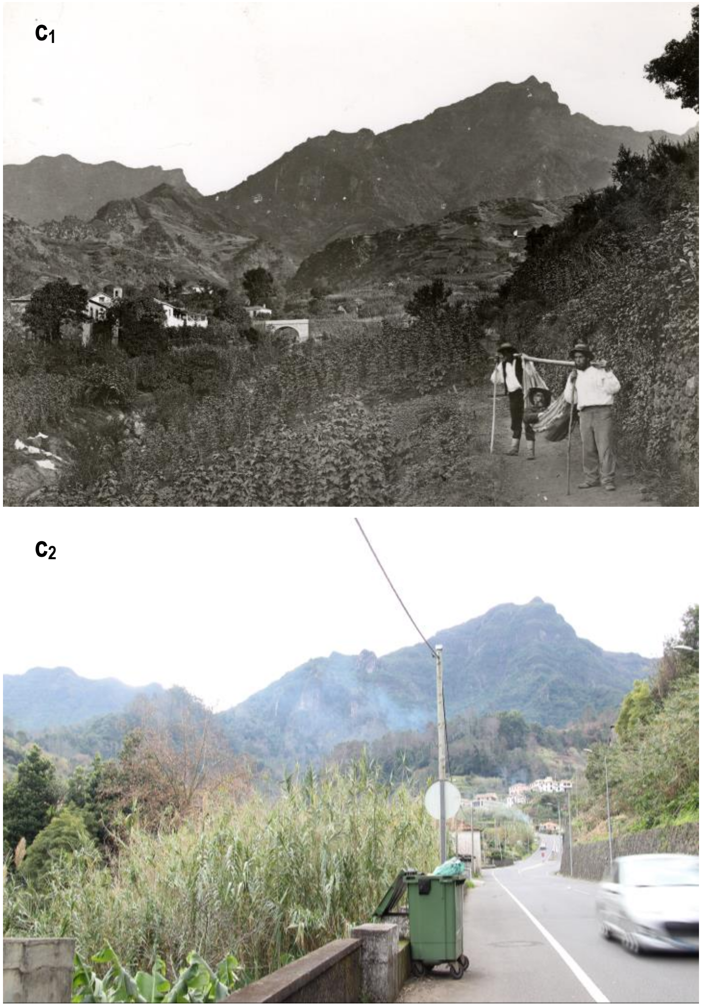


Figure 4.18 Historical and repeated photographs located in inland areas: (a1) Pico Ruivo, central highlands, in 1950s (by unknown photographer, DRF), and (a2) in 2010 (AP, AF), showing GLC = 74.5%; (b1) Camacha, facing south, in early 1940s (by Figueiras photographers, AP), and (b2) in 2013 (AP, JP), showing GLC = 93%¸ and (c1) Rosário, facing north, in late nineteenth-century (by unknown photographer, ARM), and (c2) in 2013 (AP, JP), showing GLC = 83%.

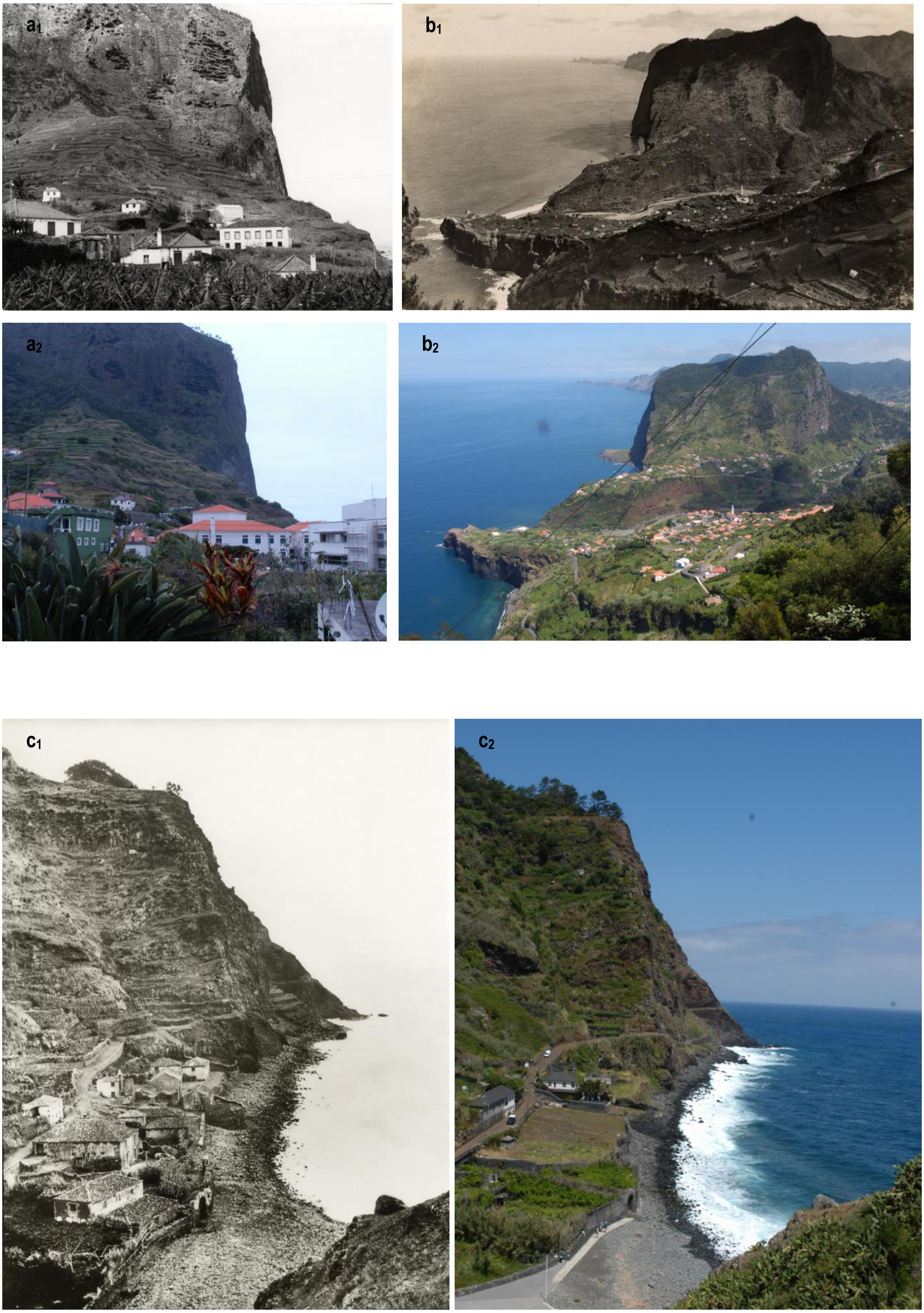


Figure 4.19 Historical and repeated photographs located in north coast: (a_1) Porto da Cruz, in early 1950s (by unknown photographer, ARM), and (a_2) in 2006 (AP, ZF), showing GLC = 70.3%, (b_1) Faial, in early 1940 (by Figueiras photographers, AP), and (b_2) in 2006 (MS, AP), showing GLC = 76%; and (c_1) São Jorge, north coast, in late nineteenth-century (by Vicentes photographers, AP), and (c_2) in 2006 (MS, AP), showing GLC = 79%.

4.3.2 Landscape maintenance

In landscapes that did not change very much (under 50% of alteration) the classes that remained greatly unchanged (Figure 4.20) were: *Construction – Code 1* (36%), *Agriculture – Code 2* (32%), *Bare rock – Code 4* (16%) and *Vegetation* (native vegetation) – *Code 312, 322* (16%). Comparison between north-south-inland photographs, have shown that classes with major agreement in southern landscapes (see also Figure 4.21) with less change were: *Construction* and *Agriculture*, sharing same frequency (43.75%), and *Bare rock* (12.5%). In sorthern areas *Vegetation* did not appear as main responsible for maintenance of the landscape in none of the photo pairs analysed. Contrarily, steady *Vegetation* (native vegetation) was the main responsible (66.6%) for the unaltered landscapes in inland (see also Figure 4.22); being also responsible the *Bare rock* (33.3%). The *Vegetation* (native vegetation) not showing much variation, was also responsible for little landscape alteration along north coast (see also Figure 4.23). However, together with *Agriculture* (16.6% each), was less significant than *Construction* and *Bare rock* (33.3% each).

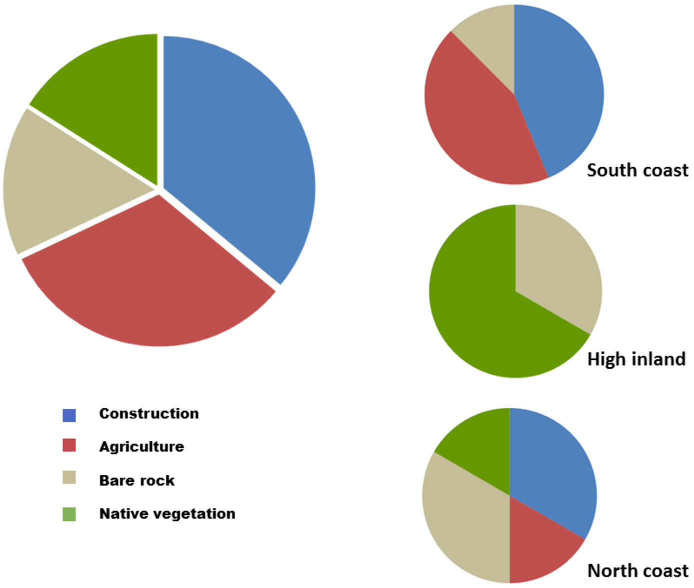


Figure 4.20 Main causes of agreement. Frequency distribution of the classes that remained greatly unchanged in little altered landscapes.

Figure 4.21 Historical and repeated photographs located in southern coast (Ribeira Brava) as an example of a pair exhibiting global landscape change under 50% (GLC = 21%), in which construction, agriculture and cliff faces showed high agreement between past and present landscape, being ultimately responsible for the low change level. Old photograph from early 1960s (by unknown photographer, ARM) and new one taken in 2011 (AP, MB).

Figure 4.22 Historical and repeated photographs located in inland (Vinte e Cinco Fontes) as an example of a pair exhibiting global landscape change under 50% (GLC = 26%), in which vegetation (native vegetation) and bare rock (stream bed and banks) showed high agreement between past and present landscape, being ultimately responsible for the low change level. Old photograph from late nineteenth century (by unknown photographer, AP) and new one taken in 2006 (MS, AP).

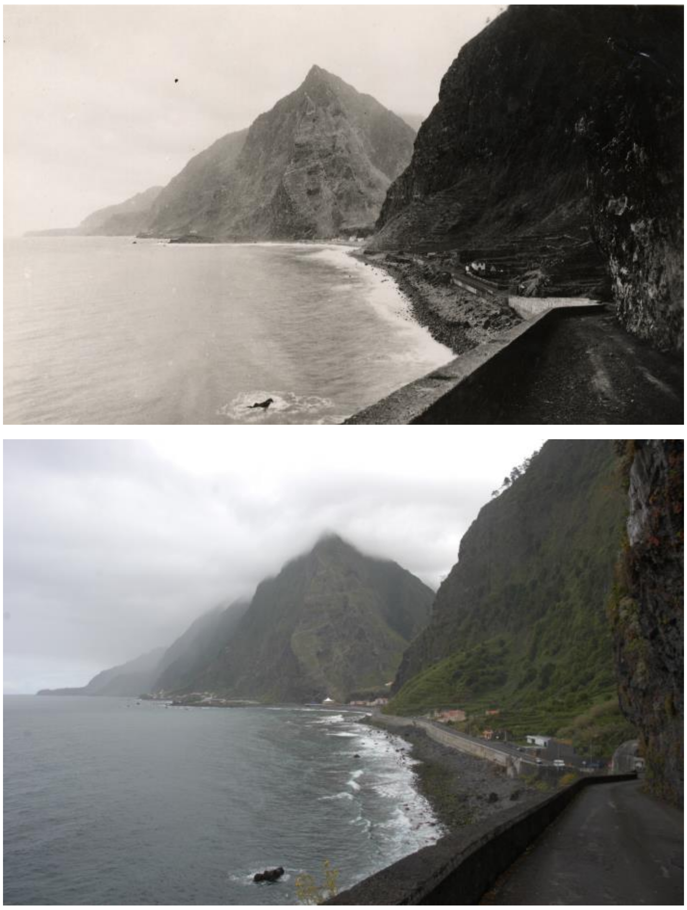


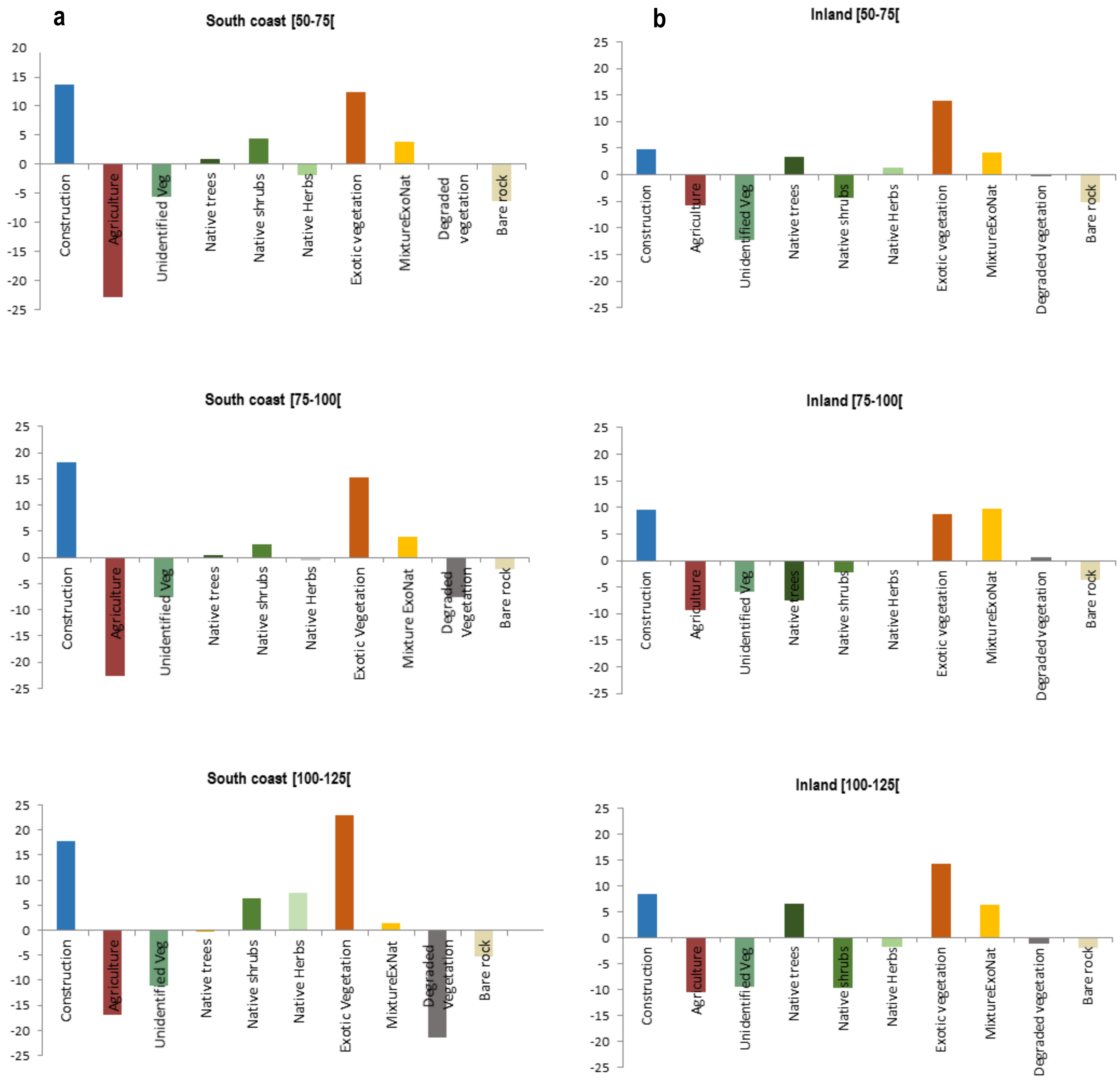
Figure 4.23 Historical and repeated photographs located in north coast (São Vicente) as an example of a pair exhibiting global landscape change under 50% (GLC = 49%), in which vegetation (native vegetation), bare rock (cliffs), construction and agriculture showed agreement values between past and present landscape, that led to low global landscape change level. Old photograph from early twentieth century (by Perestrellos photographers, ARM) and new one taken in 2006 (AP, AZ).

4.3.3 Causes of landscape change

The two level one Land cover classes that were found as main cause of change in greater number of photograph pairs (Table 4.4) were: *Agriculture* (Code 2) in south coast, and north coast in last 75-50 years, and *Vegetation* (Code 3) in inland, and north coast for periods exceeding 75 years. Excepting Water (Code 5), which never occurred as main change, the other two classes [*Construction* (Code 1) and *Bare rock* (Code 4)] where also a key reason behind landscape change, although less frequent.

Table 4.4 Reasons of landscape change, frequency of which class as major cause of landscape alteration within each set. Grey highlighted cells correspond to highest frequency value within each photographic set.

Sub-region	South coast	South coast	South coast	Inland	Inland	Inland	North coast	North coast	North coast
Age bracket	[100-125[	[75-100[	[50-75[	[100-125[	[75-100[	[50-75[	[100-125[	[75-100[	[50-75[
Construction	27.3	24.0	23.9	15.8	29.4	22.2	17.0	7.7	4.3
Agriculture	45.5	56.0	43.5	15.8	23.5	22.2	30.4	23.1	60.9
Vegetation	9.1	16.0	28.3	47.4	41.2	50.0	39.0	38.5	34.4
Bare Rock	18.2	4.0	4.3	21.1	5.9	5.6	13.0	30.8	0
Water	0	0	0	0	0	0	0	0	0



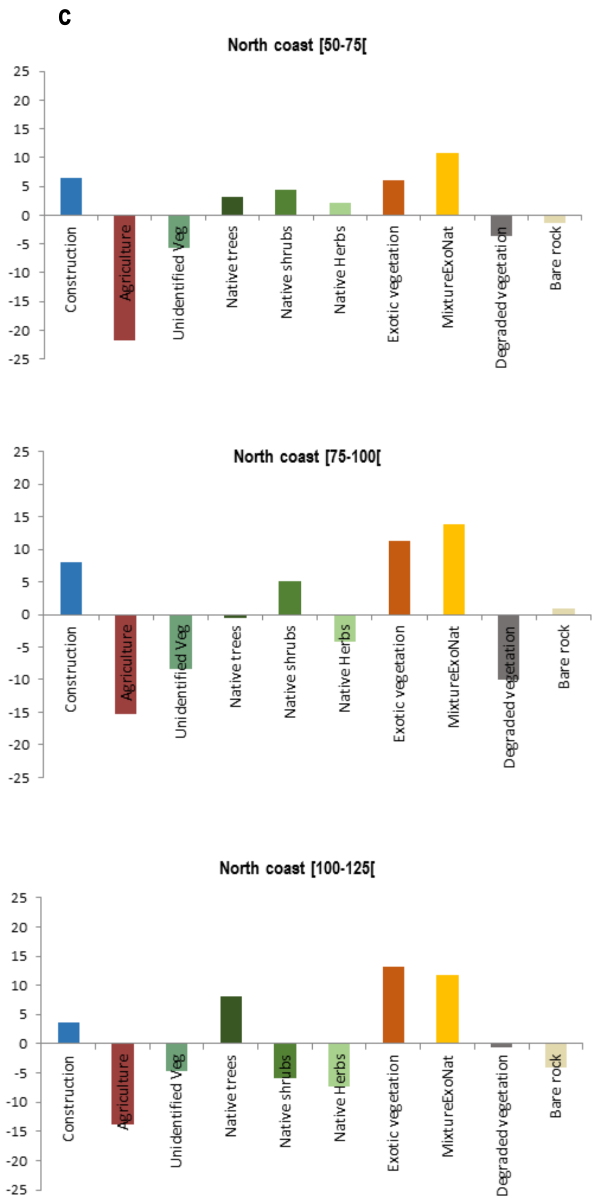


Figure 4.24 Variation that occurred between past and present in landscape features: (a) south coast; (b) inland; and (c) north coast.

Assessment of the variation that occurred between past and present (Figure 4.24) has shown that change that took place in *Agriculture* (Code 2) was mainly due to decrease in this feature, the change that occurred in *Construction* (Code 1), was driven by building growth, especially in south coast, and the alteration that occurred in *Bare rock* (Code 4), with the exception of the set from north coast in period between 75-100 years, was mainly due to its reduction. Detailed analysis of each one of the contengy tables have shown that *Construction* expansion over agricultural terraces, cliffs and stream banks, especially in south coast, and development of vegetation over those features, were the causes of *Bare Rock* decrease. Spontaneous recovery of native vegetation over clifftops and rocky stream banks was residual and detected more often in north coast and in inland, whereas in south coast much of the cliffs became covered by exotic plants as *Ageratina adenophora, Arundo donax*, *Cardiospermum grandiflorum, Opuntia tuna*, *Podranea ricasoliana.* Regarding the vegetation, which will be analysed in further detail below, it was noticed that changes were due to exotic vegetation increase, diminish of unidentified vegetation (a class that no longer exists in new photographs), and due to diverse variation in other vegetation types (Native trees, Native shrubs, Native Herbs and Degraded vegetation) depending on location and period of time analysed.

4.3.4 Native vegetation dynamics

Three maps containing interpolation of data concerning *Native trees class* (Code 312) were drawn with tools and procedures explained in methodology, aiming to infer the dynamics of late successional vegetation types for all island and for the three time periods. The interpolation process was achieved with RMSE (Root mean square error) below 25% ([100-125[= 16.6%; [75-100[= 17.60%, [50-75[= 15.90%) meaning that values predicted by these models and real values have residual differences. The patches do not represent a real extension of the vegetation on the field but the transformation that occurred between those dates and present time.

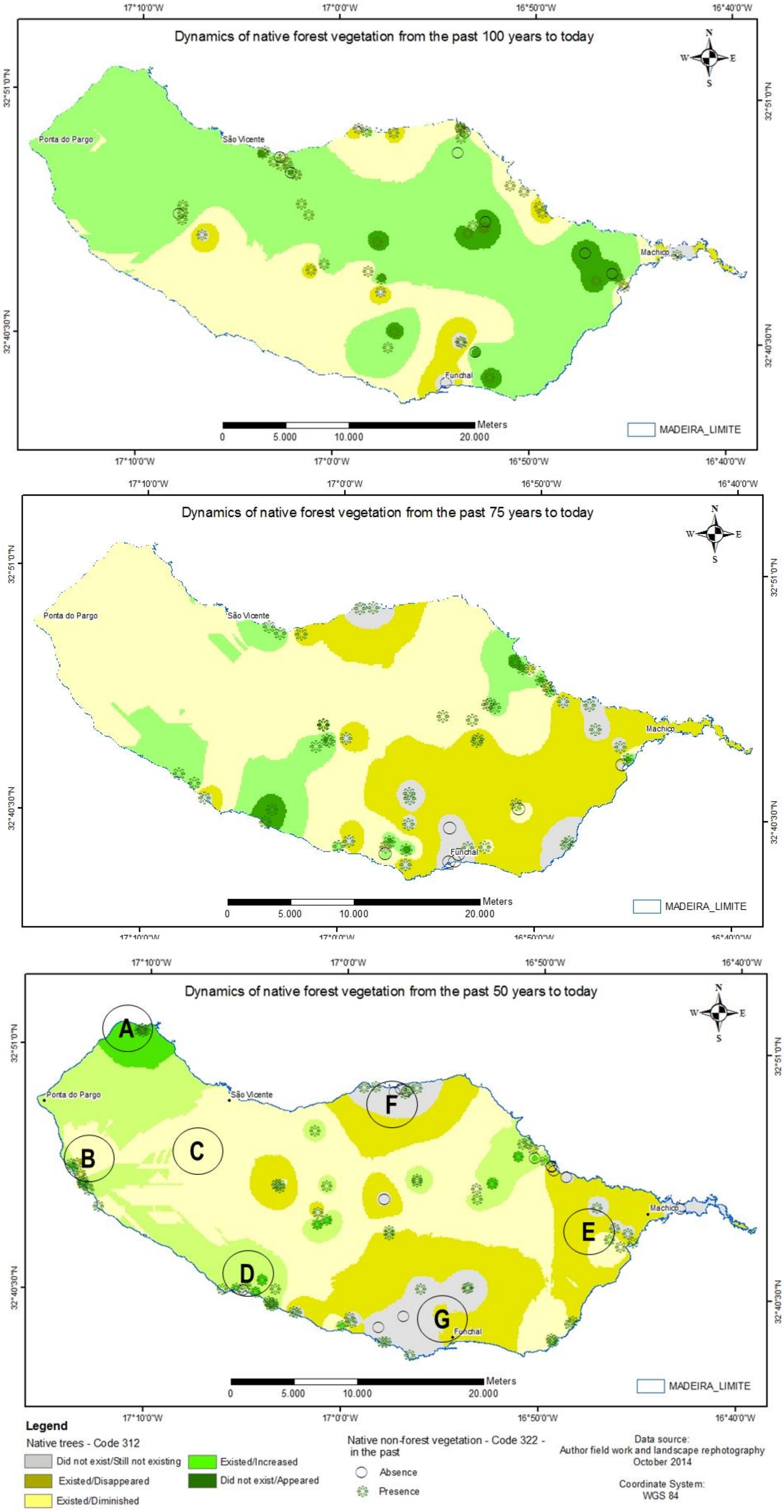
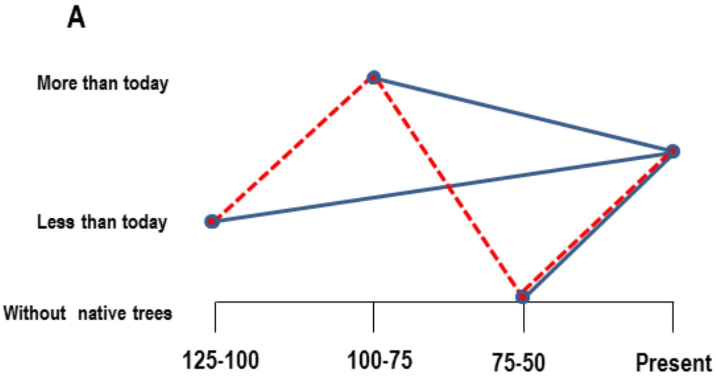


Figure 4.25 Maps containing interpolation of data concerning Native trees class (code 312), overlapped with information about presence/absence of successional stages of native vegetation, i.e. *Native non-forest vegetation class* (Code 322). Letters inside circles mark locations for which an interpretation of vegetation dynamics was made (see diagrams in following pages).

It was observed that situations where native trees were not identified in historical landscape and were still not seen in current landscape (grey feature), or existed and disappeared (yellow feature) suffered an increase. The situation where it existed and diminished (light-yellow feature) increased from 125-100 years to 100-75, but decreased from this period to 75-50 years, indicating a possible recuperation of native forest from then onwards, in places where fragments of vegetation remained. This is also supported by the behaviour shown by the other two situations where mature vegetation existed and increased (light-green feature) and where it did not exist and appeared (green feature), both suffering decline from the 125-100 map to 100-75, and then increasing thereafter. Recovery in the situations where it was not seen in historical landscape happened, but when it was surrounded by remnants of mature vegetation or by seral stages, and mainly when it was not occupied by exotic plants or farming. However, the presence of the seral vegetation was not, in itself, a sufficient condition for guaranteeing the mature vegetation regrowth, as seen in locations marked with F and G.

Some points were selected to perform a speculative exercise about the damage and the recovery that could have happened, and are shown in diagrams (A, B, C; D and E), where the continuous blue line represent the evolution shown in each map and the dashed red line a surmise of what could have happened throughout time. It is important to recall that this does not evaluate the amount of vegetation that could have existed in the ground; it represents solely the direction of change, and it is on this point of view that following descriptions should be taken:



(A) located in Porto Moniz, blue lines shows that from 125-100 years ago mature native communities increased, from 100-75 years decreased, and from 75-50 years it reappeared; implying that vegetation should have evolved in a positive way up to first decades of the twentieth century, and then have happened its destruction, to the point that was not seen in the landscape around 75-50 years ago, and recovered again since then;

Figure 4.26 Historical photograph (taken in 1950s by A. Conceição, HCC) and repeated photograph (2011, MS and AP), showing development of secondary vegetation (*Euphorbietum piscatoriae*) and appearance of more mature one (*Semele androgynae-Apollonietum barbujanae*) over the slope seen in the background.

(B) located in Paul do Mar, from 125-100 until the present vegetation increased in some areas while in others has shown a regressive development, latter trend that was also seen for vegetation from 100-75 period until today, increasing again after the 75-50 period. Once again, vegetation should have developed until the beginning of the twentieth century, and then after being in decline, without however being completely eliminated, it recovered after 75-50 years ago;

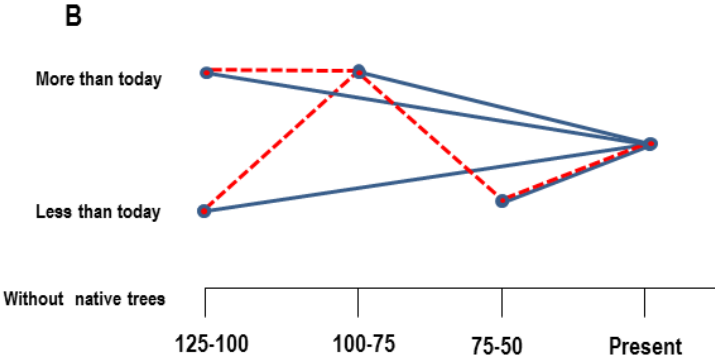
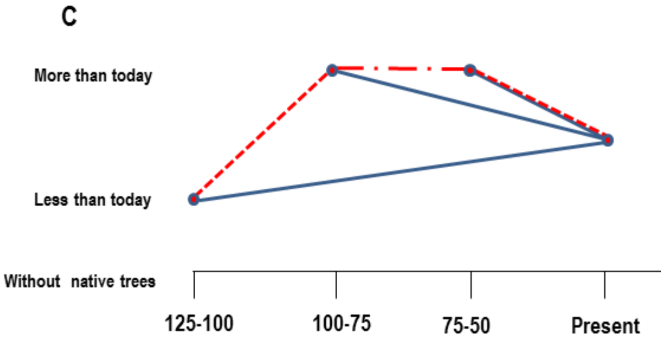


Figure 4.27 Historical photograph (taken in 1950s by unknown photographer, ARM) and repeated photograph (2006, MS and AP), vegetation recovery occurred mostly over talus deposits and forsaken agricultural terraces (*Euphorbietum piscatoriae*, and *Mayteno umbellatae--Oleetum maderensis*)

(C) located in Ribeira da Janela valley, from 125-100 until the present occurred an increase, but 100-75 and 75-50 modulation maps indicate that a decrease happened since then. While it can be assumed that mature vegetation in this area could have reached a higher level in last hundred years, it is not given any clue on when and what have happened during that time, it is not possible to infer if regression and recovery also occurred as it did in previous situations: However analysis of contengy tables of photo pairs have shown that current native vegetation derives mainly from the same type of vegetation and, each vegetation type from



the past was largely retained as the same. Further, in spite of the regeneration of mature communities, conversions from forest to high-scrub were higher than the reverse. It was also seen *Cytisus scoparius* growing over former mature vegetation, which was recently cleared due to improvements in access road.

Figure 4.28 Historical photograph (taken in late nineteenth by unknown photographer, AP) and repeated photograph (2006, MS and AP). Presently, native vegetation covers large areas, chiefly stink-laurel mesoforest (*Clethro arboreae-Ocoteetum foetentis*) and the substitution stage dominated by tree-heath and madeiran blueberry (*Vaccinio padifoli-Ericetum maderinicolae*)

(D) located in Ribeira Brava, where current mature vegetation is lesser than the one that should have existed 125-100 years ago, and more than the viewed since 100-75 period, even showing, in certain areas, a recovery from nothing after that period. It may have occurred an intense destruction between those periods, after which it recovered, without although having reached the former state;

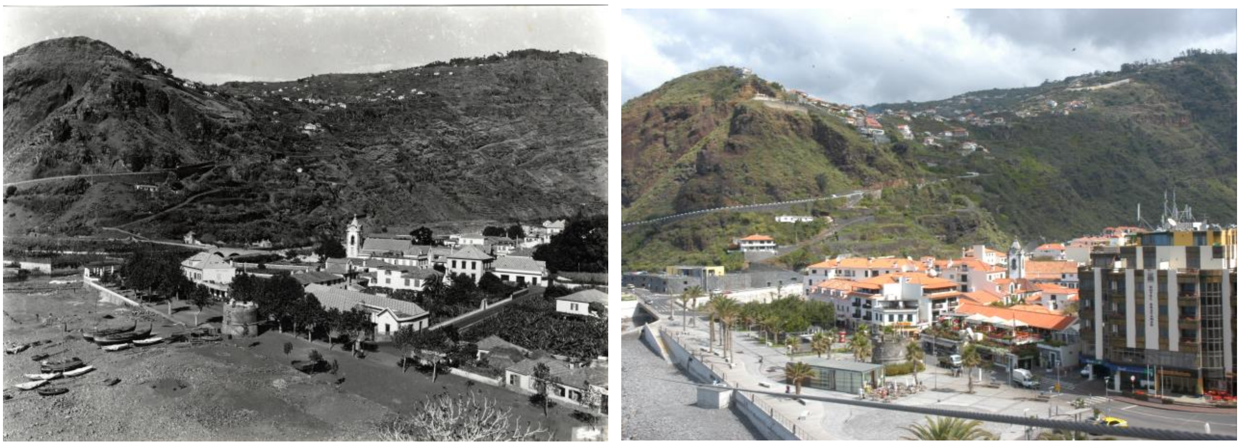
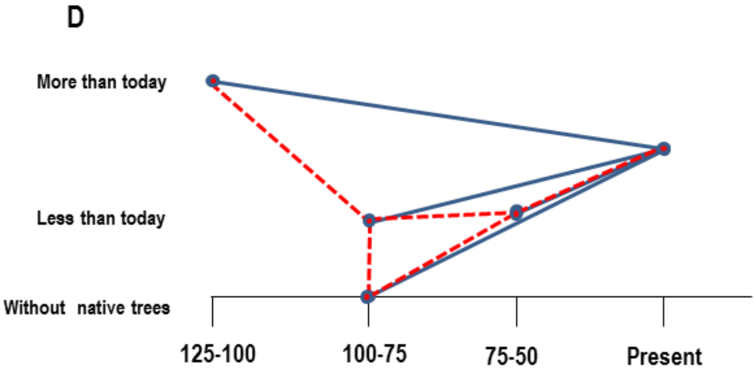


Figure 4.29 Historical photograph (taken in early 1940s by unknown photographer, ARM) and repeated photograph (2006, MS and AP). Where uncultivated lands were not encroached by exotic plants is possible to find trees of several communities (*Mayteno umbellatae--Oleetum maderensis*, *Helichryso melaleuci--Siderxyletum marmulanae,* and *Semele androgynae-Apollonietum barbujanae*) in mosaic with substitution satges (mainly *Euphorbietum piscatoriae*), occupying different positions throughout valley slopes.



(E) located in Machico, blue lines show that from 125-100 years ago two situations occurred: one where vegetation already existed and increased, and another where it did not existed at that time and appeared. Blue lines from 100-75 up to present shows that some areas that did not have native trees in the past, still not have them, while others have lost completely the vegetation that have. Blue lines representing changes that occurred from 75-50 years ago show also that some areas that did not have native trees in the past, still do not have them, and in others vegetation diminished or disappeared. Thus, it is possible to infer that in present time two situations exist, one where mature native vegetation that recovered in the end of nineteenth century, even in places where it had been destroyed, suffered new impacts during first half of the twentieth century, being completely destroyed and unable to recover to date; and another situation where part of damaged vegetation recovered until 75-50 years, being diminishing since then.

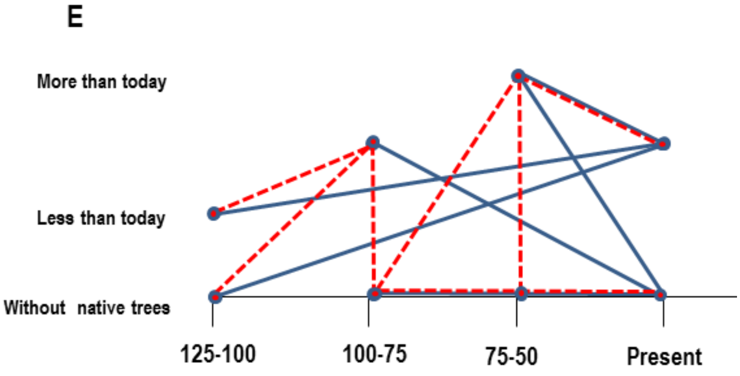


Figure 4.30 Historical photograph (taken in late nineteenth century by Vicentes photographers, ARM) and repeated photograph (2006, MS and AP). Presently, the majority of native vegetation that can still be found correspond to the substitution stages (*Euphorbietum piscatoriae* and *Globulario salicinae-Ericetum* maderincolae) replacing climax vegetation (*Mayteno umbellatae--Oleetum maderensis* and *Semele androgynae-Apollonietum barbujanae*)

Point G located in Funchal, where urban pressure is high (Figure 4.31), and point F encompassing localities [Arco de São Jorge, Ponta Delgada (Figure 4.32)], where agriculture still remains active or if recently abandoned are covered with the remnants of former crops, correspond to areas were mature vegetation disappeared long ago and no longer exists.

Figure 4.31 Historical photograph (taken in early twentieth century by unknown photographer, ARM) and repeated photograph (2012, MS and AP), located in Funchal, showing town boundaries clinging to the mountain slopes due intense urban sprawl.

Figure 4.32 Historical photograph (taken in 1930s by Figueiras photographers, AP) and repeated photograph (2013, AP and JP), located in Ponta Delgada. Although native vegetation still occurs in overhanging cliffs in *Fajãs* that soon attracted farmers, native vegetation currently seen correspond to plants of substitution stages (e.g. *Globulario salicinae-Ericetum* maderincolae)

4.3.5 Exotic species behaviour

The exotic species that were more often identified in old photographs (Table 4.5) were *Pinus pinaster,* seen in all the three sub-regions and time brackets, and *Arundo donax,* that in spite of not being seen in older southern photographs, it was also a common occurrence in all the other historical photographs. *Eucalyptus globulus, only* seen in the twentieth century photographs, was found on the hills and slopes both facing south and north. Other exotics identified in historical landscape were *Castanea sativa, Quercus robur* L.[1] and *Salix babilonica* L.[2] (only in inland), *Opuntia tuna* (only in southern coastal areas), and *Tamarix gallica* L.[3] and *Agave americana* L.[4](only in north coast), seen in very few photographs.

Table 4.5 Number of historical photographs where each exotic species was identified

	South coast			Inland			North coast		
Species	[100-125[	[75-100[	[50-75[	[100-125[	[75-100[	[50-75[	[100-125[	[75-100[	[50-75[
Agave americana							1		
Arundo donax		10	18	1	3	1	11	1	9
Castanea sativa				1	3	2			
Eucalyptus globulus		2	3		1	2			6
Opuntia tuna		3	4						
Quercus robur				1					
Pinus pinaster	7	9	8	10	9	11	10	7	10
Salix babilonica					1	1			
Tamarix gallica								1	1
Total of photographs	11	25	46	21	17	22	24	13	24

For the assessment of exotic vegetation change there were appraised transitions to other species, to other vegetation types, and to bare ground. It was not considered the shift into construction and agriculture (Tables 4.6).

Pinus pinaster, the exotic plant most frequently seen in historical landscape, showed low agreement, especially in pairs comprising the oldest photographs. Although varying according to location and time when was taken the old photograph, in the main this species was wholly or in part replaced by forest stands dominated by *Eucalyptus globulus, Acacia mearnsii*, and by mixed stands of conifers and broadleaf trees were the pine coexists with those two exotic tree species, and also along with *Pittosporum undulatum*. Areas without trees appeared mainly covered with the exotic vine *Cardiospermum grandiflorum* (south coast) or with *Cytisus* spp. and *Pteridium aquilinum* (inland). Regeneration of native vegetation also occurred, mostly bushy vegetation dominated by *Euphorbia piscatoria* (south coast) and *Globularia salicina* (north coast). Recovery by more mature native vegetation was detected, somewhat in inland and bit more significantly on the north coast, but only in pairs embracing larger time intervals and constitute by young communities dominated by *Myrica faya* and with few laurel species.

Arundo donax, the other species that was most frequently identified in historical landscape, has shown assemblages that did not alter too much, except the ones seen in photographs aged 75-100 for which agreement value

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[1] European oak, locally know as *carvalho* or *carvalheiro*

[2] Commonly known as weeping willow, and locally as *chorão*, *salgueiro-chorão*

[3] Commonly know as tamarisk, salt cedar, and locally as *tamargueira.*

[4] Commonly know as century plant, American aloe, and locally as *piteira*

was low. *Arundo donax* from the past that is no longer seen in new images has changed to *Bare Rock,* to forest stands of conifers and broadleaf trees, to assemblages where a mishmash of native and exotics coexist, and to other exotic plants as *Acacia mearnsii, Cardispermum grandiflorum* (south coast), and *Passiflora molissima* (Kunth) L.H. Bailey[1] (inland). It was observed native vegetation regeneration in spaces pervaded with giant reed in the past, although much of it is mixed with exotic plants. Even though most of native vegetation that recovered was shrubby vegetation dominated by *Euphorbia piscatoria* (south coast), *Erica platycodon* subsp. *maderincola* (inland) and *Globularia salicina* (north coast), it was also noted the development of more mature vegetation in pairs within the set with oldest photographs, but mixed with exotic tress.

Eucalyptus globulus stands seen in sets with younger photographs were the ones that remained more stable, showing higher agreement values. The loss was mostly to low vegetation cover as *Arundo donax* (coastal areas), *Pteridium aquilinum* (inland), and grassland of native herbaceous plants also in mosaic with shrubs communities of *Euphorbia piscatoria* (south coast), and *Erica platycodon* subsp. *maderincola* (inland). It also has been seen arboreal vegetation growing in spots formerly occupied by *E. globulus:* in inland communities dominated by laurel trees, and exotic woodlands dominated by *Pittosporum undulatum* (north coast) and *Acacia mearnsii* (south coast).

The *archeophyte Castanea sativa,* only seen in inland areas, has shown highest agreement in pairs comprising the oldest photographs. In these the loss of this coverage led to uncovered areas (*Bare Rock*) or native communities dominated by *Erica platycodon* subsp. *maderincola,* although it has also been replaced by *Eucalyptus globulus.* Photographs covering shorter intervals have shown smaller agreement, and transitions were mainly into woodlands dominated by *E. globulus* and stands of *Pteridium aquilinum,* as well as by forest stands dominatedby *Pinus pinaster* and *Eucalyptus globulus,* and also by native vegetation dominated by laurel trees.

Opuntia tuna, which was seen in historical photographs located in south coast, has shown a low level of agreement and shifted mainly to *Euphorbia piscatoria*, and exotic vegeteation, both mixed with other exotic plants and with native vegetation, or even forming monospecific assemblages (e.g. *Arundo donax*).

Salix babilonica that was seen in a riparian zone in only two photographs depicting the same area in different times disappeared completely remaining the bare rock in banks and bed of the water stream partially covered with *Arundo donax*, *Acacia mearnsii*, and *Brachiaria mutica*.

Tamarix gallica was seen in only two historical photographs from different locations of northern coastal areas, very close to the sea shore. Although allowing the regeneration of native scrubland dominated by *Globularia salicina*, the areas from the past still remained almost entirely occupied by the same species.

Some other species were also identified in historical photographs as *Quercus robur* and *Agave americana*, both only seen in a single pair. The agreement of *Q. robur* was high, and this species was solely replaced by trees of mature community of laurel forest. *A. americana,* which has shown low agreement level, was replaced by native shrubs (mainly *Globularia salicina*), mixture of native and exotic trees (mainly *Myrica faya, Salix canariensis* and *Pittosporum undulatum*) and exclusively exotic plants (mainly *Arundo donax*).

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[1] Commonly known as banana passion fruit, and locally by *maracujá banana.*

Tables 4.6 Evolution of exotic vegetation seen in historical landscape, taking into account six level codes: mean value of agreement (%) between past and present (what remained unchanged) and transitions (%) into other vegetation type. Transitions into antropogenic features, i.e. construction and agriculture were not considered. Only classes with transition values up to 1% are presented individualy, classes under that value are presented all together in a single value.

4.6.1 [100-125[

South coast

	Agreement	Major transition		Other transitions
Pinus pinaster	0	*Eucalyptus globulus*	55.17	Mixed forest stands of conifers and broadleaf trees (15.10), *Acacia mearnsii* (1.13), *Cardiospermum grandiflorum* (1.42), comunity of *Euphorbia piscatoria* (0.49), other (26.69%).

Inland

	Agreement	Major transition		Other transitions
Arundo donax	44.09	Mixture of native and exotic trees	51.97	Community dominated by *Erica platycodon* subsp. *maderincola* (3.94).
Castanea sativa	33.74	Bare rock	27.48	Community dominated by *E. platycodon* subsp. *maderincola* (9.27), *E. globulus* (3.64), other (25.88).
Pinus pinaster	7.91	*A. mearnsii*	11.84	Mixed forest stands of conifers and broadleaf trees (11.48), *E. globulus* (11.26), *Cytisus* spp. (10.40), *Pteridium aquilinum* (9.39), other (37.7).
Quercus robur	84.91	Community dominated by native trees	15.09	

North coast

	Agreement	Major transition		Other transitions
Agave americana	13.53	Community dominated by *Globularia salicina*	50.54	Mixture of native and exotic plants (21.77) and *A. donax* (14.15).
Arundo donax	30.90	Bare rock	10.23	Mixture of exotic species (9.56), comunity dominated by native trees (7.68), mixture of native and exotic trees (7.35), other (34.27).
Pinus pinaster	4.47	Community dominated by native trees	20.15	Mixture of native and exotic plants (22.04), mixed forest stands of conifers and broadleaf trees (11.06), *Pittosporum undulatum* (9.61), community dominated by *Globularia salicina* (4.29), *E. globulus* (3.08), *A. mearnsii* (2.96), other (21.77).

4.6.2 [75-100[

South coast

	Agreement	Major transition		Other transitons
Arundo donax	19.48	Bare rock	20.27	Comunity of *E piscatoria* (11.19), *Euphorbia piscatoria* in mosaic with grassland (14.19), *Cardiospermum grandiflorum* (10.36), other (24.57).
Eucalyptus globulus	13.45	*Arundo donax*	25.70	Comunity of *E. piscatorial* (21.31), bare rock (10.99), grassland (4.20), other (24.33).
Opuntia tuna	0.18	Comunity of *E. piscatoria*	40.82	Mixture of exotic plants (24.75), mixture of native and exotic plants (17.54), *A. donax* (3.46), other (13.43)
Pinus pinaster	11.22	*E. globulus*	38.27	*A. mearnsii* (8.52), comunity of *E. piscatoria* in mosaic with grassland (6.48), comunity of *E. piscatorial* (5.64), other (29.96).

Inland

	Agreement	Major transition		Other transitions
Arundo donax	13.48	Mixture of native and exotic trees	38.28	Bare Rock (25.53), *Passiflora molissima* (10.25), *A. mearnsii* (4.83)
Castanea sativa	0.00	*Pteridium aquilinum.*	49.59	Mixture of native and exotic trees (41.04), community dominated by native trees (4.88), other (4.49).
Eucalyptus globulus	0.00	*P. aquilinum,*	57.85	Community of *Erica platycodon* subsp. *maderincola* in mosaic with grassland (18.87), community dominated by native trees (14.59), community dominated by *E. platycodon* subsp. *maderincola* (6.76), other (1.92)
Pinus pinaster	20.18	*A. mearnsii*	20.79	Community dominated by native trees (14.59), *E. globulus* (10.53), *P. aquilinum* (10.20), other (26.71).
Salix babilonica	0.00	Bare rock	63.65	*A. donax* (27.60), *A. mearnsii* (3.37), other (5.36)

North coast

	Agreement	Major transition		Other transitions
Arundo donax	0. 00	Mixed forest stands of conifers and broadleaf trees	37.48	Community dominated by *G. salicina* (36.58), Bare rock (7.02), *Acacia mearnsii* (6.61), other (12.31)
Pinus pinaster	3.39	Comunity dominated by native trees	38.02	Community dominated by *G. salicina* (17.23), *E. globulus* (16.70), *Acacia mearnsii* (6.55), other (18.10)
Tamarix galica	73.14	Community dominated by *Globularia salicina*	26.86	

4.6.3 [50-75[

South coast

	Agreement	Major transition		Other transitions
Arundo donax	31.69	Comunity of E. *piscatoria*	15.31	Degraded vegetation (10.03), Bare rock (8.84), Comunity of *E. piscatoria* in mosaic with grassland (7.3), plus the others (26.80).
Eucalyptus globulus	65.57	Native grassland	12.90	Comunity of *E. piscatoria* in mosaic with grassland (8.41), *Acacia mearnsii* (7.12), *A. donax* (5.56), plus the others (0.44).
Opuntia tuna	12.10	Comunity of *E. piscatoria*	25.25	Mixture of exotic plants (15.32), native grassland (13.38), plus the others (33.90).
Pinus pinaster	2.17	*E. globulus*	36.26	*A. mearnsii* (24.76), Native Grassland (8.67), Mixed Exotic vegetation (8.21), *A. donax* (7.25), other (12.68).

Inland

	Agreement	Major transition		Other transitions
Arundo donax		Bare rock	100.00	
Castanea sativa	4.91	*E. globulus*	54.33	*P. pinaster* (22.09), Mixed forest stands of conifers and broadleaf trees (7.81), plus the others (10.86)
Pinus pinaster	28.39	Mixed forest stands of conifers and broadleaf trees	25.37	*E. globulus* (15.43), Mixture of native and exotic trees (11.09), plus the others (19.70)
Salix babilonica	0.00	Bare rock	76.50	*Brachiaria mutica* (17.49), *A. donax* (3.53), other (2.48).

North coast

	Agreement	Major transition		Other transitions
Arundo donax	56.58	Mixed forest stands of conifers and broadleaf trees	80.60	Community dominated by *G. salicina* (5.97), *G. salicina* in mosaic with grassland (5.96), bare rock (3.44), plus all others (19.43).
Eucalyptus globulus	57.08	*A. donax*	12.19	*P. aquilinum* (7.36), native grassland (4.44), *Pittosporum undulatum* (3.09), plus the others (15.83).
Pinus pinaster	11.63	Community dominated by *G. salicina*	19.99	Mixed forest stands of conifers and broadleaf trees (17. 11), *A. mearnsii* (10.81), *E. globulus* (10.28), other (30.17).
Tamarix galica	100.00			

Figure 4.33 Landscape zoom in of historical photograh taken in Serra de Água in late 1950s (by unknown photographer, ARM), showing *Salix babilonica* (Sb) and *Arundo donax* (Ad), and repeated photograph taken in 2013 (AP, JP).

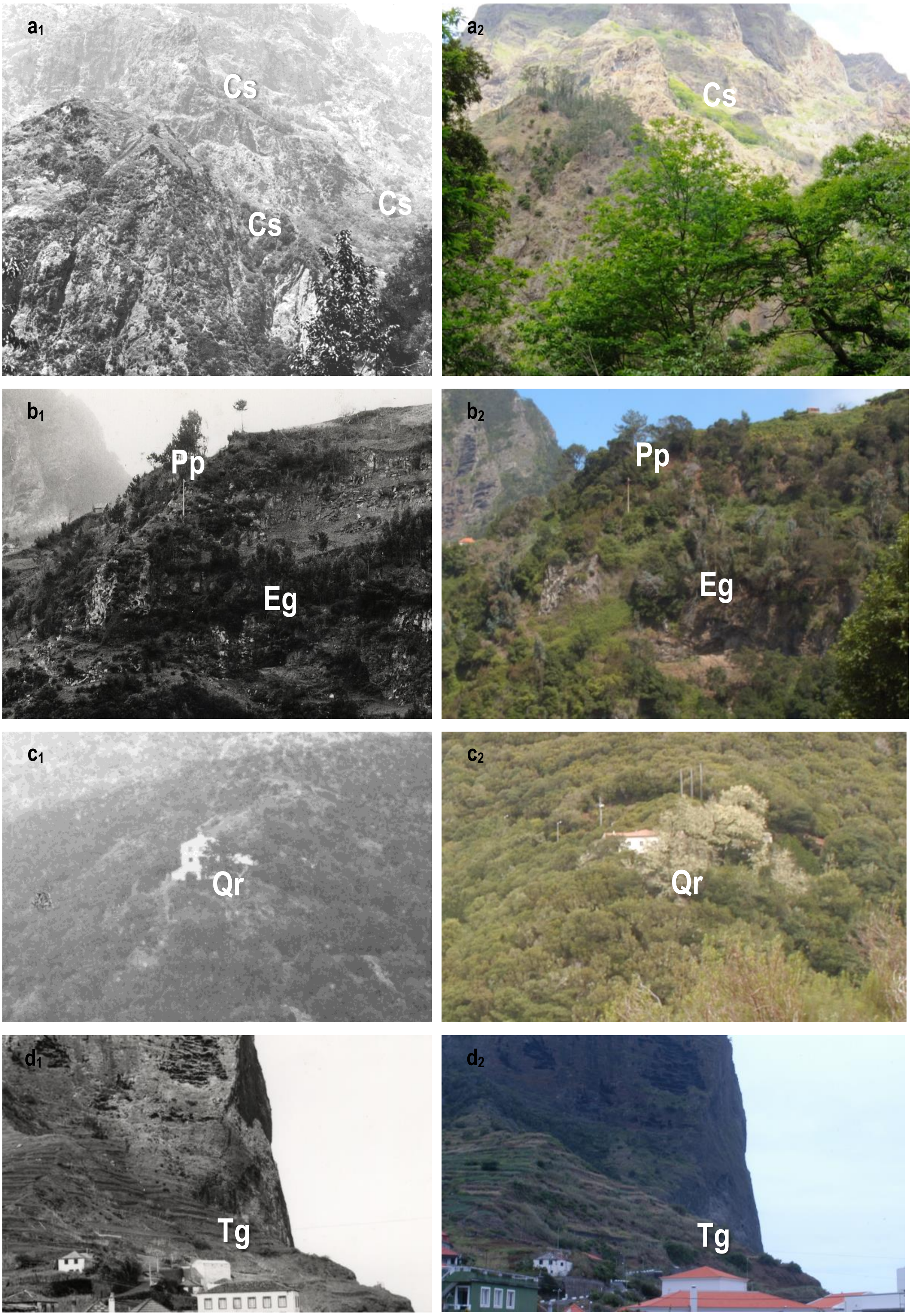

Figure 4.34 Landscape zoom in of historical and repeated photographs: (a_1) Curral das Freiras, inland in late nineteenth century (by unknown photographer, AN), and (a_2) in 2011 (MS; AP), showing *Castanea sativa* (Cs); (b_1) Faial, north coast, in late 1950s (by unknown photographer, ARM), and (b_2) in 2011 (MS, AP), showing *Pinus pinaster* (Pp) and *Eucalyptus globulus* (Eg); (c_1) Rabaçal, inland in late nineteenth century (by unknown photographer, AP), showing *Quercus robur* (Qr); and (c_1) in 2006 (MS, AP); (d_1) Porto da Cruz, north coast, in late 1950s (by unknown photographer, ARM), and (d_2) in 2006 (AP, ZF), showing *Tamarix gallica* (Tg).

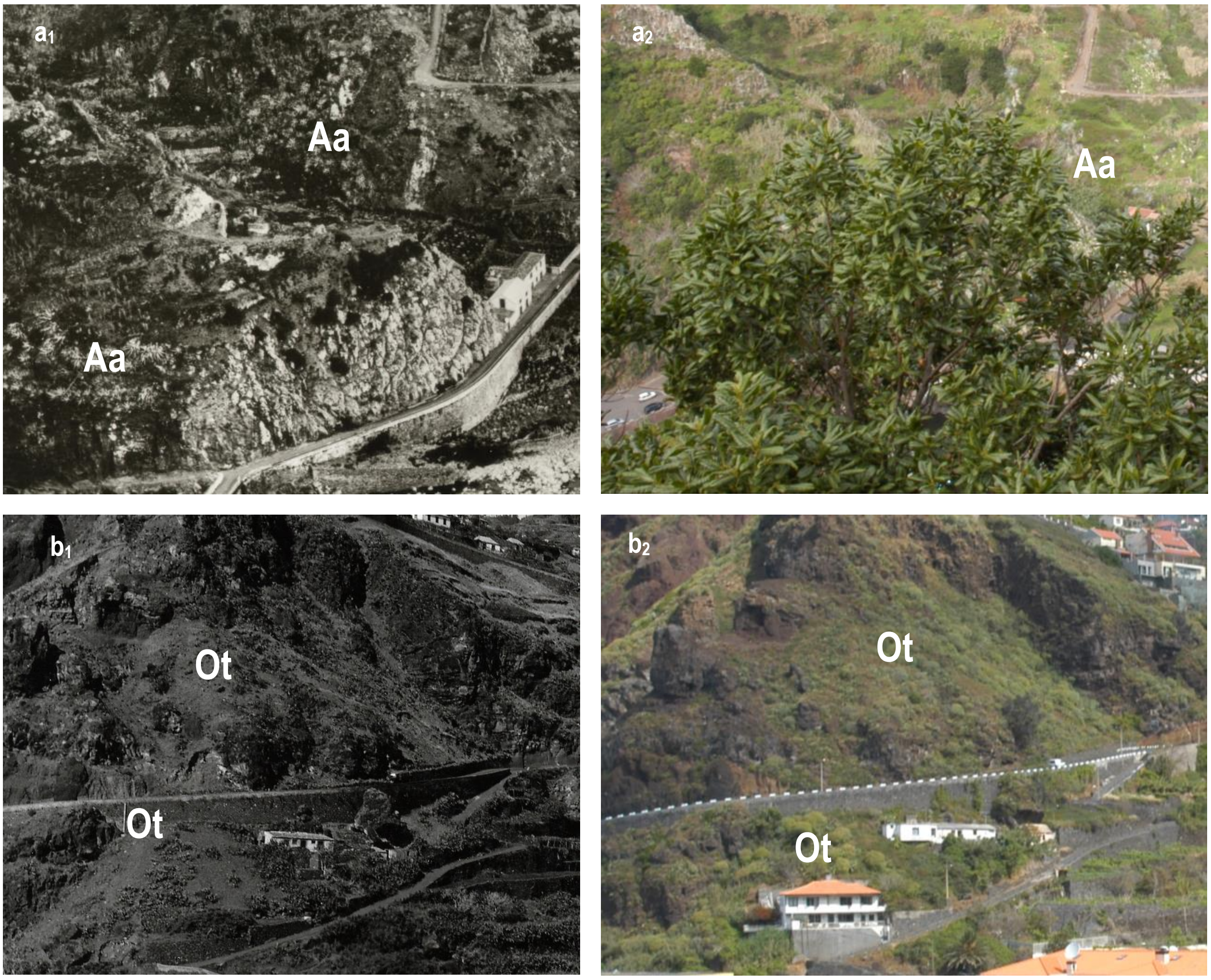

Figure 4.35 Landscape zoom in of historical and repeated photographs: (a_1) São Jorge, taken in late nineteenth century (by Vicentes photographers, AP), and (a_2) repeated photograph taken in 2006 (MS,AP) showing *Agave americana* (Aa); (b_1) Ribeira Brava, taken in late 1940s (by unknown photographer, ARM), showing *Opuntia tuna* (Ot) and (b_2) repeated photograph taken in 2006 (MS, AP), where it still persists, although hardly visible due to the growth of *Euphorbia piscatoria.*

The species that were more often identified in present landscape, and widely scattered throughout the three sub-regions, were *Acacia mearnsii*, *Arundo donax*, *Eucalyptus globulus,* and *Pinus pinaster.* Also distributed throughout the three sub-regions were seen some other species, although less frequent, as *Brachiaria mutica*, *Cardiospermum grandiflorum*, *Opuntia tuna, Tropaeoleum majus L.*[1] (mostly seen in south coast), *Pittosporum undulatum, Solanum mauritianum* (mostly seen in lowlands), C*ysitsus scoparius* and C. *striatus* (mostly seen in inland). Some of the species were seen in two sub-regions like *Podranea ricasoliana* (lowlands)*, Agapanthus praecox* Willd. subsp*. orientalis* (F.M. Leight.) F.M. Leight.[2] (inland and north coast)*, Oxalis pescaprae* (inland, and south coast where it was seen more often)*, Ulex europaeus* L. subsp. *europaeus*[3]*,* and *Ulex minor* Roth[4] (north coast, and inland, where it was seen more often). Several others were only seen in one sub-region as *Tamarix gallica, Quercus ilex* L.[5]*, Phoenix canariensis* Chabaud[6] *and Agave americana* (north coast), *Quercus robur, Castanea sativa, Hedychium gardnerianum*

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[1] Commonly known as nasturtium and locally as *chagas.*

[2] Commonly known as common agapanthus, and locally as *coroas-de-henrique*

[3] Commonly known as common gorse, and locally *carqueja*.

[4] Commonly known as dwarf gorse, dwarf furze, and locally by *carqueja*, not being made distinction from vernacular name of *U. europaeus.*

[5] Commonly known as evergreen oak or holly oak, and locally by the Portuguese name of *azenheira*.

[6] Commonly known as Canary Island date palm, and locally as *palmeira-das-canárias*.

Sheppard ex Ker Gawl.[1], and *Passiflora molissima* (inland), and *Nicotiana glauca* Graham[2] and *Pennisetum purpureum* (south coast) (Table 4.7).

Table 4.7 Number of photographs where current exotic species were seen in each set (South coast, Inland, and North coast). When an exotic species was identified in more than one replica of same location, in a time series, it was counted only once (e.g. *Hedichium gardnerianum*).

Taxa	South coast	Inland	North coast
Acacia mearnsii	24	14	17
Acacia spp.		2	
Agapanthus praecox		1	1
Agave americana			1
Ageratina adenophora	4		3
Arundo donax	50	11	46
Brachiaria mutica	23	5	6
Cardiospermum grandiflorum	28	1	4
Castanea sativa		17	
***Cytisus* spp.**	2	11	6
Eucalyptus globulus	30	27	22
Hedychium gardnerianum		1	
Nicotiana glauca	1		
Opuntia tuna	11	2	4
Oxalis pes-caprae	14	1	
Passiflora mollissima		1	
Pennisetum purpureum	7		
Phoenix canariensis			1
Pinus pinaster	15	29	30
Pittosporum undulatum	6	2	7
Podranea ricasoliana	6		4
Quercus ilex			2
Quercus robur		1	
Solanum mauritianum	3	1	9
Tamarix gallica			4
Tropaeolum majus	4	1	1
Ulex spp.		8	
Total	82	58	62

Acacia mearnsii, which was not possible to identify in historical images, replaced other vegetation (exotic vegetation, native vegetation, and also vegetation that was not possible to identify in the past) and also grew over barren areas, not only uncovered areas were vegetation showed signs of being destructed but also bare rock areas. It also established over abandoned agricultural fields, being this encroachment more visible in areas that were cultivated 75-100 years ago in the north coast (Figure 4.36-c).

Arundo donax that was more copiously seen in the lower lands (Table 4.7) has shown little agreement to former areas, meaning that new areas covered by *A. donax* have arisen. It spread greatly over forsaken agricultural fields, but also over other vegetation types, and as well over barren areas (Figure 4.36).

Eucalyptus globulus and Pinus pinaster, also abundant in current landscape (Table 4.7) were seen to some extend in the areas that they occupied before. But new forest stands dominated by each one of these two species became visible in current landscape scattered over areas which were previously fulfilled with other cover type. Compared with other tree species *P. pinaster* and *E. globulus* did not spread much over bare rock (Figure 4.36).

Species like *Tropaeolum majus*, *Brachiaria mutica*, *Cardiospermum grandiflorum*, *Pennisetum purpureum,* and *Solanum mauritianum*, were the ones that more often have developed a great deal over forsaken agricultural terraces, despite also have dispersed over other cover type. Species like *Cytisus scoparius*, *Cytisus striatus*, *Pittosporum*

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[1] Commonly known as Kahila ginger, and locally by *roca-de-vénus*, *bananilha*

[2] Commonly known as tree tabaco, wild tobacco, and locally as *tabaqueira,* not being made distinction from vernacular name of *S. mauritianum.*

undulatum, *Podranea ricasoliana*, *Tamarix gallica*, *Quercus ilex*, *Opuntia tuna*, and *Ageratina adenophora* although developing over abandoned agricultural fields preferentially occupied areas that were in the past covered with other vegetation type, and other more rugged areas lacking vegetation in historical landscape (Figure 4.36). *Castanea sativa, seen* only in inland (Table 4.7) followed a pattern very similar to other trees seen in historical landscape, maintaining for some extend the areas that were occupied before, and scattered over areas which were previously fulfilled with other cover type (Figure 4.36-b). *Hedychium gardnerianum,* that was counted as only one occurrence because was seen in same landscape twice (Table 4.7), allowed perceiving that the area on which the specie is growing it was native vegetation, more than one hundred years ago, and it was meanwhile converted into agriculture (Figure 4.36-b). Species like *Nicotiana glauca*, *Agave americana, Quercus robur, Passiflora molissima* that were seen just in one pair (Table 4.7), provided more limited information. Yet, that data has shown the capacity of these species to grow over former areas of native vegetation, at least in part (Figure 4.36).

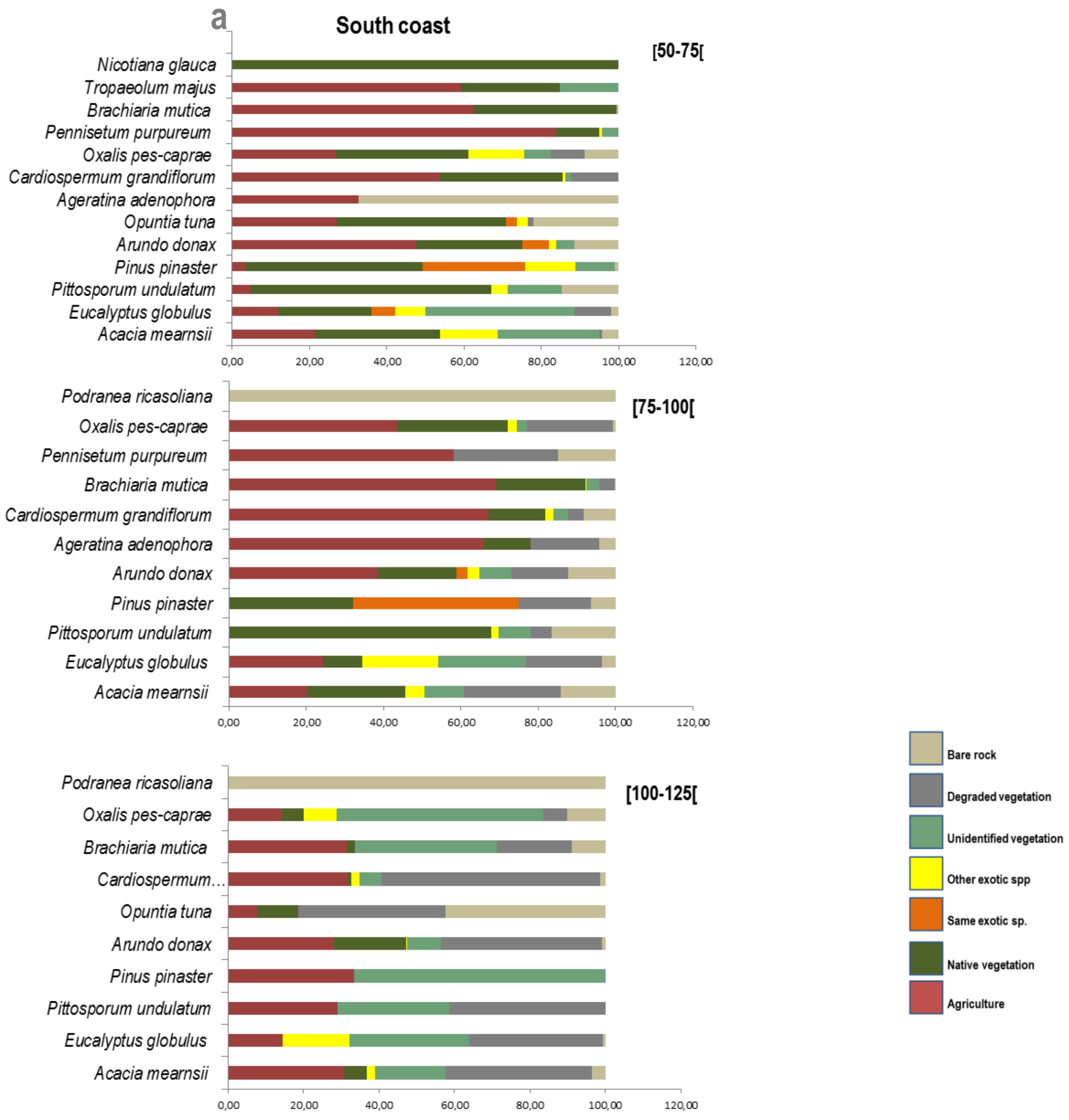


Figure 4.36 Percentage of past landscape features where exotic species, seen in current landscape, spread over: (a) south coast; (b) inland; and (c) north coast.

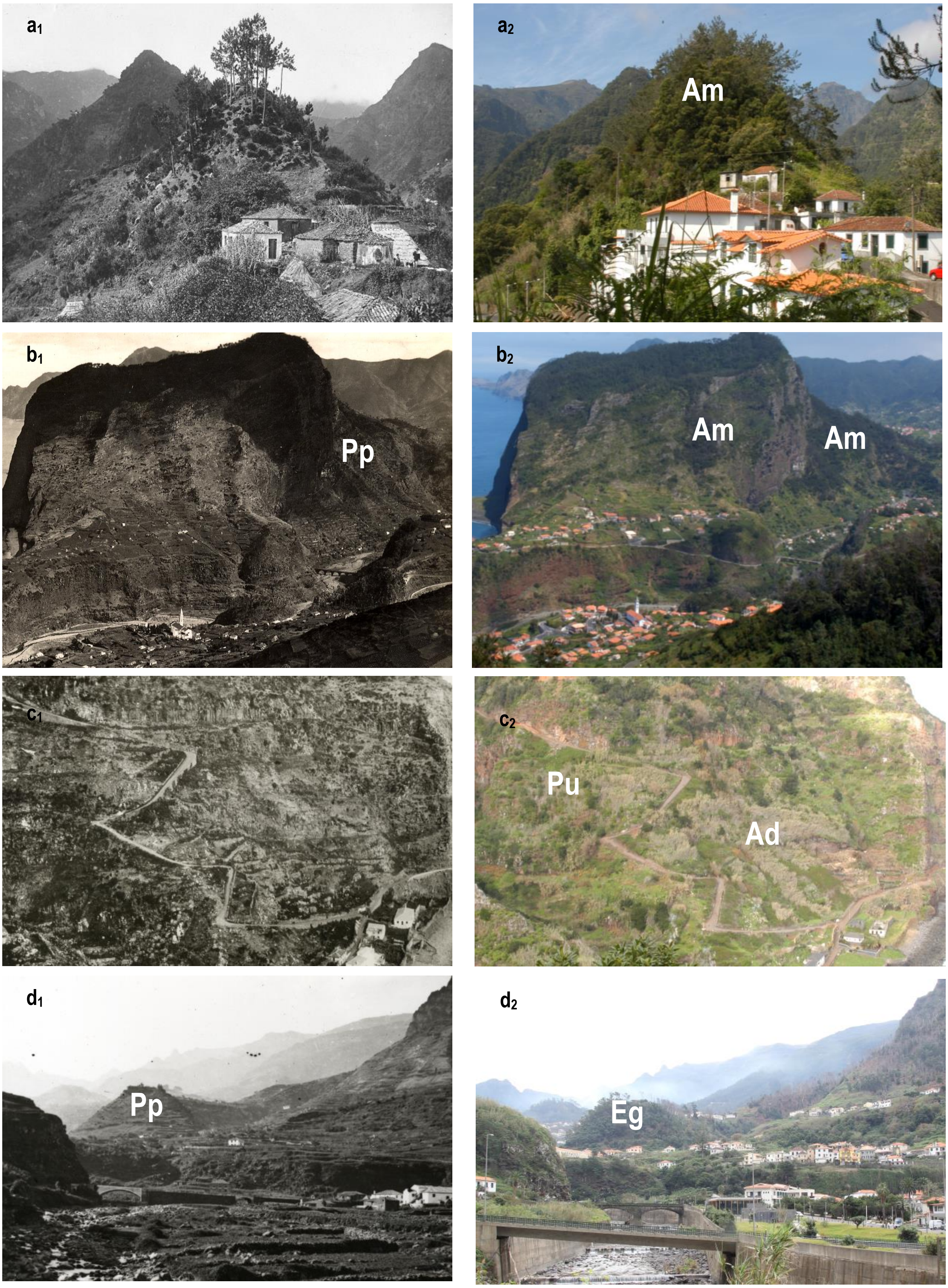


Figure 4.37 Landscape zoom in of historical and repeated photographs: (a_1) Cruzinhas do Faial, inland in late early 1940s (by unknown photographer, MA), and (a_2) in 2011 (AP, MB), showing *Acacia mearnsii* (Am) that replaced native shrubs growing in the pinewood understory (b_1) Penha de Águial, north coast, in early 1940s (by unknown phototographer, ARM), and (b_2) in 2006 (MS, AP) showing *Acacia mearnsii* (Am) that replaced pinewoods (Pp) and spread into former bare ground; (c_1) São Jorge, north coast, in late nineteenth century (by unknown phototographer, AP), and (c_2) in 2006 (MS, AP) showing *Pittosporum undulatum* (Pu) and *Arundo donax* (Ad) that invaded both forsaken terraces and surrounding barren areas; (d_1) São Vicente, north coast, late nineteenth century (by unknown phototographer, ARM), showing pinewood (Pp) and (d_2) in 2013 (AP,JP) *Eucalyptus globulus* on what must have been a mixed plantation with pine trees, recently dead affected by *Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle.

4.3.6 Vegetation growth on abandoned agricultural fields

Although figures showed variation across the sub-regions and time-brackets (Table 4.8 and Figure 4.38) there was a clear trend for exotic species dispersal over abandoned terraces, more often in bunches dominated by them, most conspicuously in south. Assemblages with native plants were also detected, but far more frequently in inland than in north coast, and more in these two areas than in southern left over fields. The former agricultural lands located in south coast were more often invaded by exotic plants than similar areas in north coast and inland which on the other hand have shown higher level of native plant species regeneration. Over coastal areas recovery was mainly by species of sub-seral stages, whereas in inland assemblages containing trees were regenerated on higher proportion than vegetation of seral stages re-established in same area.

Table 4.8 Transitions from former agricultural areas into vegetation types currently seen in the landscape. Figures correspond to average values (%) found for each area and time-brachet.

	South coast			Inland			North coast		
	[100-125[	[75-100[	[50-75[	[100-125[	[75-100[	[50-75[	[100-125[	[75-100[	[50-75[
Exotic plants	74,06	72,86	59,34	61,38	0,00	50,20	48,00	50,48	50,18
Mixture	5,94	6,91	13,58	22,73	49,27	20,02	28,98	26,90	20,11
Native vegetation	20,00	20,23	26,59	8,19	50,73	29,78	20,70	22,62	30,29
Total	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00

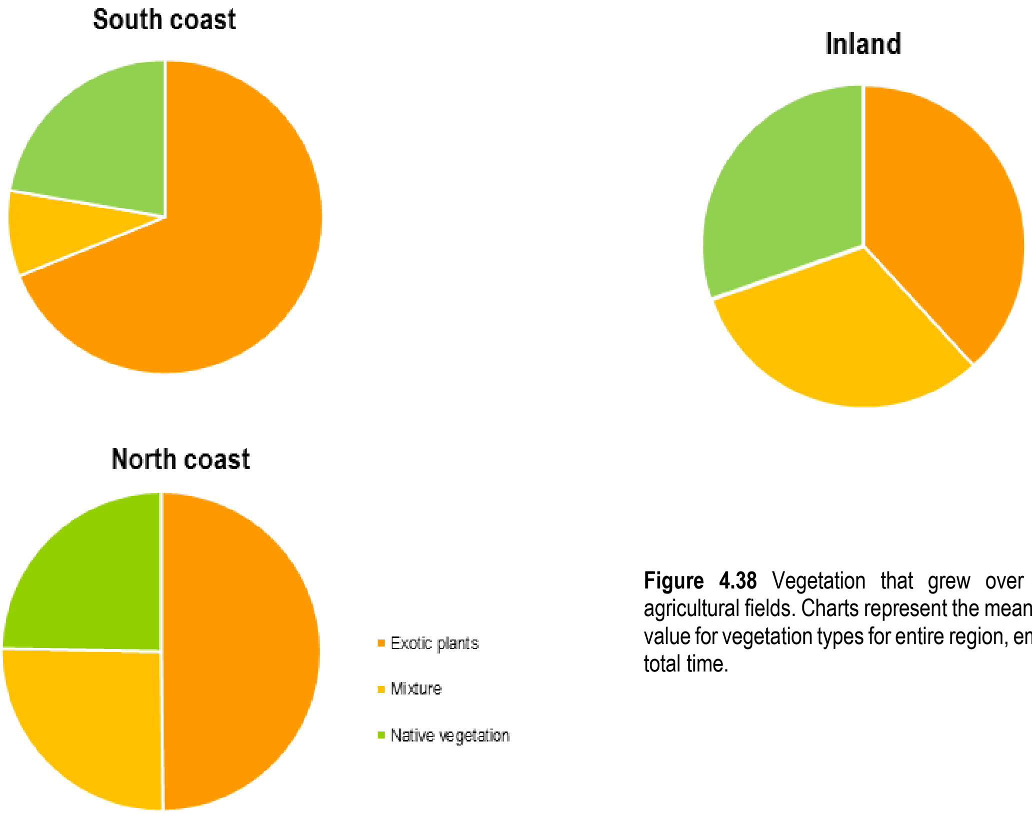


Figure 4.38 Vegetation that grew over abandoned agricultural fields. Charts represent the mean percentage value for vegetation types for entire region, embracing the total time.

Abandoned agricultural areas all over the island were in general invaded by two species: *Acacia mearnsii* and *Arundo donax,* which appeared always amongst the major transitions (Figure 4.39, and Figure 4.40).

In the south coast in addition to the two species previously referred *Cardiospermum grandiflorum* and *Brachiaria mutica* also have had significant weight in this sub-region. Lands that were no longer farmed also become covered by *Ageratina adenophora*, *Eucalyptus globulus, Opuntia tuna*, *Oxalis pescaprae*, *Pennisetum purpureum*, *Pinus pinaster, Pittosporum undulatum, Podranea ricasoliana, Tropaeoleum majus*, and less commonly by *Cytisus scoparius*, C. *striatus*, and *Solanum mauritianum.*

In inland areas, where these two species were not the most relevant, the foremost conversions were to tree species like *Eucalyptus globulus, Pinus pinaster*. In this sub-region former cropped fields also become covered with: *Castanea sativa*, Cytisus *scoparius*, *C. striatus*, and *Brachiaria mutica*, with some significance, and also *Agapanthus praecox*, *Ageratina adenophora*, *Hedychium gardnerianum, Oxalis pescaprae*, *Passiflora molissima*, and *Tropaeoleum majus*.

In north coast, where *Arundo donax* established more than *Acacia meansii,* some other species were seen also covering abandoned fields, as: *Ageratina adenophora, Brachiaria mutica, Pinus pinaster*, *Pittosporum undulatum, Podranea ricasoliana, Solanum mauritianum, Tamarix gallica*, and, although less than these, were also seen species like: *Agave americana*, *Cardiospermum grandiflorum*, *Eucalyptus globulus*, *Opuntia tuna, Pennisetum purpureum*, *Quercus ilex*, and *Tropaeoleum majus.*

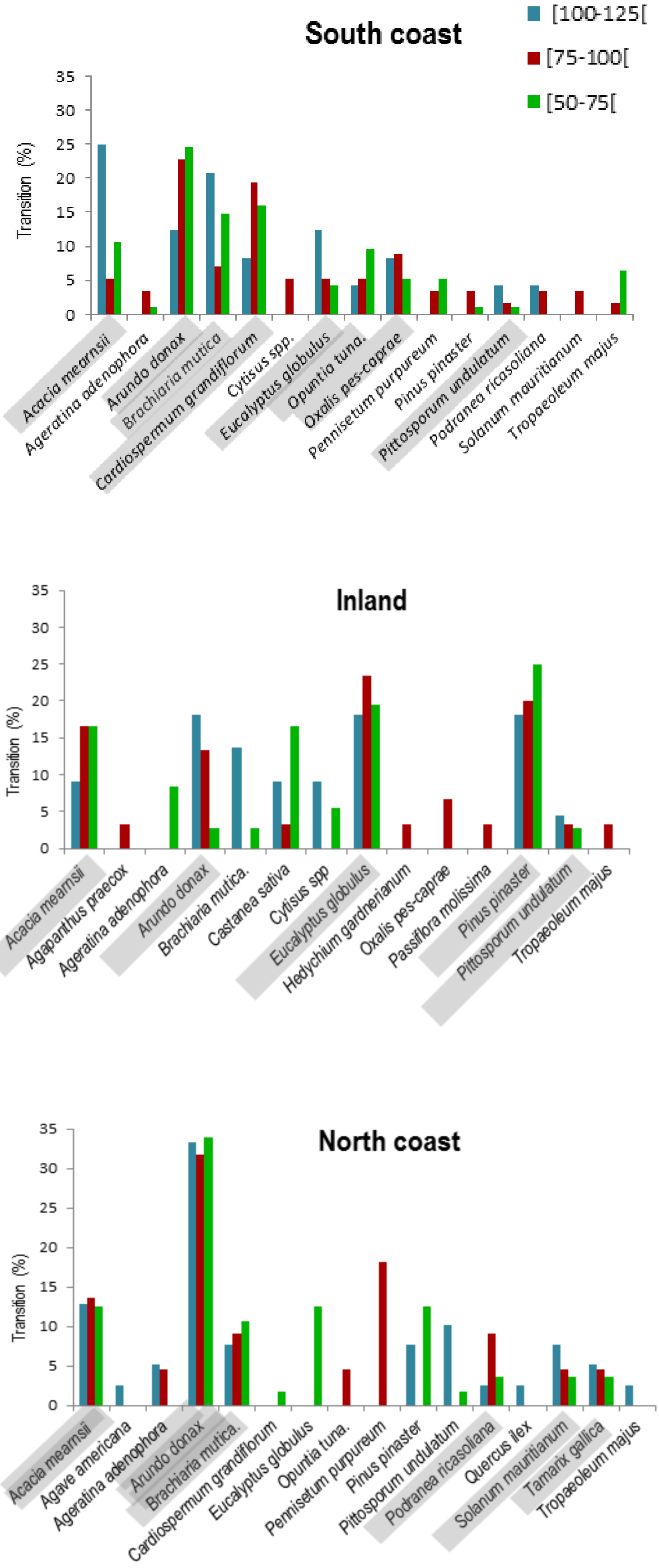


Figure 4.39 Exotic species that grew over forsaken agricultural fields located on south coast, inland, and north coast. Grey bars highlight species growing over forsaken terraces in photographs of all three time brackets.

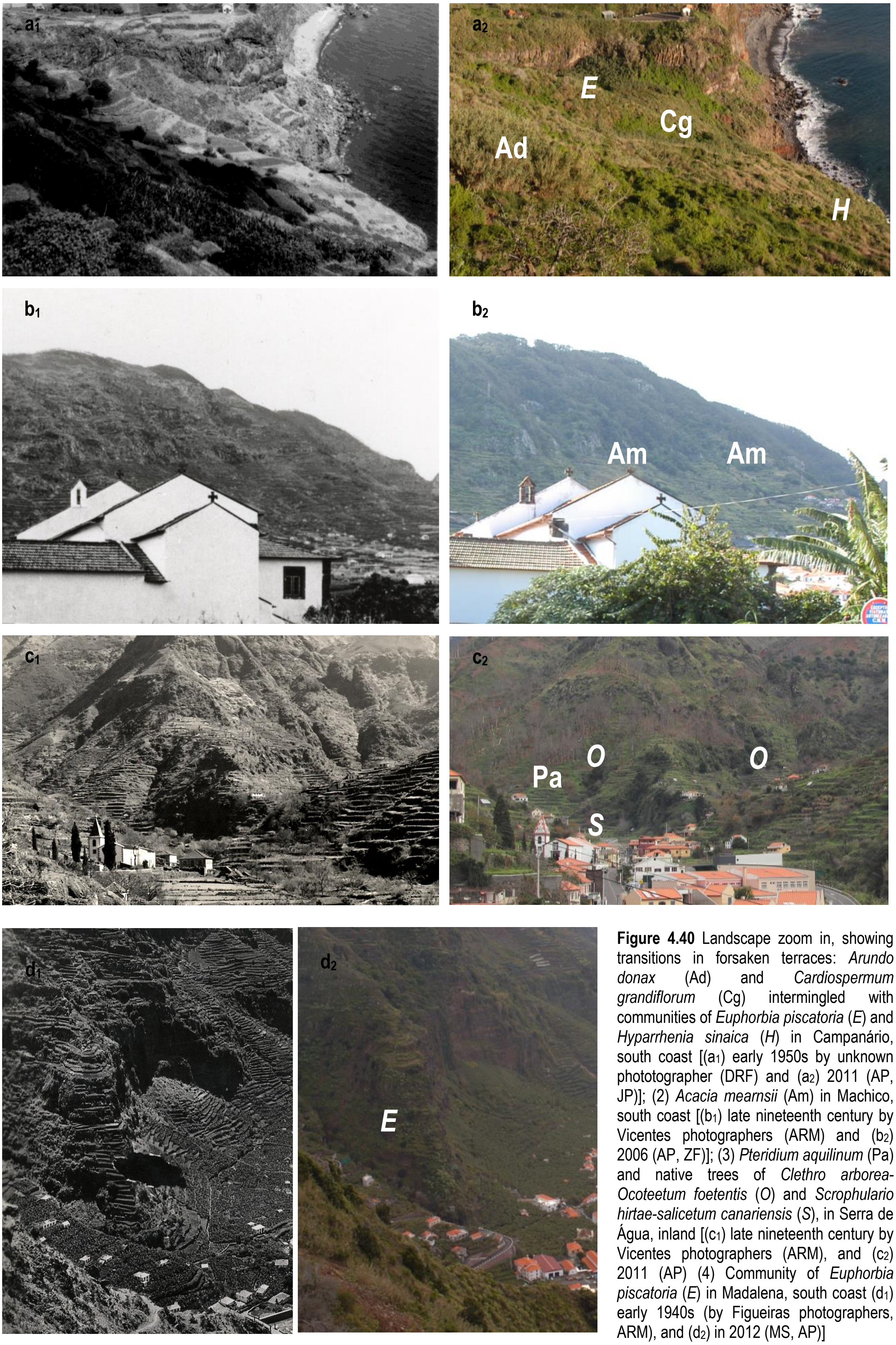


Figure 4.40 Landscape zoom in, showing transitions in forsaken terraces: *Arundo donax* (Ad) and *Cardiospermum grandiflorum* (Cg) intermingled with communities of *Euphorbia piscatoria* (*E*) and *Hyparrhenia sinaica* (*H*) in Campanário, south coast [(a$_1$) early 1950s by unknown phototographer (DRF) and (a$_2$) 2011 (AP, JP)]; (2) *Acacia mearnsii* (Am) in Machico, south coast [(b$_1$) late nineteenth century by Vicentes photographers (ARM) and (b$_2$) 2006 (AP, ZF)]; (3) *Pteridium aquilinum* (Pa) and native trees of *Clethro arborea-Ocoteetum foetentis* (*O*) and *Scrophulario hirtae-salicetum canariensis* (*S*), in Serra de Água, inland [(c$_1$) late nineteenth century by Vicentes photographers (ARM), and (c$_2$) 2011 (AP) (4) Community of *Euphorbia piscatoria* (*E*) in Madalena, south coast (d$_1$) early 1940s (by Figueiras photographers, ARM), and (d$_2$) in 2012 (MS, AP)]

Although in much less extent (see Figure 4.38), recovery of native vegetation over lands that were used for agricultural purposes in the past also occurred (Figure 4.41, and see also Figure 4.40). Over coastal areas recovery was mainly by species of sub-seral stages, whereas in inland, even though a great part of those were covered by *Pteridium aquilinum*, assemblages containing floristic composition of climatophilous communities have been regenerated on higher proportion. Should be noted that in this sub-region agricultural fields in older photographs (although it cannot be proven when their abandonment occurred) are more often covered with late successional stage (*Clethro arborea-Ocoteetum foetentis*) than early successional communities (*Vaccinio padifoli-Ericetum maderincola*), and fields seen in the more recent historical photographs (which abandonment took place less than 75-50 years ago) the proportion of these two communities are the inverse, as expected. Communities of shrubby sub-seral stages that developed over formerly cultivated areas in coastal areas were more often *Euphorbietum piscatoriae* (south coast), *Globulario salicinae-Ericetum arboreae* (north coast). Native grasslands, characterised by the presence of *Hyparrhenia sinaica*, was a common transition (especially in south cost), and was also found intermingled with shrub communities [with *Euphorbietum piscatoriae* (south coast) and *Globulario salicinae-Ericetum arboreae* (north coast)]. In north coast, compared with south coast, it was found a higher development of native woodland, both in thickets where trees belonging to *Semele androgynae-Apollonietum barbujanae* occur, as well as in mosaic with seral stages.

a

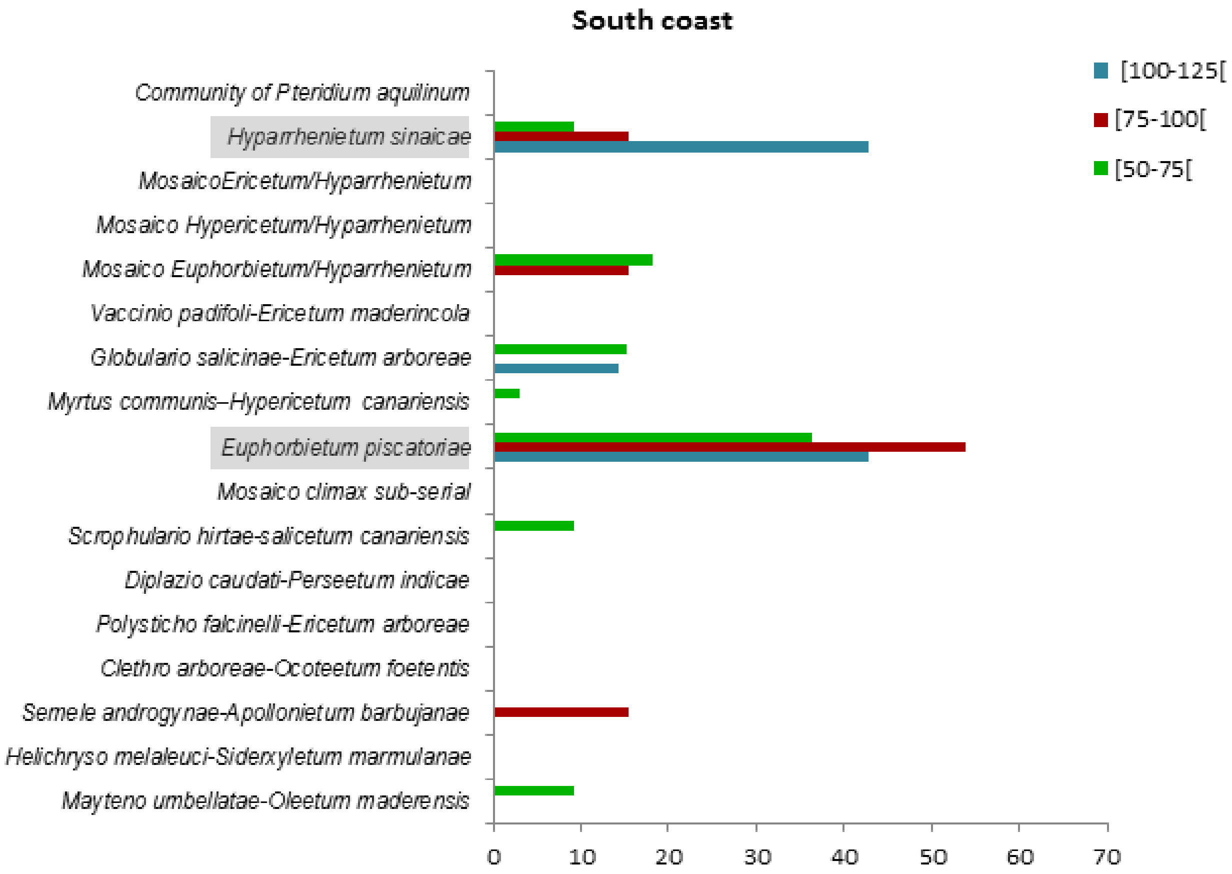
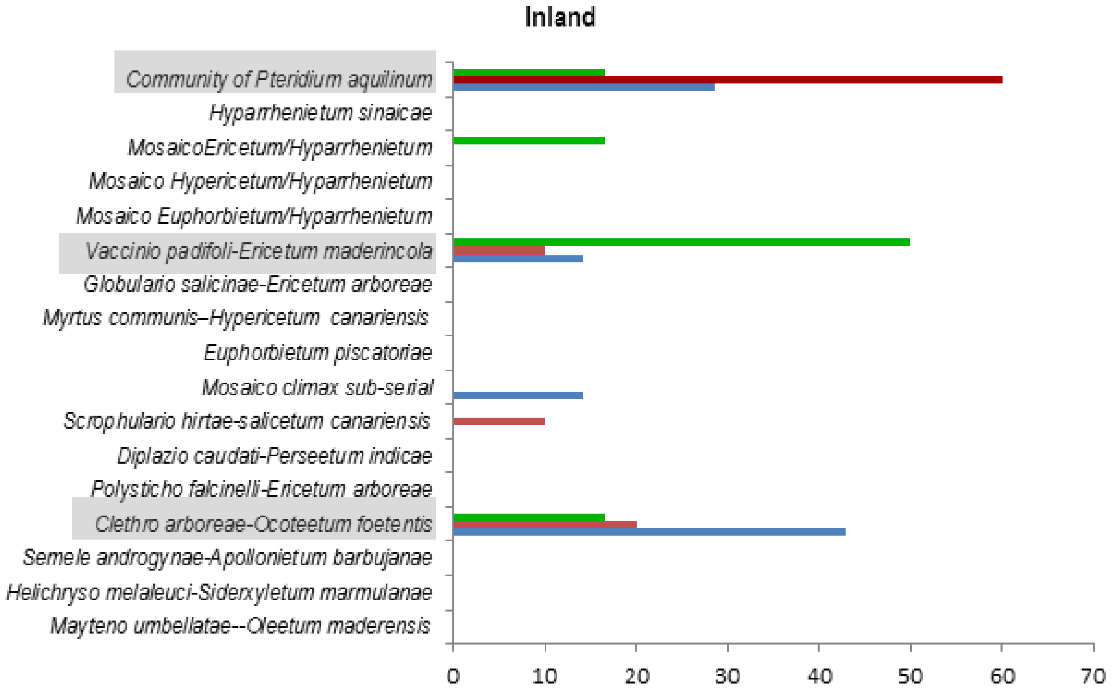
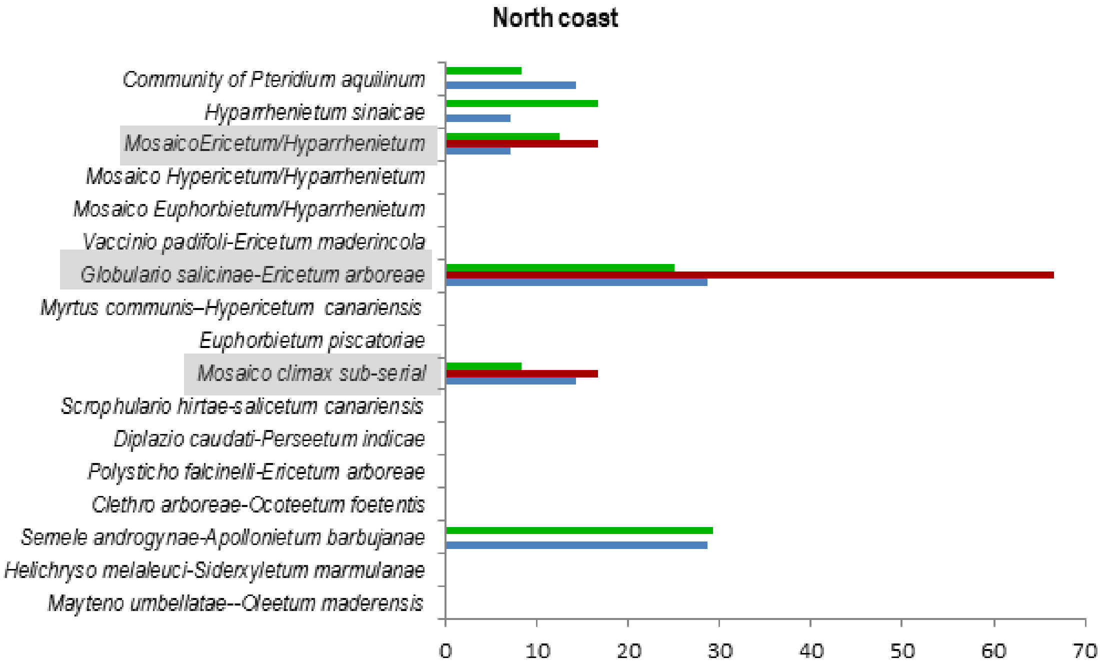


Figure 4.41 Native communities that recover over abandoned farmland, located in (a) south coast, (b) inland, and (c) north coast

b


Inland
Community of Pteridium aquilinum
Hyparrhenietum sinaicae
MosaicoEricetum/Hyparrhenietum
Mosaico Hypericetum/Hyparrhenietum
Mosaico Euphorbietum/Hyparrhenietum
Vaccinio padifoli-Ericetum maderincola
Globulario salicinae-Ericetum arboreae
Myrtus communis–Hypericetum canariensis
Euphorbietum piscatoriae
Mosaico climax sub-serial
Scrophulario hirtae-salicetum canariensis
Diplazio caudati-Perseetum indicae
Polysticho falcinelli-Ericetum arboreae
Clethro arboreae-Ocoteetum foetentis
Semele androgynae-Apollonietum barbujanae
Helichryso melaleuci-Siderxyletum marmulanae
Mayteno umbellatae--Oleetum maderensis
0
10
20
30
40
50
60
70

c


North coast
Community of Pteridium aquilinum
Hyparrhenietum sinaicae
MosaicoEricetum/Hyparrhenietum
Mosaico Hypericetum/Hyparrhenietum
Mosaico Euphorbietum/Hyparrhenietum
Vaccinio padifoli-Ericetum maderincola
Globulario salicinae-Ericetum arboreae
Myrtus communis–Hypericetum canariensis
Euphorbietum piscatoriae
Mosaico climax sub-serial
Scrophulario hirtae-salicetum canariensis
Diplazio caudati-Perseetum indicae
Polysticho falcinelli-Ericetum arboreae
Clethro arboreae-Ocoteetum foetentis
Semele androgynae-Apollonietum barbujanae
Helichryso melaleuci-Siderxyletum marmulanae
Mayteno umbellatae--Oleetum maderensis
0
10
20
30
40
50
60
70

4.4 Discussion

The results obtained support the effectiveness of using landscape photographs for the evaluation of change and vegetation dynamics as it was stated formerly by other authors (e.g. Meagher & Houstan 1998; Debussche *et al.* 1999; Butler & DeChano 2001; Hall 2001; Rhemtulla *et al.* 2002; McClaran 2003; Clark & Hardegree 2005; Kull 2005; Moseley 2006; Hendrick & Copenheaver 2009a; Western 2010). Although figures achieved were not used for ground surface coverage assessment as proposed by Butler & DeChano (2001), the methodologies used allowed to quantify the change, contrary to descriptive and qualitative analysis performed by other authors (e.g. Veblen & Lorenz 1991; Webb 1996; Turner *et al.* 1998; Vale 2001; Start & Handasyde 2002; Turner 2005b), and to obtain more objective information than the visual comparison performed in several studies also aiming a quantitative analysis (e.g. Debussche *et al.* 1999; Butler & DeChano 2001; Kull 2005; Zier & Baker 2006; Burton *et al.* 2011).

The number of samples used (200) could be considered comparatively small when compared to the amount of potentially useful landscape photographs (1193). A great part of those left out photographs were never replicated, either because it was not possible to date them, or to identify the general location of the landscape depicted or even, although located, it was not possible to retake the photograph due to view obstruction (see point 4.2.1 and 4.2.2.). In addition, some photographs were in fact repeated but it was not possible to spatially register the new photograph to the old one (clipping or distortion of the original image diverted the principal point and camera location from the real ones). The low relation (16,7%) between the number of available photographs and the ones that were repeated and used to quantitatively assess landscape change, it is a very common place situation in similar projects [e.g. 20 pairs of photographs used by Rhemtulla *et al.* (2002) from an historical collection of 735 photographs]. However, although those photographs cannot be used for comparison they still are a great source of information about historical landscape and past conditions as stated by some authors (Munroe 2003; Bierman *et al.* 2005) and as shown previously. In following subsections results from photo comparison are discussed in order to explain long-term dynamics of: landscape (4.4.1), exotic plants (4.4.2), and native vegetation (4.4.3).

4.4.1 Landscape long-term dynamics

It was found an overall change value that ranged between 9% and 100% revealing a very heterogeneous sample set that ranged from landscapes that did not suffered alteration since the nineteenth century to landscapes that have completely changed. This value is important to the perception of landscape change, but it is needed to bear in mind that repeat photography is more than a simple comparison between past and present and it should be combined with other sources to better understand causes and directions of landscape alteration (Pickard 2002).

To analyse spatial and temporal variation, in a first approach, it was used a median to compare the change that occurred in the different time brackets. As expected, the change seen in photograph pairs with the oldest photographs was higher because they include also the change that occurred in more recent years. However this trend was not observed between [100-125[and [75-100[inland sets. This can be explained by the fact that the set “inland [100-125[“ comprises a group of photographs with low change value from one area where there is no photographic record included in other time brackets. However, the trend was in fact verified for inland locations where a time series existed (Figure 4.42).

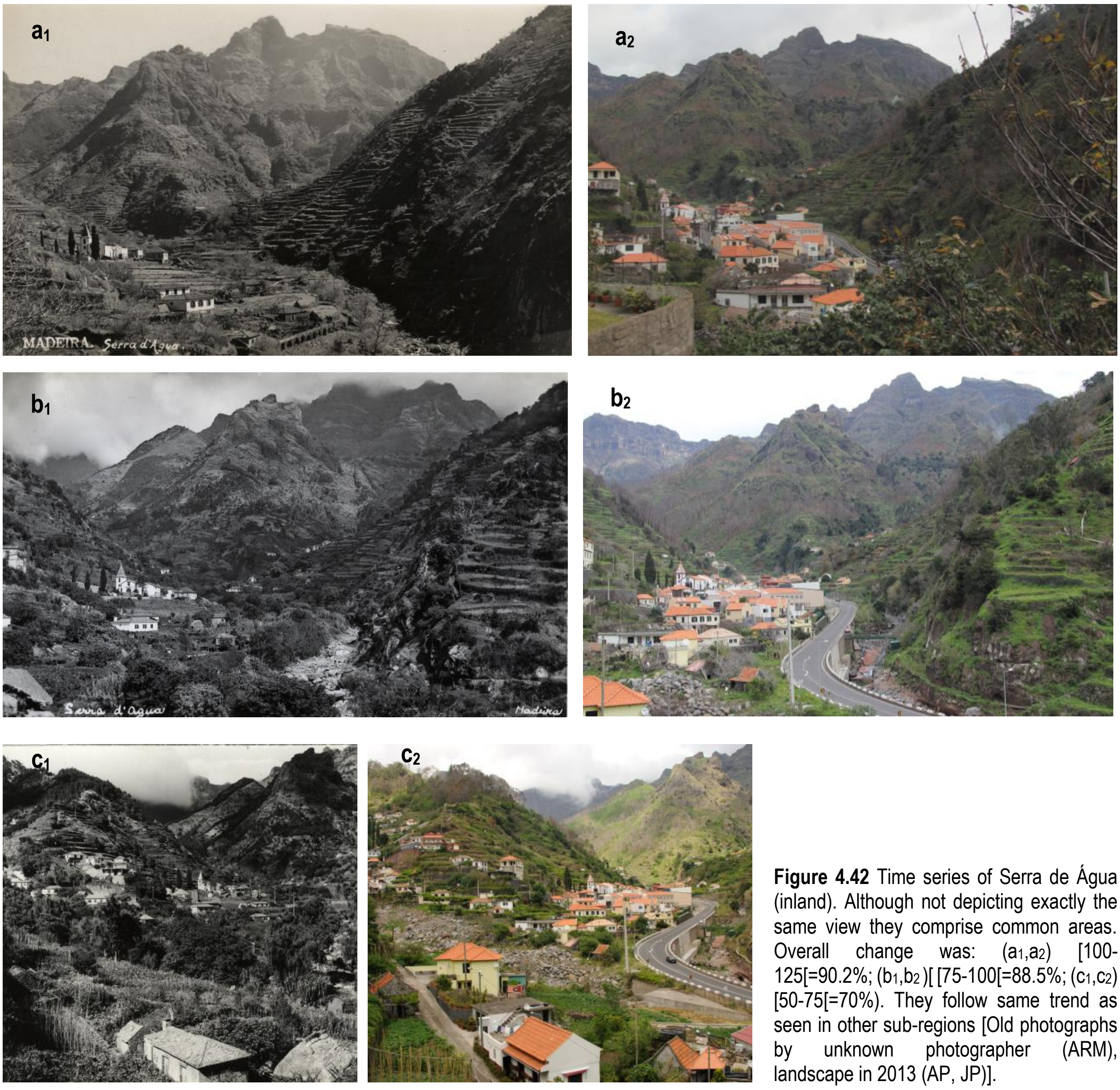


Figure 4.42 Time series of Serra de Água (inland). Although not depicting exactly the same view they comprise common areas. Overall change was: (a_1,a_2) [100-125[=90.2%; (b_1,b_2)[[75-100[=88.5%; (c_1,c_2) [50-75[=70%). They follow same trend as seen in other sub-regions [Old photographs by unknown photographer (ARM), landscape in 2013 (AP, JP)].

The change that landscape suffered over more than one hundred years was higher in south coast than the observed in inland and north coast. This assessment is much in line with what is known from past written descriptions. The extremely rugged terrain precluded access to settlements established in inland and north coast, which remained almost isolated until the twentieth century. By land, paths were painful and very dangerous[1] (Figure 4.43) and by sea, which enabled a faster communication between coastal settlements, the journey was greatly affected by weather and sea state conditions, especially in the north were quite often heavy swell prevented mooring (Frutuoso 1589; Almeida 1817; Picken 1840; Harcourt 1851). It was only after 1910 that new roads, especially designed and built for motor traffic, linked main villages in the south and allowed an easier access to the north coast. Even though some of those

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[1] As shown by the detailed description of an excursion in the interior of the island made by Harcourt (1851, p. 11, 21): "The road now assumes a different character: heretofore we have ascended and descended hills, steep enough, surely, and trodden roads that seemed slippery and hard enough: but now we long for such again; large stones and solid rocks have taken place; a perpendicular cliff is above you on one side, a precipice below you on the other: one start of your horse would be fatal.(…) Woe betide those who separated at such times from their guides: to find your way, without knowing the land-marks, is impossible. Perhaps a goat-path presents itself to your distress: you follow it along the edge of some frightful chasm till it becomes undistinguishable; you proceed, forcing your way through the underwood with which the banks are clad hanging on where the descent is almost perpendicular, till at last you are stopped abruptly by a precipice."

roads were by no means save, and many settlements remained largely isolated[1] until 1953 when it was completed the road belt encircling the island (Góis 1977; Pereira 1989). Thus, it is easy to realise why the biggest change throughout the island have occurred greatly after 75-50 years period.

Yet, even though a huge change was in fact detected for 75-50 years in south coast, this sub-region presented the smallest change in this period when compared to other sub-regions. At first sight this might seem an incongruity, yet resorting to past descriptions it is clear that south coast had undergone immense change earlier, being already much altered by then. Among many of those old description it is worth highlighting Picken (1840 p. 69):

> "(…) a scenery of which many of the elements have been supplied by the art of man: the buildings and busy scenes of the city and surrounding country; the vineyards and garden-grounds; the terraces and compartments into which the surface of the land has been laid out; the exotic trees and strange vegetation which have been introduced, these and many other artificial features have been prominent in the landscape around Funchal. (…) From the town there are several roads (…) intersecting the vineyards and garden-grounds which clothe the whole southern exposure of the hills. (…) the scenery of the south coast (...), it really seems tame and uninteresting after the marvellous scenes of the north have been witnessed".

Figure 4.43 Historical photographs from late 19th century (a, c, and d) and early 20th century (b) showing paths across inland [by unknown photographer, a and c (AN); b and d (AP)].

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[1] Not only in the interior, but also along the north coast some locations remained sheer isolated until the middle of the twentieth century, as for instance the small village of Seixal, which beyond not having terrestrial safe paths had a terrible wharf (Góis, 1977). In relation to this location Almeida (1817 p. 69) described how difficult it was the communication with neighbouring villages: *"Para São Vicente há uma comunicação dos vilões pela rocha que deveria ser proibida, porque dela sempre cai gente ao mar. É feita em grande distância, com paus presos na rocha à semelhança de escada, amarrados com vime, e tem sucedido muitas vezes desatarem-se os paus, e irem pela rocha abaixo, sempre caindo gente ao mar"* meaning: "Towards São Vicente there is a passage on the cliff that should be banned because very often people falls into the sea. It is a quite distance made with sticks projected out of the rock like a ladder. Being tied with wicker, they often unleash up and people fall from cliff into the sea."

The past change observed over the last 75-50 years in the south coast lands was nevertheless inferior to the one that occurred over places along north coast and inland during the same time. As long as these less accessible areas were at that time less altered than southern areas (Almeida 1817; Picken 1840) the change they undergone was most significant, especially after road network was built (Corrêa 1927; Natividade 1953; Pereira 1989). Indeed, it was the interior that presented the overall biggest change detected in pairs spanning the time brackets below one hundred years. Although the most easily reachable areas were already subjected to natural vegetation destruction in the late 19th century (Figure 4.44-a) most of inland areas would still have lesser degree of hemeroby than coastal areas. Although subjected to grazing and woodcutting (Almeida 1817; Sequeira 1913; Andrada 1990), much of the land was still not wooded, and had fewer inhabitants, most of whom were very poor (Figure 4.44-b), (Athayde 1813; Almeida 1817) resulting in low construction density[1]. These inland areas were the ones that have drastically changed since then.

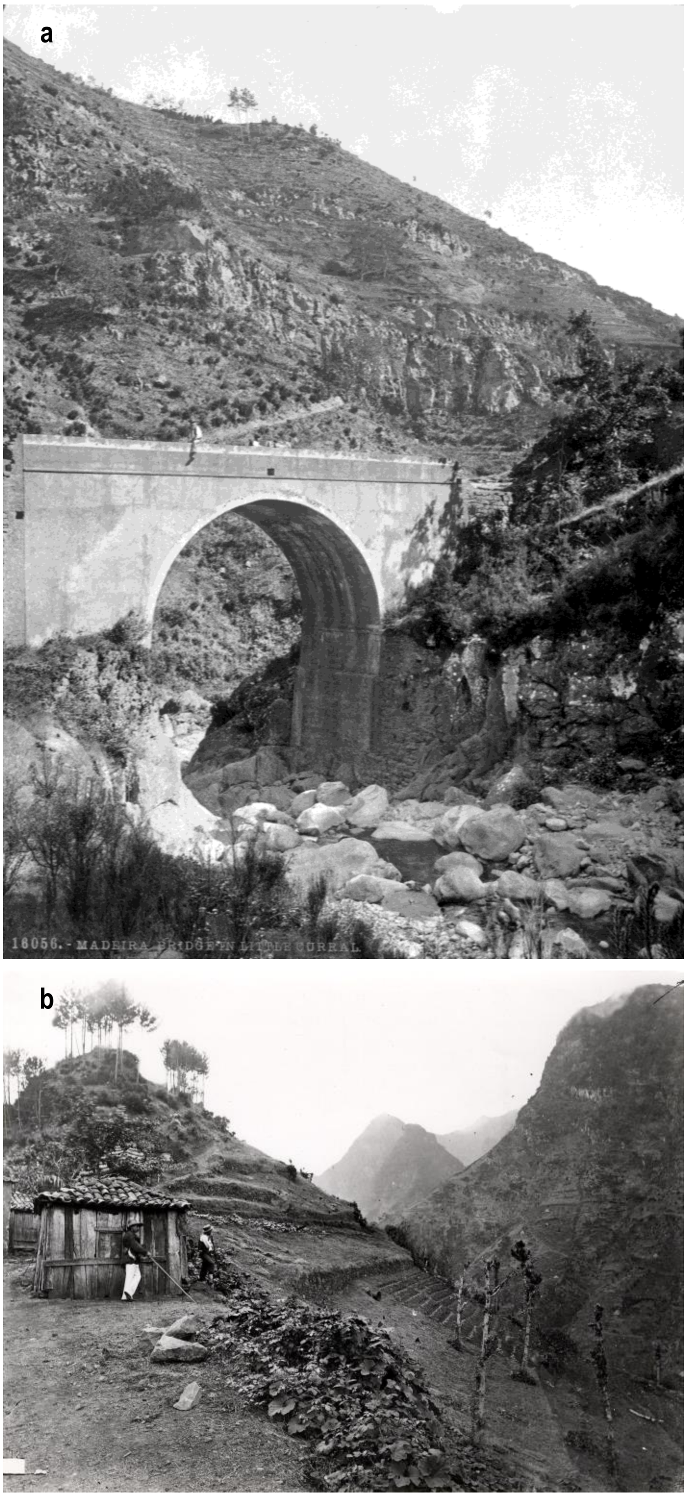

Figure 4.44 Rather easy accessible inland places, in late 19th century: (a) mountains surrounding the city of Funchal [Curral dos Romeiros, unidentified photographer (AN)]; (b) high inland facing north, near a south-north path [Cruzinhas do Faial, by unknown photographer (ARM)].

The interpretation presented above is also supported by the comparative analysis carried out with photograph pairs showing less than 50% change (see figure 4.20). Although a threshold of 20% is normally considered to accept that landscape did not change, if only those pairs were used the sample size would be too small. It was found that in the set of those none or little altered landscapes the features related to human activity were largely responsible for landscape maintenance. This sustains the assumption that part of the landscape that has not significantly changed was already

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[1] Also evidenced by nineteenth century descriptions as made by Bishop Joaquim de Menezes e Athayed (1813, p. 335) in his visit to the parish of Camacha: *"Todas as casas são cobertas de colmo espalhadas pelos mattos, (…). Apenas conta 12 casas com telhado e 2 somente de sobrado."* meaning: Almost all the houses which are scattered throughout the scrubland are covered with a roof of straw thatch (…). The village has only 12 houses with tile roof and solely 2 two-storey houses.

altered when historical photograph was made and features responsible for landscape modification at that time were the ones that changed less since then. Indeed, it is not possible to destroy a completely destroyed landscape.

This issue was also reinforced through the comparison between the three sub-regions (see figure 4.20, and also 4.21-23). It was found that it was in the south coast in which agriculture, construction, and cliff faces, have shown higher agreement between past landscape and present one, being ultimately responsible for low change level. Any type of vegetation (exotic or native) that remained unchanged did not have any significance in landscape sameness; especially that non-agricultural tree cover was almost destroyed at that time, as it was often highlighted (Ackermann 1821; Picken 1840; Harcourt 1851; Soares 1882; Sequeira 1913; Camacho 1920) and seen in historical photographs. In relation to north coast it was found that part of the landscape that did not changed was mainly due to little change in construction and cliffs, the latter a predominant feature along northern shoreline (Pereira 1989), although agriculture and native vegetation also had a role in landscape maintenance. Native vegetation together with bare rock in scarps and cliffs, were the only classes that, due its little change, resulted in the landscape that remained most frequently unchanged in inland areas. Descriptions made before historical photographs demonstrate the dominance of these features in the landscape of most remote areas:

> "(…) some of the more distant parts of the island, where the scenery is of a far grandeur and more imposing character, where rocks and ravines, mountains and forests form landscapes of the wildest magnificence, where the cultivation of man has been able to work little change on the aspect of the country; where the land is yet clothed with its ancient and native vegetation, and where both along the rocky cliffs of the north, and precipitous mountains of the interior the arrangements and ornaments of art are insignificant compared with the beauty and majesty of nature." (Picken 1840, p. 69).

To get information about motives of change, the class with highest frequency as major cause of landscape change, in each contingency table, was considered as main reason of alteration (see table 4.4.). To find out direction of change it was used the percentage of variation that occurred between two dates for each landscape feature. Being the percentage of change of each class dependent on the amount of image cover in historical photographs, it cannot be used *per se* and comparisons between classes must be interpreted taking in account the change that has previously occurred.

Although the maintenance of agricultural fields was one of the main causes of little change of some landscapes, as seen above, it was also the leading cause of landscape alteration due to decrease (land abandonment and its transition into other features). Only transitions to a very different class were considered since farm lands that switched to another culture, forsaken lands with vestiges of former crops (Code 241), and fields looking recently abandoned surrounded by farmland, and thus considered as fallow land (Code 242), were all regarded as agreement. Transitions that were responsible for this change are discussed in more detail further below.

The change that occurred in *Construction* class was consequence of the increase of built up areas, especially in south coast. It was found, however, that variation value within this class was lower in the sets with most recent photographs. As stated above such figures depend on the amount of image cover of the class seen in historical photographs, and being the percentage value lower within 75-50 photograph pairs it does not mean that construction has diminished during that period. In fact, it has increased especially in south coast after the 1980s driven by the real estate growth (Bettencourt 2007). Another fact contributed to the lower value found for construction increase in 75-50 period than the one that actually took place. Some photograph pairs showed reduction within this class. It was related to agricultural decline and the abandonment of "palheiros"[1] that due to their small size and primitive construction (Corrêa 1927) have been quickly wrecked or covered with plants after abandonment. Although considering that the latter could not have a huge impact on the variation value it could have helped to reduce expected figures. *De facto* construction activity has substantially increased during more recent times and it was compelled into former farm lands which were converted into buildings and roads (Bettencourt 2007). Likewise, building expanded into some places unfit for construction as stream banks and cliffs (Figure 4.45). Occupation of those areas not only increased frequency of damaging landslides and flood events (Baioni 2011), but also jeopardised the survival of native vegetation, by preventing spontaneous recovery and remnants of native vegetation, as it was stated in neighbouring islands (Otto *et al.* 2007).

Figure 4.45 Construction over river bed and banks, and also over shore cliffs, especially in south coast. Ribeira dos Socorridos (a_1) in 1930s (Figueiras Photographers, AP), and (a_2) in 2010 (MS, AP); Porto Novo Cove (b_1) in first quarter of 20th century (unidentified photographer, ARM), and (b_2) in 2006 (AP, ZF).

As outlined in Results, expansion of the construction over cliffs and stream banks was one of the causes of *Bare Rock* decrease, especially in south coast. However, there was another reason linked to the development of vegetation over those features. Despite it can be admitted that in a few old photographs shadows and lack of colour could have hindered visualisation of rupicolous vegetation, for the majority it was clear enough that steep faces classified as *Bare rock* were almost uncovered. The recovery of native vegetation that occurred in former barren rocks

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[1] A type of shed built with rubble walls and straw roofs, as seen in figure 4.14.

areas was residual. Nevertheless, appearance of vegetation in those areas was facilitated by the fact that the *Bare rock* feature was surrounded by scattered clusters of native vegetation that due to its location on inaccessible ravines survived[1] the massive destruction (Almeida 1817; Jardim & Menezes de Sequeira 2008). Spontaneous recovery of native vegetation over cliffs and rocky stream banks was detected more often in north coast and in inland, whereas in south coast much of the cliffs became covered by exotic plants as *Ageratina adenophora, Arundo donax, Cardiospermum grandiflorum, Opuntia tuna, Podranea ricasoliana.*

4.4.2 Exotic plants long-term dynamics

Exotic species is one of the most serious environmental problems affecting ecosystems around the world. Most exotic species have harmful effects, altering the structure and function of native ecosystems and being a serious threat to biological diversity. Their impact depends not only on their biology but also on native ecosystem resilience and the time length of the invasion. Restoration of invaded ecosystem is often compromised by lack of data on invasive species long-term behavior (D'Antonio & Meyerson 2002; Henderson *et al.* 2006). In this subchapter, findings of each exotic species identified at landscape level are discussed aiming to provide some insights useful for restoration projects and conservation plans.

Ageratina adenophora (Figure 4.46) was introduced in Madeira Island prior to 1840 as ornamental plant and it was recorded as garden escape since 1855 (Lowe 1868). It became, since then, widespread and very common all over the Island[2], occupying lands from sea-shore up to more than 1000 metres (a.s.l) (Lowe 1868; Grabham 1926; Press 1994). Even after the interest for ornamental use was lost, this species continued to be farmed in view of being used as green manure (Vieira 2002) which would have contributed for the overrun, especially along forsaken agricultural areas. It was stated by the latter author that the species become very abundant[3] in early 1960 and started to be considered a serious ecological and economical problem. Aiming to reduce adverse effects on agricultural output and native vegetation it was made an attempt to suppress *A. adenophora* by introducing a pest control[4] (Vieira 2002). Apart from the backlash against this measure that it could have nowadays, no monitoring data that could give an insight into the outcome was made. Although, Vieira (2002) reported the success of parasite establishment, there is no information about efforts made to evaluate action efficiency and to check if its activity was confined to *A. adenophora*, being the latter of particular concern since Asteraceae is the family with larger number of endemisms (Jardim & Menezes de Sequeira 2008).

Because it was not possible to identify the species in historical photographs, although it could be present given the above, it was not attainable to realise if it increased or diminished in comparison with the past. Results have shown *A. adenophora* development over abandoned fields, and also over bare rock, especially on south coast, and over former native vegetation, especially on north coast. All over the island, it is profusely scattered over stream banks,

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[1] As pointed out by Almeida (1817, p. 53) "(…) se acha todo descoberto de arvoredo, com apenas algumas árvores dispersas, e isto em lugares onde os carvoeiros não têm chegado." meaning: the land is almost unclothed, only with a few sparse trees, and solely where charcoal-burners could not reach.

[2] Regarding this species Grabham (1926) have written that *Ageratina adenophora* (under *Eupatorium adenophorum* Spreng.) was a very noxious species that has invaded the island.

[3] The local common name *Abundância* (abundance) clearly indicates the profusion of the species which was already evident in the past, when it was also known as *inça muito* (spread-much) (Lowe 1868).

[4] *Procecidochares utilis* Stone, the eupatorium gall fly (Vieira, 2002).

rocky cliffs, wastelands, stone walls supporting terraces, and in the understory of exotic and native woods. Some environments where the species is installed nowadays, as ravines and garden edges, were also referred in the nineteenth century as being densely clothed by this species (Lowe 1868), but at that time it has not been mentioned the spread throughout agricultural fields. While is true that a great part of the plants are garnished with galls, and thus less competitive in xeric environment[1], results have shown that *A. adenophora* also invaded environments with lesser water availability, as exposed bare rock ravines and forsaken terraces[2], being a clear indication of control measures failure.

It is not among the 100 world worst invasive species (Lowe *et al.* 2000), but it is considered a problematic species in the great part of the islands of Macaronesian archipelagos (Silva *et al.* 2008b), and especially in Madeira Island where it was already targeted as motive of concern by Sjögren[3] (1972; 2000) and Press (1993). More recently it was subjected to control measures but only within protected areas, especially in laurel forests (Silva *et al.* 2008a).

Figure 4.46 *Ageratina adenophora* in exotic forest edges and over stone walls (2015, AP)

Arundo donax (Figure 4.47), as referred in the Introduction, was a very early introduction (Menezes de Sequeira *et al.* 2010) and by the end of the nineteenth century it was already identified has being very common (Menezes 1894). It was largely employed for a broad variety of uses[4] but especially, along south coast, for trellised vineyards (Figure 4.47). By the eighteenth century it was so sorely needed that land owners reserved a part of the land to grow it, and its shortfall prevented vine cultivation[5] (Forester, 1777). Its demand and strained utilisation could explain both the fact that it has been one of the exotic species most frequently identified in historical landscape, and at the same time why being *A. donax* so common it was not seen in older southern photographs (see table 4.5). The intense gathering of reed[6] in the past and almost until the beginning of this century (Vieira 2002) could be the explanation for the species disappearance and replacement by other vegetation type in some areas. Given that all around the world *A. donax* has

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[1] Survey studies conducted in other regions, where the same biological control was undertaken, have shown that control was rather effective over dry environments but that it was absolutely negligible in moister zones (Bess & Haramoto 1972).

[2] Where it frequently forms a community with *Rubus ulmifolius* (*Rubo ulmifoliae-Ageratinetum adenophorae* Rivas-Martinez *et al.* 2003)

[3] Under *Eupatorium adenopherum*.

[4] *Arundo donax* was one of the non-food crops that had the largest variety of applications. Since the formerly referred employment in grape cultivation, and to protect agriculture fields from wind and erosion, the leaves and stalks tops were used as fodder for cattle (Bowdich 1825), stalks were used for construction (ceilings and inner walls covered with plaster) and for a variety of handcraft as baskets, bird cages, fishing rods, musical instruments and toys, as well as fuel (Silva & Menezes 1946; Vieira 2002).

[5] "The owners of vineyards are however obligated to allot a certain spot of ground for the growth of bamboos [a common name of giant reed, although less frequently used]; for the lattice-work cannot be made without them; and I was told some vineyards lay quite neglected for want of this useful reed" (Forster 1777, pp. 23-24)

6 Not only by cutting the aerial part of the plant, but greatly by removing rhizomes, to prevent the encroachment into croplands and to use them after drying [a rather curious application was to make up the traditional Crib (known as *lapinha*) at Christmas (Vieira 2002)].

shown its ability to prevent other species installation by modifying ecosystem properties (Henderson *et al.,* 2006), being a threat to riparian ecosystems throughout Mediterranean-climate regions (Rieger & Kreager 1989; Bell 1997; Boland 2006; Quinn & Holt 2008; Silva *et al.* 2011) it is likely that these conversions could not have happened without being 'helped'. In addition to ample elimination in the past, the fact that this conversions were seen in areas with less water availability[1] afforded the installation of native species with xerophyllic character as *Euphorbia piscatoria* (south coast), *Erica platycodon* subsp. coast). Although rather anecdotal, this evolution into native vegetation might mean that the recovery by native vegetation is possible in areas currently invaded by the giant-reed, but it also reveals that it is only attainable if adequate and persistent measures to eliminate *A. donax* are taken (Pupo-Correia *et al.* 2010 a, b), and in case of certain environmental conditions as suggested by (Quinn & Holt 2009). A quite peculiar result was the significant change of the areas formerly covered with this perennial grass into bare rock, insofar *A. donax* was also introduced to prevent soil erosion.

However, the fact that former *A. donax* areas had change into other cover type does not mean that it had diminished. Actually, this species was one of the species more often seen in new photographs (see table 4.7), especially in southern and northern low lands, but also in low-lying inland areas, confirming species distribution[2] indicated by Vieira (2002). According to the results it spread greatly into forsaken agricultural fields, but also over other vegetation

Figure 4.47 (a) Detail in historical photograph showing *Arundo donax* planted in terraces edges (Ad) and being used for trellises (t). Ribeira dos Socorridos by early 1930s (Figueiras Photographers, AP) (b) forsaken agricultural terraces covered by *Arundo donax*. Calheta, south coast in 2010 (AP, MB).

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[1] As shown by Boland (2006, p. 309) the invasion by *Arundo donax* in riparian environments it is made by "fragments providing the initial long distance dispersal; rhizomes maintaining the clump; and layers carrying out the fast spread into open space, (…) it is less dynamic outside the flood zone expanding slowly via rhizomes", hence the importance that would have had to pull it in those areas that are currently reed-free (Pupo-Correia *et al* 2010 a,b).

[2] According to Vieira (2002, p. 195) *Arundo donax* "(…) *encontra-se cultivada e, hoje, sobretudo, naturalizada, por toda a zona baixa da Madeira, até pouco mais de 500 metros de altitude* (…)" meaning: it is cultivated, and nowadays it is mainly naturalised and distributed over low lands, under an altitude of 500 metres.

types, and as well over surrounding barren areas (see Figure 4.36). According to Vieira (2002) the species became very abundant on stone walls and edges of the terraces, as well as on rocky outcrops and cliffs, not being referred its presence within fallow farming lands. Because out of field boundaries the development of the plant was not avoided, contrarily to clumps within agricultural holdings which were controlled in the past, might explain the spread out of the species into surrounding wastelands (Pupo-Correia *et al.* 2010a, b).

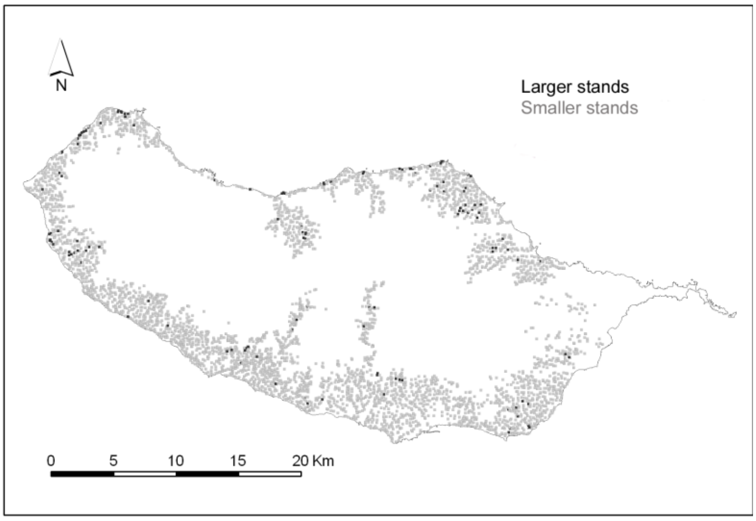

Figure 4.48 *Arundo donax* expanded into riparian zones and into potential areas of *Mayteno umbellatae-Oleo maderensis sigmetum* and *Semele androgynae-Apollonio barbujanae sigmetum* [distribution map based on GIS analysis of current aerial photography (Pupo-Correia *et al.* 2010 a, b)].

Arundo donax largely invaded headwater streams and permanent riparian environments (Figure 4.48), as seen in other places (Bell 1997; Herrera & Dudley 2003; Lawson *et al.* 2005; Coffman 2007), were *Scrophulario hirtae-Salicetum canariensis* might be able to develop, but also exhibited resilience in face of water scarcity and dispersed into areas with less water availability. Indeed, results have shown that *A. donax* seen in current landscape grew greatly over former agricultural fields (see figure 4.36). Actually it was the main species that invaded forsaken terraces (see figure 4.39). Agricultural abandonment and the disuse of the traditional applications in recent decades were the main causes of its increase (Silva & Menezes 1946b; Vieira 2002; Aida Pupo-Correia *et al.* 2010 a,b). The proliferation that happened into drier zones can also be explained that out of flooding zone *A. donax* increase its endurance, as a way compensate slowdown of dispersal rate (Rieger & Kreager 1989). In addition, fire could have been a factor that contributed to increase the spread of this species. Several accounts suggest that infestations of giant reed not only increase fire frequency but also that after fire events it quickly responds by sending new shoots, faster than any other species (Rieger & Kreager 1989; Bell 1997; Dukes & Mooney 2004). Fire, whether accidental or intentional, being a common practice to clear land (see chapter 1, point 1.2.2.2) gave competitive advantages and helped to create monospecific stands (see chapter 2). Thus far, these low lands that could allow the development of communities included in vegetation series as *Mayteno umbellatae-Oleo maderensis sigmetum* in southern areas and *Semele androgynae-Apollonio barbujanae sigmetum,* also in northern areas, are currently covered with *Arundo donax* (Figure 4.48).

Arundo donax, is one of the species of the 100 most invasive species of the world including Macaronesia (Lowe *et al.* 2000). However in Madeira island it was not targeted for invasive species suppression efforts (Silva *et al.* 2008b), contrarily to Azores where a eradication programme was applied (Silva *et al.* 2011).

Cardiospermum grandiflorum (Figure 4.49), is currently found throughout the three sub-regions, although it was more often detected in photographs depicting southern coastal regions (see table 4.7) supporting distribution suggested by Short (1994) i.e., mainly south coast up to 400 metres (a.s.l.). It was introduced in 1930s to be used for covering garden arbours, and in spite of no longer planted it become very common and it is densely-growing over

Figure 4.49 A 'curtain infestation' of *Cardiospermum grandiflorum* over a stream bank. Funchal, south coast, 2015 (AP).

wastelands, stone walls, along stream banks and roads, and over forsaken terraces. The species was considered as newly naturalised in late 1960s (Hansen 1968), although its presence was already been pointed out by Grabham (1934), identified then as the very similar and closely related species *C. halicacabum* L. (Vieira 2002). Even though it was possible that this species was already present in latest historical photographs, it was not possible to identify it and to get information about its long-term dynamics. Notwithstanding the above, obtained results have shown that although the species invaded different environments it greatly overran lands that were no longer farmed, especially in southern areas (see figure 4.36) This is also supported by the fact that southern abandoned fields were greatly covered by the balloon-vine (see figure 4.39) presenting themselves as a single patch formed by *C. grandiflorum* growing together forming a 'curtain' (Figure 4.49). This species is included in the list of 100 most invasive species in Macaronesia, affecting Madeira Island and some other from Canary archipelago. But, up till now, no attempt have been made to control it (Silva *et al.* 2008b) as it has been carried out in some other places where this smothering species it is also a hard-hitting invasive plant (Foxcroft *et al.* 2008; Foxcroft *et al.* 2013).

Opuntia tuna (Figure 4.50), as stated in introduction (1.2.2.2), was introduced in the eighteenth century and it was intensively cultivated aiming production of red dye carmine in the mid-nineteenth century (Silva & Menezes 1946b; Vieira 2002). At that time, cultivation of this plant was encouraged as well as the crops were highly protect by regulations that imposed fines to be applied to the ones being caught destroying *tabaibos*[1]. The specie become quite common from the beginning of the nineteenth century as shown by vegetation models presented since then (see chapter 2, point 2.1.2), and in such a manner that its name was given to the lowest belt by Kuhl (1826), "Region of Cacti", and by Lowe (1857), "Region of Cactus and Banana". The several vegetation models, even not using the designation, referred the species as being very abundant and growing frequently alone upon bare rocks, under 300 metres, where other tropical and subtropical plants also grew (Kuhl 1826; Macaulay 1841), what was also supported

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[1] (...) *se torna necessário não só animar a multiplicação da cultura dos cactos, ou tabaibas, onde se nutre a cochonilha; mas primeiro que tudo proibir a incalculável destruição das tabaibeiras, que diariamente lhes fazem os boieiros para uzarem dellas debaixo das corças* [corsas] (...) (Posturas de Paços de Concelho de Câmara de Lobos, 1852, pp.422-423); meaning: (…) "it is necessary not only to increase the cultivation of prickly pear cactus, where the cochineal feeds, but first of all it is needed to forbid the incalculable destruction that on daily basis is carried out by drivers of ox-drawn sledges who use them under the runners [to facilitate the slide over paving stones] (…)".

Figure 4.50 *Opuntia tuna* forming quite dense stands and in open mosaic with the community of *Hyparrhenia sinaica.*

by description in travelogues[1], paintings (see figure 1.6) and historical photographs. Today, even though occasionally grown for its fruits, which are locally rather appreciated, most of the plants arise spontaneously (Vieira 2002).

Opuntia tuna, seen in historical photographs, located in south coast (see table 4.5), showed a low level of agreement and shifted mainly to *Euphorbia piscatoria* (see tables 4.6.2, 4.6.3 and figure 4.34-2), although transitions into exotic vegetation also have happened. These results can be in part explained by the fact that many individuals still are affect by *Dactylopius coccus* (Costa), despite the attempt to produce carmine dye production was dropped prior to the twentieth century (Vieira 2002). Although several surveys on *Opuntia spp*. in areas where it became invasive (Zimmermann & Granata 2002) have shown that pests stunt plant grow, Madeiran plants greatly dispersed along southern coastline being also found along north coast and inland (see table 4. 7), areas where it was not seen in past. The species invaded disturbed areas, as forsaken agricultural fields and wastelands, and also replaced native vegetation (see figure 4.36). Because these latter transitions were mainly seen in pairs encompassing older historical photographs the conversion from native vegetation into *O. tuna* may could have happened due recurrent destruction of native vegetation (see point 4.3.4) not meaning encroachment capacity in undisturbed areas. Nonetheless, the species can be found today forming sometimes very dense stands on slopes and cliffs overlooking the sea in south coast, intermingled with other exotic plants or in mosaic with native grassland (communities dominated by *Hyparrhenia sinaica*), especially in southeastern areas where *Euphorbia piscatoria* is not seen. It is included in the list of the 100 most invasive species in Macaronesia, affecting exclusively the islands of Madeiran archipelago, no eradication programme was ever launched (Silva *et al.* 2008b).

Podranea ricasoliana (Figure 4.51) was one species that could not be seen in historical photographs inasmuch as it was introduced only after 1940s. It was introduced for arbours and pergolas in gardens located in warmer locations under 400 metres, from where it escaped. Being an extremely vigorous climber and drought resistant, it was also used to support soil and banks, mainly in Funchal and surroundings (Vieira 2002). Although results have shown major predominance in Funchal urban area, where it grows profusely over the steep rocky banks of main stream crossing the valley, as referred by previously cited author, it was also seen growing on north coast (see table 4.7). There, although vine blanketing patches are not as large as in south coast the species was seen in different locations indicating

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[1] As the one made by Isabella de França (1854, p. 61) "The prickly pear is quite a weed; all over the country below a certain height, it grows over every bare rock or bit of ground not otherwise occupied. (…) Hitherto it has been suffered to grow where the land was not wanted for anything else, but now they are planting it with the view of rearing the cochineal insect."

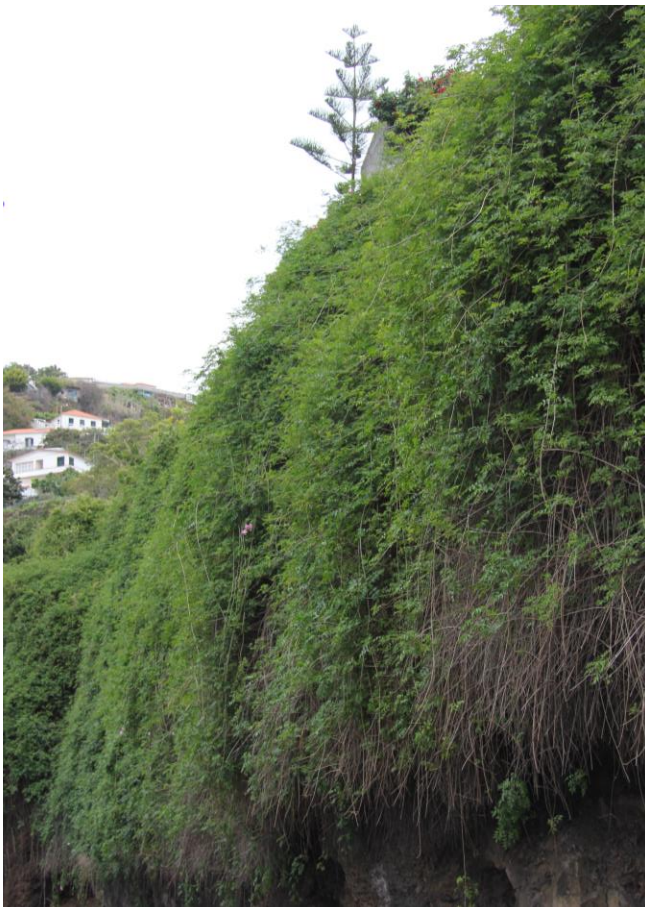

Figure 4.51 *Podranea ricasoliana* which densely covers a cliff preventing any other vegetation growth. Funchal, 2015 (AP).

greater dispersion. Contrarily to southern stands that developed mainly over bare rock, in northern areas *P. ricasoliana* rambled over forsaken terraces and native vegetation (see figure 4.36). While it can be assumed that native vegetation could have been destroyed prior to the invasion, being the place already disturbed, it is acceptable that this plant could have been responsible for that loss. It is a known fact that climbing habit offers ability to compete by stifling and killing non-climbing vegetation, and several surveys have shown that exotic vines establishment can block succession for decades (Paul & Yavitt 2010).

Among the exotic species identified in historical landscape some species stood out from the rest. In addition to *Arundo donax* that was already discussed, particular emphasis should also be given to *Pinus pinaster*, seen in all the three sub-regions and time brackets, *Castanea sativa*, seen over the three periods in inland areas, and *Eucalyptus globulus* which was only seen in twentieth century photographs, but dispersed all over the island (see table 4.5).

The first of those three species to be introduced was *Castanea sativa*[1] (see also point 1.2.2.2), supported by early reference of Frutuoso (1589) giving it as very common in several points of the island, and the size of some chestnut photographed in late nineteenth century or early twentieth century (Figure 4.52). It was introduced not only due its value for building purposes, but greatly for the fruit which was an important food supply[2]. The species was distributed across a belt between the altitude of 200 and 800 metres (Vieira 2002) where it was the most abundant tree until the middle of the nineteenth century, in such a manner that sometimes it was mistakenly referred as native[3]. Landscape descriptions and particularly the vegetation models built at that time (see point 2.1.2), attest quite well its preponderance. Although not all of them included its name in the designation of the vegetation belt, as Lowe (1857) did by calling the second region by “Vine and Chestnut”, they also stated it abundance: “Of foreign trees, the most

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[1] Although it is not possible to know exactly when it was introduced, the Royal Decree enacted in 1562 ordered the plantation of chestnut trees (Camacho 1920).

[2] As stated by following descriptions: “chestnut is also very abundant and the fruit used as principal source of farinaceous food” (Ackermann 1821); and also “The most valuable of the trees which have been introduced into the island is the Spanish Chestnut, which furnishes food to the population in some higher grounds” (Harcourt 1851, p. 113).

[3] as e.g., Soares (1882), and in the a list of plants, growing in the gardens arranged by two English gentleman living in Madeira, included in Harcourt (1851, p.157).

conspicuous is the Chestnut, *Castanea vulgaris*[1], which was introduced by the early settlers; it forms fine woods on the lower parts of the mountains, especially in the interior, and on the north coast" (Macaulay 1841, p. 74). Lowe (1857-1868) localised it above 400 metres up to almost 800 metres, although its presence was also signaled over slopes under 400 metres high, especially on north coast where it was used to support vines (Almeida 1817; De França 1854; Lowe 1857). Photographs taken at the end of the nineteenth century and first half of the twentieth century showed *Castanea sativa* as being close to the upper limit indicated or higher (see table 4.5). In lower areas, where it should have occurred until mid- nineteenth century, in late 1800s photographs were seen young and dense pine stands (Figure 4.53).

Figure 4.52 Old postcard, sent in 1905, showing one multi-secular chestnut, which was used as shelter.

Agreement between chestnut trees stands seen in the past and present ones was very low (see table 4.6 and figure 4.36). Given that a great part of chestnut groves were destroyed by a plague that affected this species during the second quarter of the nineteenth century[2] (De França 1854; Paiva 2007) the maintenance of these patches could be explained in part by the fact that still is cultivated in some inland areas and also, because it is naturalised and spontaneously occurring around the grounds where it was planted (Vieira 2002). Several surveys undertaken to evaluate regeneration of chestnut woodlands in which *C. sativa* is native have shown that this species has abundant seed regeneration and vegetative reproduction capability, being able to regenerate even after huge disturbance as fire (Maringer *et al.* 2012). However, most of the areas seen in the past are currently covered by other vegetation type, mostly *Eucalyptus globulus*, alone or mixed with *Pinus pinaster*. It was also detected regeneration of native vegetation, mainly shrubby and herbaceous vegetation, and more rarely laurel trees, over talus deposits at the base of cliffs with remnants of native vegetation.

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[1] *Castanea vulgaris* Lam, *nom. superfl*. used instead the currently accepted designation *Castanea sativa.*

[2] "At the mount, and at the same level or thereabouts, all over the Island, are large chestnut plantations (…). Unfortunately a disease has attacked the chestnut trees, and many of them are dead." (De França 1854, p. 62). The disease above referred was most likely *Phytophthra cambifora* (Petri) Buisman, which causes 'ink disease' (from the Portuguese *tinta dos castanheiros*, or *mal da tinta*), firstly recorded in mainland Portugal in 1838, from where it has become wide-spread in Europe (Paiva 2007).

Allthough its area was reduced (Vieira 2002), newly formed stands took place over native vegetation, farming lands and other exotic trees[1], the latter seen in pairs encompassing latest historical photographs (see figure 4.36). Possibly resulting of plantation, but on the bases of the above, it could also been from escaping from cultivation or, especially in transitions from *Pinus pinaster* and *Eucalyptus globulus*, due to regeneration from a seed bank remainder of the time that those lands were covered by chestnut groves. In addition to studies that revealed regeneration capacity of *C. sativa* even in adverse conditions, others have shown its ability to regenerate in pine woodland understory from seed bank (Onaindia *et al.* 2013) supporting the interpretation carried out above.

Pinus pinaster was introduced during the eighteenth century but it was more cultivated from 1840s onwards, being intensively sown throughout the second half of the nineteenth and at the beginning of twentieth century (see point 1.2.2.2). It was referred by Lowe (1857) as being present in the Temperate belt, named "Vine and Chestnut Region"[2], not being found at that time above the altitude of 762 metres. It is naturalised from early twentieth century, regenerating in cool, moist areas close to old pine stands. Since it was also introduced in higher altitudes it ended up as dominant tree of exotic forest dispersed between 500 and 1200 metres above sea level, until the end of the twentieth century when it reached an area of about 120,000,000 m^2 (Vieira 2002). It was the species more often identified in historical photographs, not only due its peculiar branching habit, crown shape, and rectilinear contour of the stands (Figure 4.53) that facilitated its identification even in very distant backgrounds, but also because it was in fact the species more abundant at that time.

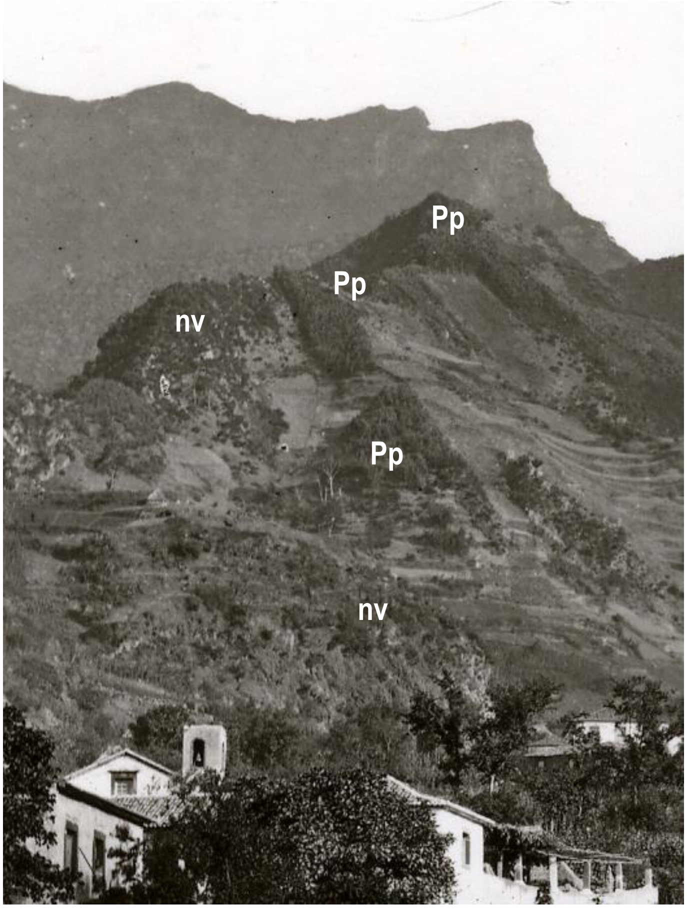

Figure 4.53 Landscape detail showing stands of young pines (Pp), recognised by their straight contour, surrounded by agricultural fields. Shruby native vegetation (nv) is seen in rock out crops. Rosário, late nineteenth century by unknown photographer (ARM).

The agreement between past and present pinewoods was low (see table 4.6), especially in photograph pairs made at an interval of more than one hundred years. Stands with clear signs of fire, which are not currently clothed with trees, were seen in inland covered by *Pteridium aquilinum*, *Cytisus scoparius*, and *Cytisus striatus*, species that clearly benefit with this type of disturbance (Duc *et al.* 2000; Leblanc 2001), and by *Cardiospermum grandiflorum*, in southern lower lying areas. Its substitution by other tree species (see table 4.6) happened in the main by *Eucalyptus globulus,* and also by *Acacia meansii* and *Pittosporum undulatum*, often forming mixed stands (Figure 4.54)

Regarding to conversion from *P. pinaster* into *E. globulus* it is interesting to note that some unclothed grounds seen in historical photographs

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[1] Mainly *E. globulus* and *P. pinaster.*

[2] Included in "cultivated and naturalized" together with *Pinus pinea*: "Stone Pine and Pinaster" (Lowe 1868, p. iv).

from the early twentieth century, and covered today with *E. globulus* (e.g. summit of Cabo Girão), were covered with pines in the previous century, as testified by some descriptions[1]. Some of these transitions were triggered by afforestation with *E. globulus* that become preferred by its strong root system considered ideal to forest steep slopes (Sousa 1946), its fast-growing rate, and wider array of desirable products (Vieira 2002). This boosting into pure stands of *E. globulus* or mixed with *P. pinaster* was shown by some remarks[2] made in the beginning of the twentieth century. Although Vieira (2002) stated the continuity of its plantation, it was largely restricted to private lands and it was not use for afforestation of commonage lands (Andrada 1990), also supported by the fact that this species was not included in lists[3] of plants introduced by the forest services since early 1950s (CFF 1952-1965, 1954-1972, 1965-1968).

Figure 4.54 Former *Pinus pinaster* stands being replaced by (a) *Eucalyptus globulus*, in mixed stands, that regenerated after fire, by (b) *Acacia mearnsii* and (b) *Pittosporum undulatum* that took advantage of the space freed up.

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[1] As described by Picken (1840, p.58): "On the summit of the cliff [Cabo Girão] there is a plantation of pines."

[2] As e.g. "(…) as mattas extensas e espessas d'eucalyptos e pinheiros do Visconde de Cagongo marginam a leste com a estrada do Meio e a levada da Serra e a poente com a Ribeira de João Gomes (…) a matta é extensa e percorre-se bem em meia hora de caminho sob sombras do arvoredo aromatizado de effluvios d'eucalypto e pinho" (Corrêa 1927, p. 165) meaning: "the wide and thick woodlands of eucalyptus and pine trees, which belong to Visconde de Cagongo, are located (…) [slopes located in northern part of Funchal valley] (…) a broad forest that we cross in half an hour under the shade of the trees and an intense fragrance of eucalyptus and pine tree".

[3] Several pine species were introduced as *Pinus insignis, Pinus halepensis, Pinus sylvestris* L., *Pinus canariensis, Pinus patula, Pinus radiata, Pinus nigra, Pinus mughus* Scop., but not *Pinus pinaster* (CFF 1952-1965, 1954-1972, 1965-1968).

Also, recurrent fires[1] (Ferreira *et al.* 2000; Fernandes *et al.* 2005), and the plague of *Bursaphelenchus xylophilus* which for same years now it is also causing destruction of pine stands (Fonseca *et al.* 2010), can be pointed out as cause of shift in the pinewoods. These, that fulfilled the landscape from nineteenth century until not so long ago have change into other species.

Although the species is considered one of the 100 most invasive species of the world (Lowe *et al.* 2000), and so it is also in some Islands of the archipelago of Azores, this behaviour is not observed in Madeira Island (Silva *et al.* 2008b). In fact, in the view of the foregoing it can be considered quite the reverse.

The disappearance of pinewood in some locations allowed regeneration of native vegetation. As expected, whilst the regeneration seen in photograph pairs encompassing smaller time intervals was restricted to species belonging to seral communities as *Euphorbietum piscatoriae,* in south coast, and *Globulario salicinae-Ericetum arboreae*, in the north coast, more mature stages were seen, but only in pairs embracing longer periods. Even so, the species most often seen denoted a very early stage of *Semele androgynae-Apollonietum barbujanae* and *Clethro arboreae-Ocoteetum foetentis*, virtually composed by *Myrica faya* and *Laurus novocanariensis* and only along the north coast and in inland, respectively, under certain conditions as for instance greater availability of propagules (Figure 4.55).

Although pinewood area suffered reduction, it still persists in the landscape (see table 4.7). However part of *Pinus pinaster* currently seen where it was in the past (see figure 4.36) are mostly seen in younger photographs set. This means that most of the older pine stands have changed into other cover class.

However, as results have shown new pinewood areas emerged over unidentified vegetation, uncovered areas, other exotic vegetation (*Castanea sativa*), and quite significantly over native vegetation, and forsaken agricultural areas. Whilst shift from areas of unidentified vegetation and uncovered areas, might be a merely maintenance or renewal, its installation over native vegetation and forsaken fields have other entails. According to Corrêa (1927) the several crises beyond emigration and severe farm labor shortage, forced upper farming lands into less demanding

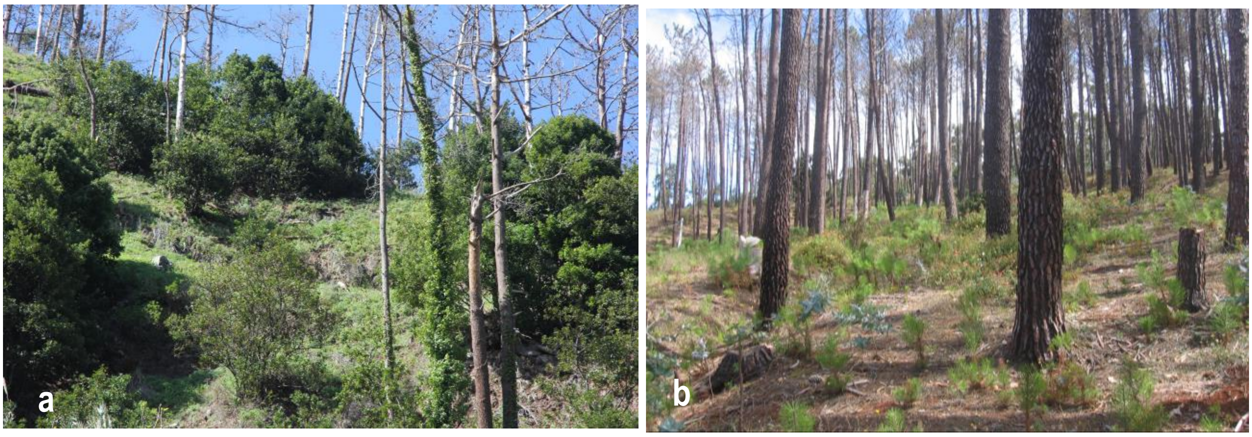

Figure 4.55 Pine stands after fire in *Semele androgynae-Apollonietum barbujanae* potential area. (a) north coast close to fragments of native vegetation spots: regeneration of native occurred, mainly *Laurus novocanariensis* and *Myrica faya* [São Vicente, 2013 (AP, JP)], and (b) south coast, without any native vegetation in the neighbourhood, surrounded by eucalyptus stands: regeneration of pine woodland and invasion by *Eucalyptus globulus* [Cabo Girão, 2013 (AP, JP)].

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[1] Although *Pinus pinaster* has some characteristics that allow pine to recover after fire, as thick bark and pinecones opening by heat, they tend to disappear under high frequency of huge fires, contrarily to *Eucalyptus globulus* that are much more adapted in these situations due efficient regrowth from burnt rootstock (Ferreira *et al* 2000, Fernandes *et al.* 2005)

crops, frequently pine woodland (Figure 4.56). Being naturalised, as sated above it could spontaneously developed, after disturbance, in areas of former native vegetation.

Eucalyptus globulus, as previously seen, it is nowadays dispersed over areas where other exotic trees abundantly occurred in the past, i.e. *Castanea sativa* and *Pinus pinaster*. Although introduced in the beginning of the nineteenth century, given some large sized trees occurring in several *quintas*[1] around Funchal (Vieira 2002), afforestation with this species must have started in mid-nineteenth century (around 1857-1860) when it was planted the woodland belonging to Visconde Cagongo, from where seedlings were taken into other parts of the island (Pereira 1989). It was not indicated by this author what species of eucalyptus was used, but it seems likely to be *Eucalyptus globulus.* This was the eucalyptus species more frequently seen by the end of nineteenth century and early 1900s in several points of the island, among which the location of the woodland above referred (Silva & Menezes 1946b). It was the species that was more intensely planted from the beginning of the twentieth century, and it was still planted in late 1960s (CFF 1962-1964, 1965-1968). It is no longer cultivated, but being naturalised it occurs as subspontaneous around places where it was introduced (Vieira 2002). It is not included in the list of 100 most invasive species of the world (Lowe 2000), but that status was assigned for most of the islands of the northern archipelagos of Macaronesia, including Madeira Island (Silva *et al.* 2008b).

Figure 4.56 Upper terraces as well as most distant farming lands were converted into less demanding crops, normaly pine trees, as in this case. Destroyed by fire the pine woodland was converted in a thicket of acacia.

Eucalyptus was not seen in historical photographs of the nineteenth century, confirming that the species was not quite abundant at that time. It has come to be seen in photographs of the beginning of the twentieth century and in north coast only after the first quarter. Older stands were almost lost (see tables 4.6). Even though regeneration of native vegetation of seral stages as *Euphorbietum piscatoriae* (in south coast) and *Vaccinio padifoli-Ericetum maderincolae* in mosaic with native trees of *Clethro arboreae-Ocoteetum foetentis* (in inland) has taken place, in the main the changed was into *Pteridium aquilinum* (in inland), and into the non-native *Arundo donax* (in south). Stands seen in latest photographs, were not so greatly affected as the oldest but were also lost in part. In these areas recovery of native vegetation was also detected, mostly native grassland (dominated by *Hyparrhenia sinaica*), alone or forming

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[1] *Quinta* is the Portuguese noun for farm, meaning also estate with elaborate house and big garden, as in this case.

mosaics with scrub community of Madeiran tree-spurge (*Euphorbietum piscatoriae*), *Pteridium aquilinum*, and exotic plants as *Arundo donax, Pittosporum undulatum*, and *Acacia mearnsii.*

Recovery of native vegetation in areas formerly occupied by *Eucalyptus globulus* sometimes occurs also as seen in neighbouring island of Canarian archipelago, as shown by Arevalo *et al.* (2011). However, progress toward full recovery tends to be jeopardise by the presence of exotic plants, as *Arundo donax*, as earlier discussed, as well as *Pittosporum undulatum*, and *Acacia mearnsii* (Figure 4.57), which behavior is going to be discussed below.

Figure 4.57 Stands of *Eucalyptus globulus* being invaded by *Acacia mearnsii,* which covers not only the edges but is also seen in the understory.

Newly formed areas of *Eucalyptus globulus* came forth from other cover types (see figure 4.36) and becaming the species more often identified in current photographed landscape. Even more than *Pinus pinaster*, which was the most abundant tree by the end of last century[1] (Vieira 2002). Although results do not permit to get data about actual ground surface coverage they allow to confirm the increase of *E. globulus* at the expense of *P. pinaster*[2]*.* Despite eucalyptus was also seen currently growing over forsaken agricultural areas, and native vegetation, similarly to what was seen for *Pinus pinaster*, it is also clearly visible that it settled on areas formerly occupied by other exotics seen in the past (*Castanea sativa* and *Pinus pinaster*).

Looking, as a whole, at the changes that these three species (*Castanea sativa, Pinus pinaster*, *Eucalyptus globulus*) that occupied and were the dominant across a belt between 200 metres a.s.l.[3] and 1200 metres a.s.l.[4], have suffered throughout time, it pops out a certain 'successional' trend: *Castanea sativa* stood out up to mid-nineteenth century, *Pinus pinaster* during late nineteenth century and beginning of the twentieth century, when 'conversion' into eucalyptus has begun, and *Eucalyptus globulus* that came out as the tree dominating over the landscape (Figure 4.58). However, solely stands seen in latest photographs remained largely unchanged and the ones seen in photographs encompassing larger periods almost disappear. These findings allow to speculate that hegemony of eucalyptus is coming to an end, and sooner or later it is going to be supplanted by another vegetation type. In light of the foregoing, it will certainly not be native vegetation, at least not so soon, if at all. According to (Figueiredo 2013) in current climatic condition the stands of eucalyptus, as well as pinewoods, are highly susceptible of being invaded by *Acacia mearnsii:*

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[1] According to Vieira (2002) *Pinus pinaster* and *Eucalyptus globulus* were covering an estimated area of about 120,000,000 m^2 and 20,000,000 m^2, respectively.

[2] According to data included in 2010 Forest Inventory, *Pinus pinaster* was covering 4,120,000 m^2 and *Eucalyptus globulus* 7,295,000 m^2 (Moreira *et al.* 2015).

[3] The lowest altitude that one of these three species was planted [*Castanea sativa*, according to Vieira (2002)].

[4] The highest altitude that one of these three species was planted [*Pinus pinaster*, according to Vieira (2002)].

Although no projections were made for *E. globulus* and *P. pinaster* in future climatic scenarios, projections made for *Acacia mearnsii* have shown that this species will loose area at lower edge but it will expand to new upper areas, increasing the area of potential conflict with potencial areas of laurel forests. Since many of these areas are currently covered with *E. globulus* the progress of *Acacia mearnsii* into these areas will surely prevent regeneration of native vegetation.

Other two trees were also seen in historical landscape: *Salix babilonica* and *Quercus robur*, both seen in a single-location in inland. *Salix babilonica* it is not naturalised, and it was not referred as having been an early introduction in the island neither by Silva & Menezes (1946c) nor by (Vieira 2002). It was seen in photographs from first half of twentieth century, along a stream bank where in earlier photographs it was seen *Salix canariensis*. The recent alteration of stream bed, due road construction, led to disappearance of all individuals that were viewed in that image.

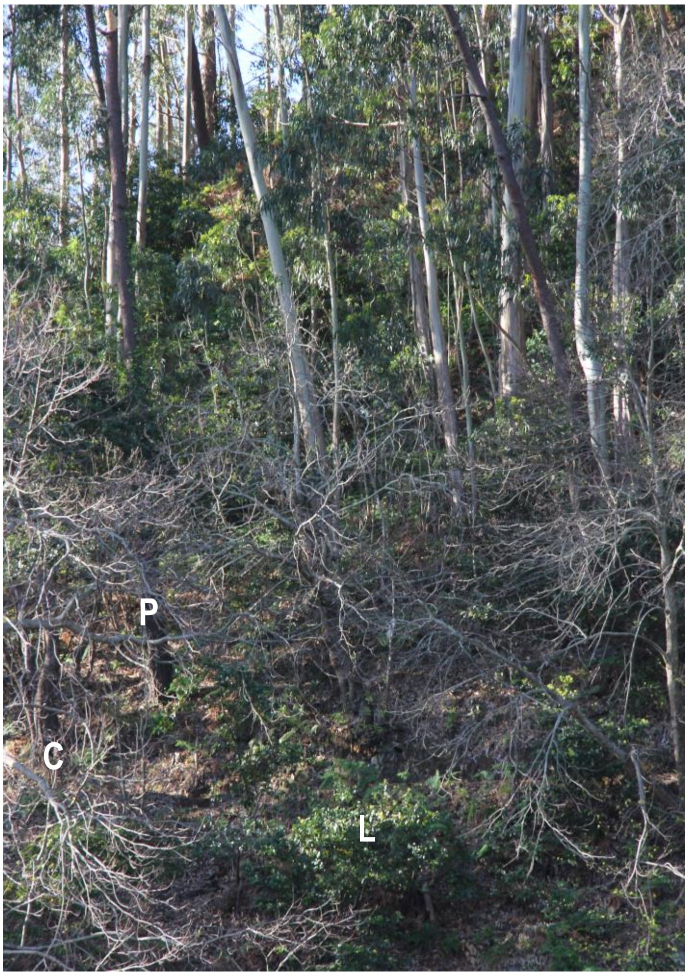

Figure 4.58 In a stand of eucalyptus located at 549 metres a.s.l. there still is evidence of former pine woodland that was burnt (P), and young chestnut trees (C) and laurels (L) are witnesses of ancient occupations. Serralhal, 2015 (AP).

As for *Quercus robur*, its introduction occurred in the early nineteenth century and European oak was greatly planted in parks and gardens of *quintas*, as well as for lining streets and afforestation (Silva & Menezes 1946b; Vieira 2002). It was often cited in nineteenth century descriptions (Harcourt 1851; De França 1854; Soares 1882) showing that it was distributed all over the island. It was firstly given as naturalised by Menezes (1894), and it is not widely spread due to high mortality of seedlings affect by powdery mildew (Vieira 2002). It was seen only in one historical photograph, forming a single stand formed by few individuals, in a forest park, surrounded by native vegetation. The agreement was very high, and the loss of native vegetation to this species was quite similar to what happened in opposite direction, not being recognised invasive behaviour[1]. Oak trees occur in current landscape, occasionally, here and there, either isolated or in mixed stands.

Two other species were still identified in historical landscape: *Tamarix gallica* and *Agave americana*. The first one was introduced at the beginning of the nineteenth century, and it was referred by Lowe (1857) as rarely cultivated in a few *quintas*, being carried out to Porto Santo where it became almost immediately naturalised. In Madeira, although cultivated both in the south coast and north coast, it can be found occasionally as escaped from cultivation (Vieira

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[1] Richardson *et al.* (2000b) recommended to use the term 'invasive plant' when naturalised plants produce large number of reproductive offspring, being found far from parent plants more than 100 metres, in less than 50 years, if they spread by seeds, and more than six metres, in less than 3 years, if they reproduce by vegetative propagation.

2002). Although temporary streams in southeast of the island support a community dominated by *Tamarix gallica* (*Tamaricion africanae*) (Costa *et al.* 2004) they were not covered by landscape photographs depicting that area. It was detected in twentieth century photographs in two different locations of northern coastal areas, very close to the sea shore, although not seen in older photographs, and areas from the past remained almost entirely occupied by the same individuals. A slight lost allowed regeneration of native scrubland dominated by *Globularia salicina*, and on the other hand it was able to spread but mainly over former agricultural areas and bare rock. For now, contrarily to Porto Santo island, where it is "remarkably common" (Vieira 2002 p. 174), *Tamarix gallica* does not seem to be a matter of concern for Madeira island, for now.

Agave americana was introduced during the first half of the nineteenth century to be used in rocky gardens and to produce ropes (Vieira 2002), being given as naturalised and greatly abundant on rocky banks around Funchal by Menezes (1894). It was identified only in one historical photograph, from the late nineteenth century, located in the north coast. There, it still is seen scattered all over the sheer rock faces, although results indicated low agreement level. What has happened was that during this time individuals were lost for other vegetation type (mainly *Globularia salicina* and *Arundo donax*) but new individuals appeared, almost over former native vegetation. The species was not seen in other two photographs depicting surrounding areas, neither in old nor in new photographs, reveling that during this time (125-100 years) it did not spread out of the historical range. It is identified as invasive species for most of the islands of the northern Macaronesian archipelagos, including Madeira Island, were it is referred as threatening some protected areas in south coast (Silva *et al.* 2008b). Results have shown, however, that in those northern areas although naturalised[1], it does not shows signs of invasive behavior up till now, contrarily to Tenerife Island, where it was introduced at about the same time and become one of the most dispersed exotic species (Arévalo *et al.* 2015).

Among the trees more often seen in present landscape (see table 4.7) there is one that was not identified in historical landscape: *Acacia mearnsii.* As it was found the species grew over other vegetation (native vegetation, pines, and eucalyptus), over uncovered areas, and also across forsaken agricultural fields (see figure 4.36), being in this last case, one of the main species towards which past farming lands have changed (see figure 4.39), frequently with signs of having been meanwhile used to grow other trees (e.g. pine trees).

According to Vieira (2002) the black wattle establishment occurred around 1930-1940s when it was introduced due to a strong need for firewood. In fact, old references to this species[2] were not found and *Acacia mearnsii* only started to be cited in Madeiran botanical literature after it was given as naturalised by Hansen (1971). However, in Andrada (1990) a reference is made, under the synonym *Acacia molissima*[3]. Although not planted by the Forest Services it was recommended because, at that time, it was thought to be not invasive, contrarily to other species of the same genus as *A. dealbata*. This two species *A. mearnsii* and *A. dealbata* are very similar[4] and often confounded. On

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[1] Richardson *et al.* (2000b) recommended to use the term 'naturalised plant' when casual alien [exotic] plants sustain populations over many life cycles without anthropogenic action, or in spite of it, remaining or not close to parent plants.

[2] The list appended by Harcourt (1851), included several *Acacia* species that were cultivated in the garden of two *quintas*, but it does not refer *A. meansii*, and excepting *A. dealbata*, none of them become naturalised. The plan for afforestation of the commonage land around Funchal, in 1913, implemented the plantation of several wattle tree species, as *Acacia dealbata*, and *A. melanoxylon* (Sousa 1946), but not *A. mearnsii*. Likewise, the lists of plants used by *Circunscrição Florestal do Funchal* for afforestation since early 1950s, showed large scale use of *A. melanoxylon*, but no reference to *A. mearnsii* was made (CFF 1952-1965, 1962-1964, 1965-1968).

[3] *Acacia mollissima sensu auct.* (*ambiguous synonym*).

[4] They are both bippinate, and in a landscape level greenish-grey leaves of *Acacia dealbata* are very similar to dark-green leaves of *Acacia mearnsii*. They are more easily distinguishable by the colour of the spherical flower heads that are of a bright yellow in *A. dealbata* and pale yellow in *A. mearnsii*.

the photographed areas only *A. mearnsii* was identified, forming almost monospecific stands or being the dominant species, not being seen at all *A. dealbata*[1]. Other *Acacia* species were also seen in the photographed landscape, *A. melanoxylon* R. Br. and *A. longifolia* (Andrews) Willd., often in mixed stands where they were not the dominant species, and thus not highlighted in current research.

While it can be assumed that over prior vegetation and forsaken terraces *A. mearnsii* could have been planted, the colonisation of bare rock should have been made by its own means, confirming its status as invasive species. Although it was stated by Mochiutti *et al*. (2008) that *Acacia mearnsii* in some environments is not invasive because it has seed dispersal limited to very close areas[2], does not invade areas where soil is covered with native vegetation[3], and it allows native vegetation regeneration in old stands, results achieved have shown that *A. mearnsii* it is an invasive species behaving like in many places all around the world (Rejmánek & Richardson 1996; Richardson *et al.* 2000), being one one of the 100 most invasive species in all world (Lowe *et al.* 2000). Although it was not referred as such for Madeira Island (Silva *et al.* 2008b), every data collected pointed to invasive behaviour of this species. It colonised areas were it was not planted taking advantage of disturbances, especially after fire (Albano 2010, 2011), and forms almost monospecific stands with very few native species (see chapter 2) being an obstacle to native vegetation regeneration.

However, the environmental impact of *Acacia mearnsii* surpasses the fact of being highly pervasive and responsible for loss of biological diversity. It increases the fire risk and reinforces soil erosion, especially in harsh rainfall conditions (Figure 4.59) as it was shown by local surveys (Menezes de Sequeira *et al.* 2011b) as it was also stated in other places (DeBano 2000; Doerr & Thomas 2000; Wilgen *et al.* 2001; D'Antonio & Meyerson 2002).

Another exotic tree that it is likewise a problematic issue due negative impacts on native ecosystems is *Pittosporum*

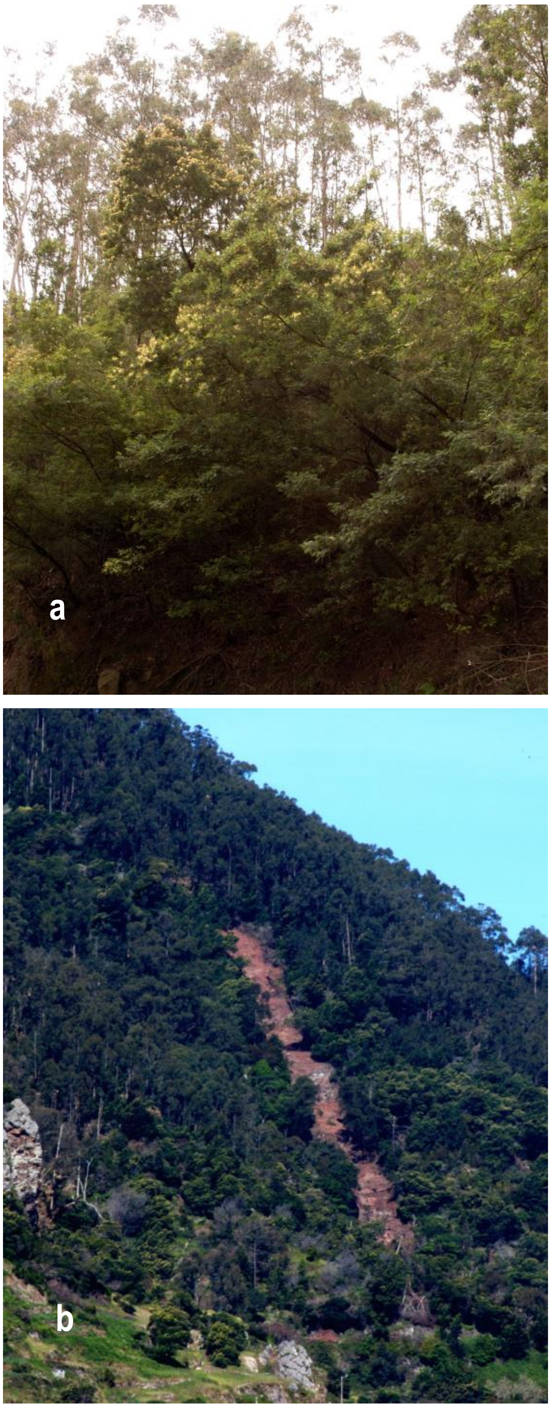

Figure 4.59 *Acacia mearnsii* and landslides. Trees tend to bend and become uprooted, facilitating landslide during heavy rain conditions. (a) Quinta grande, 2010, and (b) Machico, 2010 (MS, AP).

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[1] At landscape level the pale yellow flowers, depending on sunlight, look sometimes more intense yellowish, reinforced by golden apexes on young shoots, raising doubt whether species it is. However, identification of specimens collected confirmed that it was in fact *Acacia mearnsii* (Turland 1994).

[2] Because seed dispersed under gravity. Contrarily, in steep slopes of Madeira Island dispersal of the seeds of *Acacia mearnsii* it is greatly favoured.

[3] Because it needs light for seed germination and seedling growth, unless some disturbance occurs exposing it to light.

undulatum. Its adverse effect may be neglected by the fact that visual impact is minor when compared to that caused by the other exotic trees discussed earlier, due close resemblance of its foliage with some native plants, at least at certain times of the year[1]. Yet, precisely for this reason its distribution can be underestimated posing an even greater threat.

Pittosporum undulatum was introduced before 1850s, being mentioned by Harcourt (1851) as being present in the gardens in a couple *quintas* in Funchal. It was already naturalised in late nineteenth century, and seen at that time growing over rocky places around those gardens (Menezes 1894), however, it was not possible to identify the species in historical photographs. Today it is highly dispersed all over the island, and it is rather common, especially in humid and cool places (Vieira 2002).

As results have shown, *Pittosporum undulatum* (Figure 4.60) established over former native vegetation, giving evidence to invasive character already pointed out: " a species that due to its capacity to invade native vegetation areas it is becoming a real scourge"[2] (Vieira 2002 p. 148).

Since it also dispersed into disturbed places as forsaken agricultural fields and degraded vegetation areas it can be assumed that those areas formerly covered with native vegetation were previously cleared by some disturbance, allowing the establishment of this exotic, not being then evidence of aggressiveness. However, having been a species introduced in far-off locations, i.e. in gardens of southern *quintas*, and commonage lands near Funchal[3] but it was not used by forest services for afforestation (CFF 1953-1965, 1962-1964, 1965-1968), it demonstrates, in fact, its exceptional dispersal capacity. This scattered pattern of invasion it is quite consistent with dispersal by birds as it happens in its native environment (Gleadow & Narayan 2007). In Madeira Island fruits are eaten by the common blackbird (*Turdus merula* L) being seeds dropped at large distances reaching patches in the middle of the native forest, where species that spread along a front hardly arrive, as it happen in the native area, where these birds were introduced (Henderson *et al*, 2006),. Also, because it is a shade tolerant species (Gleadow & Walke 2014) it is able to thrive in the understory representing a serious menace to less disturbed patches of native vegetation. *Pittosporum undulatum* prevents development of shade intolerant species by reducing light caused by dense canopy, but also shade tolerant due to allelopatic effect as some bioassays have shown (Gleadow 1981).

Figure 4.60 *Pittosporum undulatum* growing over forsaken agricultural terraces and encroaching in native vegetation that was already regenerated. São Vicente, 2013 (AP,JP).

Pittosporum undulatum is not included in the list of the 100 most invasive species (Lowe *et al.*

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[1] The species that it is also an invasive species in Azorean archipelago, where it is named by *incenso*, it used to be called in the past by *faia* (Vieira 2002), analogy that reflects the similarity with native vegetation.

2 Translated from original texto, in Portuguese: "O incenseiro, como também é conhecido, tem tendência a tornar-se uma verdadeira praga da floresta madeirense, (…)" (Vieira 2002, p.148).

[3] *Pittosporum undulatum* was one of the trees included in the list of trees for afforestation commonage land around Funchal (Sousa 1946).

2000) but is regarded as environmental weed in several parts of the world beyond its native range (Mullett 1996; Goodland & Healey 1997; Howell 2003). It was included in the list of 100 more invasive species of Macaronesia, being therein referred as one of the species that poses major threat to conservation biological diversity, especially in Madeira and Azores (Silva *et al.* 2008b), Evaluation of the risk of this invasive plant in Madeira have shown it as the major threat especially for the sclerophyllous vegetation (Figueiredo 2013).

Some of the species seen today as invasive species were introduced through agriculture, either to help farming practices, as *Arundo donax* discussed earlier, or as an effort to improve soil, as *Cytisus scoparius* and *Cytisus striatus,* and to create pasturelands or to produce forage for stabled livestock as *Ulex europaeus, Ulex minor, Brachiaria mutica*, and *Pennisetum purpureum.*

The two species of *Cytisus* were brought into the Island at different times. *Cytisus scoparius* was introduced much earlier, being referred for the first time by Sir Sloane during his visit in 1687 [1] (Menezes de Sequeira *et al.* 2010). It must have become very abundant in the early nineteenth century, being its name associated by Kuhl (1826) to the "Region of *Spartium"* (1200-1600 metres a.s.l.), and it was referred by Lowe[2] (1862 p.123) as being naturalised and "diffused so extensively, both by culture and self-propagation, as to appear perfectly indigenous: flooding the mountain-sides for miles with seas of golden blossoms", and seen in " Region of Laurel and Heath" (760-1676 metres a.s.l.). Although its indigenousness was hypothesised (Vieira 2002) based on early descriptions[3] referring the term *giesta,* today is consensual that *Cytisus scoparius* it was introduced from abroad (Jardim *et al.* 2007). This species that could have been brought from England or Scotland[4] was "sown extensively in the mountains for the purpose of being either cut down for firing, or burnt on the spot, every 5-7 years to fertilize the ground, and cause it to produce a single crop (…)"(Lowe 1862 p. 122), what confirms the purpose of its introduction and the continuity of practices that were a fad in the beginning of the nineteenth century, as described by Almeida (1817) (see p. 19). Not until later it was applied as green manure, being cultivated for this reason until the middle twentieth century. As for the other species, *Cytisus striatus,* it is known that it was introduced during the1940s and early 50s, when an enormous quantity of seeds was purchased aiming to cover mountain bare ground and wastelands (Vieira 2002). None of these two species appear on the lists of plants introduced by the Forest Services (CFF 1952-1965, 1952-1981, 1962-1964, 1965-1968) allowing to assume that *C. scoparius* and *C. striatus* were not sown since then.

It was not possible to distinguish *Cytisus scoparius* and *C. striatus,* at landscape level, given they are very similar and were introduced in same areas (Figure 4.61). The broom was more often seen in inland areas, as expected due to sowings on uplands for more than 150 years, but it also appeared at lower altitudes, probably from its use as green manure. Nowadays it is not cultivated at all, but because it fell into disuse[5] and being a very competent invasive plant (Lafay & Burdon 2006), it tended to increase. In addition being a pyrophilous species it has taken the opportunities created by frequent fires to occupy areas were other vegetation formerly grew, as seen in other places where the species is a major ecological problem (Downey 2000; Caldwell 2006; Srinivasan *et al.* 2012). Local studies (Menezes de Sequeira *et al.* 2011 a,b) have shown that these two species increase fire risk, tend to form monospecific stands

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[1] See chapter 2, point 2.1.2, p. 37.

[2] Under *Sarothamnus scoparius* L

[3] Those early descriptions most likely referred *Genista tenera* (Jardim *et al*. 2007).

[4] Lowe (1868) based this statement in the fact that Brotero in *Flora Lusitana*, omitted this species as indigenous to Portugal.

[5] It was much used in the past as previously seen for green manure, as well as to make baskets, brooms and to use as fuel (Vieira 2002).

Figure 4.61 *Cytisus* spp. also covers large areas in not so high places, as these mountains surrounding Funchal, 2015 (JP,AP)

reducing biological diversity, and facilitate sheet erosion on steep slopes. Environmental problems related to *Cytisus scoparius* are not new. Its use in the past had some painful consequences as seen in Almeida (1817) who described uncontrolled fires and forest destruction due to broom being burnt in the spot, causing afterwards soil erosion, and being thereby one of the main causes of landslides (see also p. 19).

Both species are not included in the list of the 100 most invasive species of the world (Lowe *et al.* 2000) but are considered noxious weed in several parts, especially in north America. In Macaronesia, whereas *Cytisus scoparius* is considered a plague also in several islands, as well as in Madeira, *Cytisus striatus* only occurs in this latter region (Silva *et al.* 2008b).

Ulex spp. were introduced in highlands, with the similar aim of producing material to green manure but also to be used as fodder (Silva & Menezes 1946b;Vieira 2002). *Ulex europeus* may have been introduced in early nineteenth century and it was recognised by Lowe (1862) as being naturalised and almost as common as broom, especially in higher-lying areas. *Ulex minor* started to be grown around 1940s with seeds brought from mainland (Vieira 2002) and it was greatly introduced by Forest Services as nursery plant for protection of seedlings used for afforestation and also to create pastureland[1], becoming naturalised around 1960s (Vieira 2002).

Similarly to *Cytisus* spp., the two species of *Ulex* coexist in the landscape not being possible to distinguish them to that level. It was only detected in current landscape photographs depicting inland areas where, in the past, has seen almost only herbaceous vegetation and bare ground. Several surveys have pointed out *Ulex europaeus* as an invasive plant, it is included in the list of the 100 most noxious exotic species of de world[2] (Hill *et al.* 2000; Lowe *et al.* 2000), and also evaluated as one of the 100 most harmful plants in Macaronesian region (Silva *et al.* 2008b). The dense thickets seen in current photographed landscape confirmed its capacity to develop impenetrable monospecific stands. But, more surveys and monitoring data are needed to envisioned potential impacts. Because some gorse-infested

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[1] The mountain pastures were set up mainly in Paul da Serra and Poiso, and involved not only sowing this species (under the common name of *tojo molar*) together with a long list of forbs and grasses, but also clearing the land by removing heath to allow grassland installation (CFF 1952-1965, 1962-1964, 1965-1968).

[2] It was been pointed out by Hill *et al.* (2000) several characteristics that can reduce native plants growth, as: It grows intensively and rapidly forming thick impenetrable stands, shades out native seedlings; affects soil properties, facilitating some other exotic species, and increases fire risk.

stands in photographed landscape areas have been subjected to mechanical clearing, in last years, perhaps the outcome will provide an opportunity to sharpen up and clarify these issues.

The perennial gramineae *Brachiaria mutica* and *Pennisetum purpureum,* were the exotic grasses that stood out in photographed landscape. In part because they have very peculiar characteristics[1] which facilitate the recognition at landscape level, but also because they cover larger areas.

Brachiaria mutica was introduced prior to the twentieth century to be used as fodder, being cultivated over field margins (Cope 1994; Vieira 2002), and it was given by Menezes (1894)[2] as being already naturalised in several points of the island. Although not currently cultivated it is seen covering agricultural terraces (see figure 4.36), where the abandonment of farming, allowed this sprawling perennial herb to invade, especially in low-lying areas (see figure 4.39). Yet, as results have shown, *B. mutica* also spread into wastelands, bared or covered by vegetation, especially over places with moister soils. Given that it reproduces mainly by vegetative propagation, its dispersion into scattered locations must have been carried out by local farmers. Its subsequent disuse and lack of control allowed the spread around the areas where it was introduced (Vieira 2002). Although not included in the lists of most invasive species (Lowe *et al.* 2000; Silva *et al.* 2008b), it is a significant trouble in several areas around the world, out of the native range: Especially in places where it was planted to create ponded pasture, where it also spread into non-target places, replacing native vegetation and destroying streams (Mitchell 1996).

Pennisetum purpureum was introduced during the twentieth century, after the World War II, to be used as roughage for livestock, and, like *Brachiaria mutica*, it was cultivated in field boundaries within agricultural lands. It was already naturalised in 1960s, being frequently seen along roads and water courses (Cope 1994; Vieira 2002). In results it was seen covering mostly forsaken agricultural terraces (see fig. 4.35), only in southern areas. This is in line with information provided by those authors that limited this species to lower-lying warmer areas of south coast. Its dispersion along this coast, when still was very used, was promoted by farmers that spread it both by seed and cuttings (Vieira 2002). It is no longer cultivated but the unmanaged forage plantings that equally are not grazed allowed it to spread into surrounding areas. Although not considered one of most invasive species, as long as its growth and fructification are not limited by regular grass cutting, it can locally expand and spread by seed to new areas. Because it tends to form densely tufted clumps it can that hinder the development of native vegetation, and have disastrous consequences as seen in other places where it was introduced with the same aim (Pheloung 1995; Ismail *et al.* 2015)

Contrarily to above-mentioned species, which were introduced aiming to ensure the subsistence of local inhabitants, some other exotic species were brought to the island to be used as ornamental plants. As it happen all around the world, because they were often chosen for their hardiness, they become naturalised and spread. Some were already mentioned and discussed as *Ageratina adenophora*, *Podranea ricosaliana*, *Cardiospermum grandiflorum* and *Pittosporum undulatum*, but some others were also seen showing quite relevance at landscape level as *Solanum mauritianum*, *Oxalis pes-caprae*, and *Tropaeoleum majus* and some other species, that were not seen abundantly or highly dispersed across photographed landscape as *Agapanthus praecox*, *Hedychium gardnerianum*, *Nicotiana glauca*, Passiflora *molissima*, *Phoenix canariensis*, and *Quercus ilex.*

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[1] *Brachiaria mutica* has prostrated culms and it is bright, glossy green in colour all year around; *Pennisetum purpureum* forms densely tufted clumps that can grow up to 3 metres, with colour ranging from greenish to yellowish.

[2] Under *Panicum barbinoide* Trin.

Figure 4.62 Forsaken terraces covered by *Solanum mauritianum*. Camacha, 2015 (AP).

Solanum mauritianum was introduced in the nineteenth century as ornamental plant, having Lowe (1872, p. 81) taken the responsibility for that deed (under *S. auriculatum* Aiton), also calling the attention for its quick-dispersion by birds: "Hence its rapid diffusion since 1833, when it was first raised by myself from dried berries (…) received from Rio de Janeiro, though the sp. is said to be originally from Madagascar and the Mauritius.". The species was already naturalised by late 1800s and in early twentieth century quite abundant, although confined to Funchal and surroundings. Today it is spread all over the island over wastelands, dumps, road edges, forest areas, and forsaken terraces (Figure 4.62) especially moist locations (Vieira 2002) where it normally forms communities almost monospecific (Costa *et al.* 2004).

S. mauritianum was not identified in historical photographs and in current landscape was seen more often over low-lying areas, greatly along north coast were it encroached forsaken agricultural fields forming dense stands. In inland it appeared over areas that where fulfilled by native vegetation in the past (see figure 4.36). Although it can be assumed that it could have been an opportunistic invasion after disturbance in those areas, may be a warning sign for the potential threat to undisturbed communities, as it happens in places where it become an 'environmental weed'. Surveys in areas were *S. mauritianum* become one of the major invasive of riparian environments have shown that once established it is really hard to control, since it produces a huge seed bank and resprout from cut stems. Because it is spread by birds, and pollination are partially autogamus, a single plant represent a menace which demands early detection and rapid response (Witkowski & Garner 2008). It was considered a threat to Madeira protect areas and subject to control in laurel forest protect area. (Silva *et al.* 2008a).

Oxalis pes-caprae, it is a species that was introduced as ornamental (Mullin 1994) although no trace exists of when it must have occurred. It was given by Lowe (1857) as being already naturalised and described as quite abundant in early twentieth century by Menezes (1914), and considered a harmful weed affecting main crops and causing significant damage to local economy (Vieira 2002).

It was mainly seen in southern low-lying areas (see table 4.7), over forsaken agricultural fields where its presence was already linked as infesting species. But it was also seen in other areas (see figure 4.36), to where dispersal must have been caused by human activity, since the species here in Madeira, as frequently occurs in introduced range all over the world, reproduces exclusively via bulbils (Vieira 2002; Ross *et al.* 2008; Verdaguer *et al.* 2010). It is important to note that the presence of this species in photographed landscape, it is certainly higher. Because identification at landscape level heavily relies on colour, especially on yellowness of the mats, being *O. pes-caprae* a cryptophyte only bare ground is seen in part of the year. Surveys undertaken in areas with similar climate, have shown that it covers the area where it establishes forming dense carpets that inhibit the development of other plants. Because it produces many bulbils that fragment easily it can spread into long distance due human activities, also invading undisturbed scrubland and forest habitats (Vilà *et al.* 2006; Salas-Pascual *et al.* 2011). This species is one of the 100 most invasive species of Macaronesia, affecting Madeira Island and, in the same way, the island of Porto Santo and all the islands of the archipelago of Canaries (Silva *et al.* 2008b).

Tropaeoleum majus was introduced prior 1850s insofar Lowe (1857) firstly recorded it as naturalised, being then found over wastelands surrounding gardens and vineyards in Funchal, and in several places along the north coast. It is a plant that invaded mainly southern forsaken agricultural fields, although it was not detected as one of the main plants that covered those spaces (see figure 4.36 and 4.39). It also developed over areas where in the past another vegetation type occurred mainly herbaceous and shrubby vegetation. Since it is an essentially prostrate plant it covers effortlessly low vegetation, hedges and terraces walls, but it is highly unlike to smother taller plants because it hardly scramble over them. Although being a plant that in Madeira Island can be perennial (Lowe 1857) it was not identified in historical images and likewise its presence in current landscape may have been belittled. In spite of flowering in Madeira almost all year around (Short 1994), it only blooms brightly during spring-summer showing only then the orange masses of which identification at landscape level depends on. Although it is not included in invasive species lists (Lowe *et al.* 2000; Silva *et al.* 2008b) its harmfulness must not be overlooked. It was submitted to surveillance and eradication on some Pacific islands (West 2002) and several studies have shown its allelopathic effect on other species germination (Formagio *et al.* 2011).

Agapanthus praecox, *Hedychium gardnerianum*, *Nicotiana glauca*, *Passiflora molissima*, *Phoenix canariensis*, and *Quercus ilex* that were likewise seen in photographed landscape, also deserve a reference. However, because they were not frequently or abundantly seen across photographed landscape, illations about their behavior should be taken with some caution.

Agapanthus praecox was, and still is, one of the plants more often used in the Madeira Island for gardening since it was introduced in late nineteenth century (Menezes 1914). It has been widely grown in gardens, parks, and especially in roadsides and for lining paths beside the l*evadas*[1]. The hardiness that made it greatly appreciated in gardening also was the reason why it become established, spreading from the areas where it was cultivated and being found some years after by Grabham (1934) as fully naturalised and seen everywhere. According to Vieira (2002) although being found from sea shore up to 1000 metres (a.s.l.), persisting where it was introduced and invading new areas, it is more abundant above the altitude of 300 metres, in places with wetter weather. According to this author, although often seen in borders and under forest canopy it was not showing then significant penetration in native forest.

In photographed landscape *Agapanthus praecox* was only seen in two locations (see table 4.7), that although being in accordance with altitudinal range adduced by the latter author, probably do not represent the reality, since much of it is hidden by the crowns of the trees. It was referred by Sjögren (2000), although not considered a potential threat to native vegetation. It was also referred by Press (1993), who although not considering it a quite aggressive

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[1] Local designation for an irrigation channel very common in the Island of Madeira

invader, called the attention to the fact that being so copiously planted it was hampering native vegetation regeneration in a huge area. Indeed, it was given as invasive plant for Madeira island by Silva *et al.* (2008b), but until now not subjected to control has it happened in some areas (Wotherspoon & Wotherspoon 2002). On the basis of the above, being native forest crossed by many *levadas*, it cannot be considered immune to its invasion: first from clumps along those paths and second as Press (1993, p. 245) stated: “The biggest danger from these plants[1] in Madeira seems to be the predilection of local people to introduce them to new sites, even very remote ones, at every opportunity”.

Hedychium gardnerianum was introduced in the late nineteenth century and it was firstly recorded as naturalised in the early twentieth century by Menezes (1914), although not considered at the time as being very frequent. It was greatly planted in gardens and parks all over the island from where it dispersed into wastelands, forsaken fields, especially the ones close to streams, mainly after the 1950s (Vieira 2002). This species is among the top 100 of the worst invasive species (Lowe *et al.* 2000), invading not only disturbed open areas, where it prevents regeneration of native vegetation, but also, being a shade-tolerant plant, it forms dense thickets in the understory of close-canopy forests smothering and displacing native groundcover vegetation of undisturbed sites (Williams *et al.* 2003). Sjögren (2000) highlighted the noxious role of this species in Azores, but no reference was made to the threat that it can represent to Madeira native vegetation. However, Press (1993) advised early measures to stop this species that was already colonising the lower forest hedges. In 1997, a project (LIFE97 NAT/P/004082) aiming to eradicate several exotic species occurring in forest edges, also tackled *H. gardnerianum*, but although control of this species was achieved inside of the laurel forest, in key areas outside complete eradication have failed (Neves 2000). According to (Silva *et al.* 2008a) at date a programme to control this species was still operating in Madeira.

Hedychium gardnerianum was seen in a single location in inland (see table 4.7), close to a stream, where in the oldest photograph was identified native vegetation, and in the latest one was observed farming land and unidentified vegetation, reveling that in this case it didn´t displaced native vegetation but settled in already disturbed area. But, in light of the above, even though it was not seen in an extensive way in photographed landscape, it must not be overlooked.

Nicotiana glauca was most probably introduced in the late nineteenth century, because only at that time it was mentioned by Lowe (1872, p.172) who, comparing its *status* in Madeira with its strong presence in the archipelagos of Canary and Cape Verde, stated that it “occurs, but has not yet at all established itself in Mad.” However, it expanded rapidly since Menezes (1914) referred it as being quite common. It was seen in a single location (see table 4.7), near sea shore, in small group of plants spread over a steep cliff. Location that coincides with the range indicated by Vieira (2002) who stated that *N. glauca* was only found on south coast up to 200 metres (a. s. l). Although not being included in the list of the top 100 invasive species of the world (Lowe *et al.* 2000) it has proven to be successful invader, being able to recourse to authogamy as way to overcome the lack of pollinators becoming a significant invasive especially in of semi-arid environments all over the world (Ollerton *et al.* 2012). It became an issue in several Macaronesian islands, demanding heavy control measures (Silva *et al.* 2008b). Madeira Island, given all mentioned, in spite of seeming fairly innocuous for vegetation of higher belts, it surely upset the balance of aero-haline communities of sea cliffs.

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[1] Press (1993) was referring together with *Agapanthus praecox, Hydrangea macrophylla* (Thunb.) Ser., another plant much used with the same purpose, which was not identified at landscape level in photographed areas.

Passiflora mollissima was firstly reported (under *Tacsonia molíssima* HBK) as cultivated plant by Menezes (1914). Since then it became widely spread, mainly in wet places above the altitude of 500 metres, were it is often confounded at landscape level with *Passiflora* x *exoniensis* hort. ex L. H. Bailey (Vieira 2002). *P. mollissima,* was given as being naturalised by Hansen (1971) who found it in areas adjoining the native forest. Being maintained by local people, to commercialise the fruits, seeds were allowed to be dispersed by birds and today it entered deep into the forest (Vieira 2002). It was only seen in one photograph in inland in accordance with distribution indicated by the latter author. This species is considered as invasive in Madeira Island, but it is absent in all islands of the Macaronesia (Silva *et al.* 2008b). Although it was not included in the list of most invasive species of the world (Lowe 2000) it is also a serious invasive species in certain areas, demanding huge effort to control this vigorous climbing plant, which can grow up to 20 metres into the forest canopy and scramble over lower vegetation, smothering and destroying it (Beavon 2007). According to Silva *et al.* (2008a) an effort to reduce the spread of this vine was made by applying eradication measures in laurel forest.

Phoenix canariensis was introduced in the nineteenth century and referred for the first time as being present in Madeira Island by Menezes (1914), without special emphasis in relation to other palm trees also cultivated at the time. It was used in gardening and although introduced by Forest Services since late 1950s in Porto Santo Island, there is no record that it must have been introduced for afforestation in the Iisland of Madeira (CFF 1952-1965, 1953-1968, 1965-1968). According to Vieira (2002), this was the only palm tree showing signs of being quite naturalised and spontaneously appearing near the gardens and road sides, on wastelands and rocky slopes. It was seen in one single location, on a cliff below a small village on northern coast (see table 4.7), where some old palms trees grow nearby. However, the main reason of being quite scattered around the island, as all over the country, was the growing interest in these plants for gardening[1], and not the fact that it is naturalised and spontaneously dispersed. In addition, it is currently threatened by *Rhynchophorus ferrugineus* (Olivier), that since 2007 is affecting palm trees throughout the country (Ramos *et al.* 2013).

Quercus ilex was firstly referred for Madeira Island by Menezes (1914) in spite that its introduction must have happened long before given the size of few specimens found in some *quintas* (Vieira 2002). It was used for afforestation from early 1950s, being introduced specially in higher regions (CFF 1952-1965, 1962-1964, 1965-1968). It was only seen in a single location (see table 4.7) forming a monospecific stand stretched over a hillside, very dense, and with clear signs of having been planted, in a place where in the past a pine wood existed. It appears as naturalised close to gardens and parks in Funchal and neighbouring localities (Vieira 2002), but not being considered to be invasive and a minor matter of concern (Lowe *et al.* 2000; Silva *et al.* 2008b). However, *Quercus ilex* is showing signs of becoming invasive in some places where it was introduced in parks and gardens being now established out of those areas (Thomas & Dines 2010). For this reason it would be prudent to keep a watchful eye on the evolution of this species.

4.4.3 Native vegetation long-term dynamics

Concerning the native vegetation, it needs to be borne in mind that sampling focused somewhat more significantly on areas with considerable anthropic influence. Indeed, in Madeira Island it is hard to imagine a landscape

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[1] According to Ramos *et al.* (2013) during recent years palm trees became frequently used in landscaping being *Phoenix canariensis* the one more often used.

which was not submitted to human influence. Although human role was already discussed at some length, it should be recalled that since the beginning of settlement even the most remote and hidden places were subjected to man-made actions. Persisting fires, logging, grazing, and introduction of invasive exotic species, deeds that in one way or another prevented or delayed native vegetation recovery, and eventually changed species composition in recovered areas[1]. As previously stated (see Chapter 2, p. 27) even if in larger scale a single composition exists, after disturbance, species that occur in smaller areas can be stochastic subsets, resultant from a smaller species pool and affected by environmental filters[2] (Fattorini & Halle 2004; White & Jentsch 2004; Prach & Řehounková 2006). In Madeira Island given the steepness of the slopes the loss of vegetation in the past was always followed by soil loss, as historical descriptions have shown, and regrettably it is still occurring nowadays (Baioni 2011; Menezes de Sequeira *et al.* 2011b). With such loss, seed banks and mycorrhizal inoculum tend to disappear (Amaranthus & Trappe 1993; Lockwood & Samuels 2004), and regeneration of native vegetation becomes dependent on its resilience in face of alien colonisers, and on diaspores from the remainder vegetation, sometimes refugee in inaccessible sites, and possibly impoverished (Hobbs & Norton 2004, Temperton & Zirr 2004; Wagner 2004).

As stated in results, larger areas containing quite preserved native vegetation were only seen in inland and slopes facing north coast. Through the analysis of the contingency tables it become apparent that current native vegetation derived mainly from the same type of vegetation and each vegetation type from the past was largely retained as the same type. These results, which could only be expected for forest or for high-scrub if located in scarps as permanent topographical community (Capelo *et al.,* 2004), revealed that secondary vegetation undergone little successional change. Furthermore, conversion of forest to high-scrub was higher than the reverse pointing out to imbalance between recovery and disturbance rates. This was also supported by the data obtained by interpolation (see figure 4.25 and also diagram C) that allowed inferring that although in these inland areas vegetation is currently more developed than it was 100-125[3] years ago, it is less developed than it probably was in more recent past (100-75-50 years). Although recovery from bare ground and earlier successional states have significantly developed in progressive succession, creating the impression that it is a well preserved mature-forest, the foregoing evidences suggests that in fact there is a regression of successional dynamics (Pupo-Correia *et al.* 2011b).

In addition, Results have shown incursion of *Cytisus scoparius* into recent clearings, in disagreement with the evolution trend observed for old bare parcels that recovered to native vegetation. This can be evidence of the colonisation capacity of this exotic species, as previously stated, even in areas without intense anthropogenic disturbance (Pupo Correia *et al.* 2008). This happened in the presence of seed bearers that could allow the autochthonous vegetation regeneration, being therefore an indicium that in this case ecosystem resistance was low in face of this invader (Levine *et al.* 2004), turning the above situation a major threat to native forest (Figure 4.63). Being this place an already protected area[4], (Menezes de Sequeira et al. 2007) this can only mean that current measures to conserve the largest area of natural forest of Macaronesia are not sufficient to curb its excessive disturbances.

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[1] According to Fantorrini & Halle (2004) if stress and disturbances are severe enough to cause local extinction, it will in turn affect abiotic filters being generated a feedback loop that can drive to disappearance of some species and emergence of new ones.

[2] Abiotic and biotic filters that shift the set of species, being particularly important the time when each species arrive, since many species do need biotic interactions from the beginning to be able to recolonise a space that was disturbed (Hoobs & Norton 2004)

[3] For this area only photographs with 100-125 years where available.

[4] Areas of native forest of *Clethro arboreae-Ocoteetum foetentis* become more effectively protected since the Forest Services were installed in 1950s, also under protection of the Natural Park created in 1982, and lately classified by UNESCO as "Unesco Heritage site", which in fact have contributed to its conservation (Menezes de Sequeira *et al.* 2007).

Even so, recovery by native trees and shrubs in places where they were not seen in the past also occurred. Regeneration was seen more often over barren land areas, or in areas carrying low sparse vegetation, than in areas previously occupied by exotic plants and agriculture. However, recovery of native vegetation in those areas may have been facilitated by the fact that those places were closer to native vegetation refugee or included scattered vegetation of less mature seral stages. In fact, recovery by trees belonging to mature stages only occurred if vegetation of seral stages were seen in the spot in historical photographs (see figure 4.25, and diagram A). In spite of the fact that, as it was also seen, the presence of the seral vegetation was not enough to allow the mature vegetation regrowth (see figure 4.25, and diagrams G, F). This happened in areas where remaining native vegetation is under huge stress (urbanisation and agriculture), and as seen above, in such cases earlier states of succession become quite permanent (White & Jentsch 2004).

Figure 4.63 (a) Recently formed clearing which was invaded by *Cytisus scoparius*, Rabaçal, 2006 (MS,AP). (b) Same clearing seen from the road above, 2006 (AP, AF).

In 'barren areas', which were not submitted to agriculture due to their location and conditions[1], and were mainly used for fodder cutting; firewood gathering; and for grazing[2] (Almeida 1817; Corrêa 1927; Natividade 1953), recovery was higher than in areas with exotic plants and farming. According to Kent (2012), human activities have different impacts on soil conditions (Figure 4.64). Doing nothing is the only one that do not have influence on soil conditions, chopping and mowing, although having some impact are less damaging[3], livestock rearing have further impact on soil conditions[4], and finally agriculture, that within such activities is the one that affects more directly soil conditions, by ploughing and sods-cutting, together with indirect influence of manuring, and the inappropriate, but rather frequent practice of burning to prepare land. As consequence, these activities influence the vegetation that is going to cover those places after the disturbance is removed.

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[1] As the following description shows: "a mancha incrível de retalhos, de minúsculos poios que se sobrepõem e ajustam ao sabor do relevo do solo como peças de um gigantesco puzzle, começa nas fajãs (…) e só cessa no alto, junto à coroa florestal, onde a água escasseia e o clima já é adverso à cultura agrícola (…)" (Vieira 1953 pp. 41,42), meaning: the incredible mosaic of patches, formed by small agricultural terraces, starting in *fajãs* [talus deposits] (…) sprawling up to the forest, where water is scarce and the climate have adverse effect on agriculture. Also, Almeida (1817) pointed out water shortage as main cause preventing cultivation of higher lands.

[2] According to Corrêa (1927) the several crises that affected the main agricultural productions since mid-nineteenth century (see footnote p. 126) led to livestock stabling, and only 36% of the animals remained grazing unsupervised.

[3] Those activities retain succession in lower stages and indirectly influence soil, but do not affect seed bank and underground structures, as much as grazing and agriculture.

[4] Depending on the animals that are being grazed, beyond the notorious destructive effect on aerial parts, they can affect seed bank and the underground structures. Also, soil can suffer physical alteration due compaction caused by treading, and chemical modification due manure, preventing regeneration, even after animals removal.

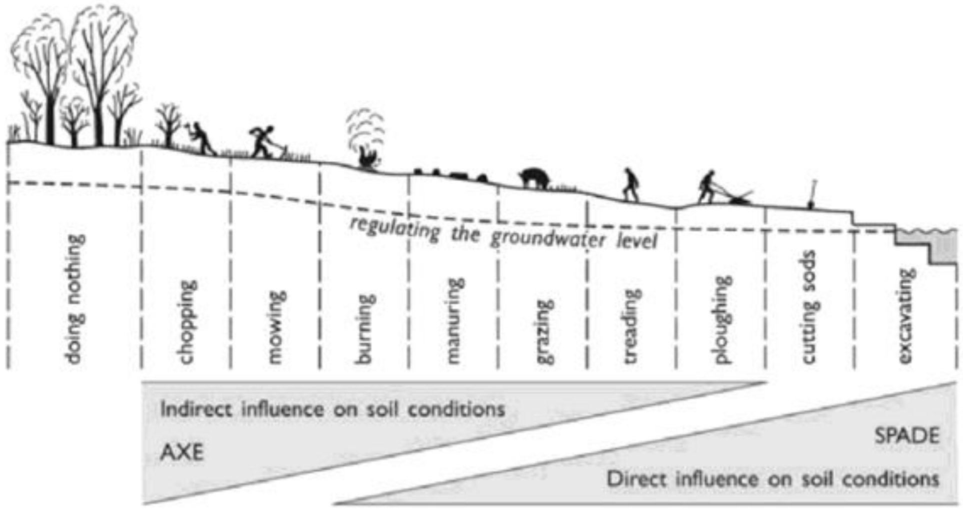

Figure 4.64 Biotic control of plant communities through impact on soil conditions. Redraw from Bakker (1979) by Kent (2012).

Thus, in those areas that were unfit for agriculture, the regeneration of native vegetation will have been facilitated by the fact that grazing and firewood gathering are still less restrictive to native vegetation than agriculture, allowing to conserve seed bank, trunks and roots that sprout, and are not directly related with exotic plants introduction as farming is. However, as shown by Arévalo *et al*. (2007) regeneration of laurel forests greatly rely on dispersal of fruits from other sites, especially the ones brought by frugivorous, apart from seed pool. This explains differences between west and east, north and south. Regeneration of native vegetation in bare areas happened more often in spots where historical descriptions have shown that native vegetation still occurred in the neighbouring areas. Regeneration of native forest vegetation in southern bare areas was limited due to lack of native seed sources and due to the prevalence of disturbance. Moreover, long term grazing and wood cutting prevented those areas to be used for afforestation hindering land occupation with exotic trees. This fact along with colonising strategies of the native plants (such as *Erica arborea, Erica platycodon* subsp. *maderincola, Euphorbia piscatoria, Globularia salicina, Myrica faya, Myrtus communis*) seems to have coferred a selective advantage to native tree-shrub vegetation in relation to the invading phanerophytes.

The recovery in former areas of exotic plants by native vegetation was limited and occurred only in certain circumstances. This was the case of exceptional conditions as seen in *Arundo donax* spots (see tables 4.6, and discussion p. 182) where a slight regeneration of native vegetation occurred both due to edaphic conditions favourable to native xerophytic shrubs and strong pressure on this exotic plant or as seen in situations of species that do not prevent native vegetation development, as for instance *Eucalyptus globulus,* under certain circumstances (see tables 4.6, discussion pp. 191-192 and Chapter 2). This example of native vegetation regeneration showed that spontaneous regeneration follows successional model proposed by Capelo *et al.* (2004): shorter periods only afford regeneration of lower seral stages, whilst situations embracing larger periods of time allowed development of mature communities within the same vegetation series (Figure 4.65).

These findings also pointed to a very slow recovery: around 25 years between each state, i.e. from perennial grass-forb stage to shrub community, and from this to the establishment of shade intolerant species that initiate the young forest (Figure 4.65). This lapse of time is much longer than the generalised value of 25 years to reach the climatic climax from a primary succession in the presence of diaspore rain and without disruption (Sänger & Jetschke 2004).

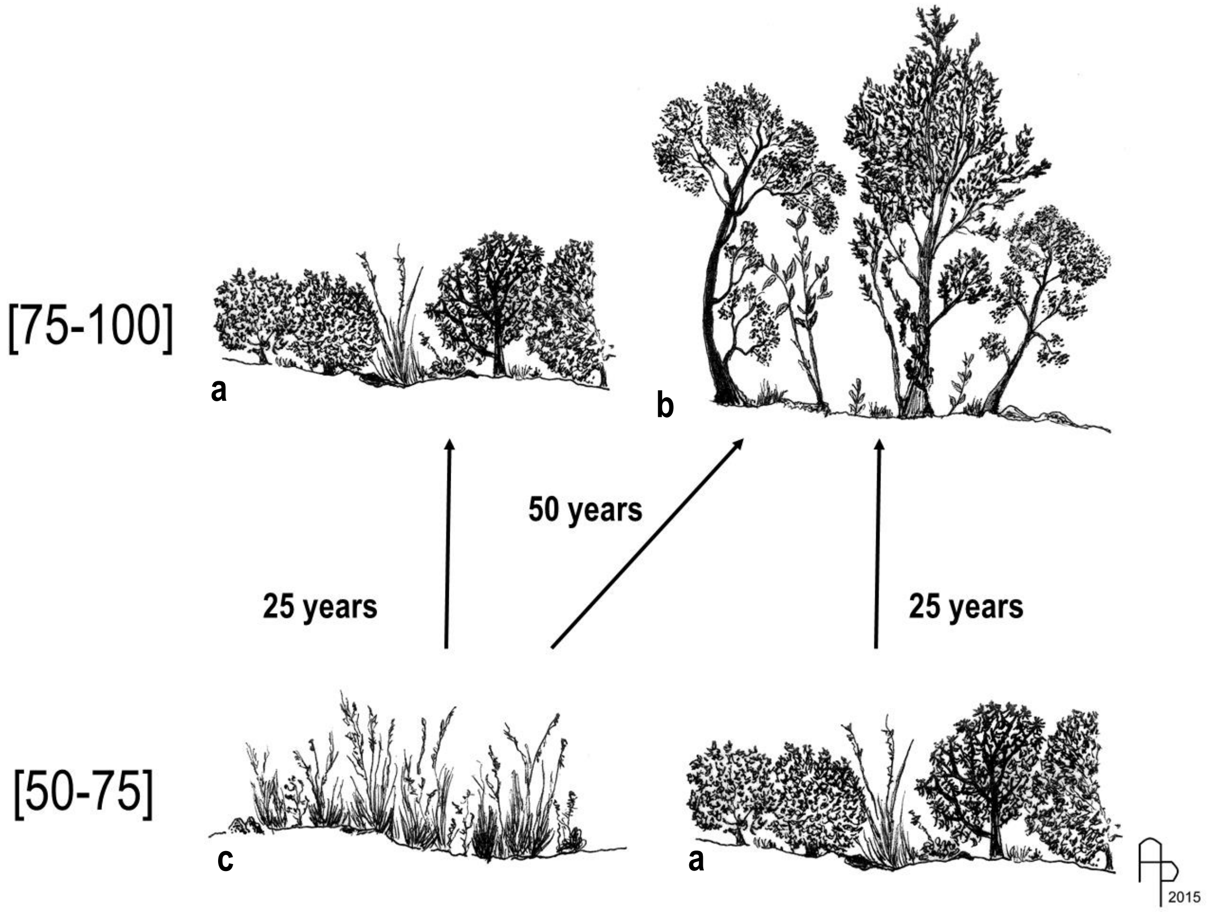

Figure 4.65 Spontaneous recovery of native vegetation where eucalyptus stands were seen in historical landscape 50-75-100 years ago. (c) Community of *Hyparrhenia sinaica*, (a) *Euphorbietum piscatoriae*, and (b) *Faial/Urzal-faia*l. Succession was, in this case, rather slow due to disturbance (e.g. fire), lack of initial favourable edaphic conditions, and absence of seed bank.

Surveys performed in Mediterranean laurisilva of La Palma Island (Canary islands) have shown that in clear-cut small areas of laurel forest, if soil was preserved, recovery from annual herbaceous stage to shade tolerant species of climax community, required between 15 to 25 years (Bermúdez *et al*. 2007). Insofar sites in photographed landscape were subject to several disturbances[1] vegetation renewal is heavily dependent on the restoration of soil conditions and sources of propagules, which are often located in very remote places. It is therefore hardly surprising that the period of time found was far higher than the one observed in neighbouring island.

A native species which greatly expanded over sites where exotic trees priory existed, especially in inland areas, was *Pteridium aquilinum* (see tables 4.6). This species is widely distributed in most areas of the northern hemisphere where it is often considered a noxious weed within its native range (Marrs *et al*. 2000). In Madeira Island it belongs

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[1] Disturbances that occurred since settlement, as fire, wood cutting, grazing, agriculture, and exotic species introduction, i.e. the type of environmental pressures that cause alteration and soil loss, and reduction or even disappearance of the seed bank (Bossuyt & Hermy 2001) as discussed before.

naturally to forest communities (as e.g. *Clethro arboreae-Ocoteetum foetentis*) and first substitution stages (as e.g. *Vaccinio padifoli-Ericetum maderincolae*), not being found in lower seral stages (Costa *et al.* 2004). This tendency is close to the role of this species as a mid-successional plant occupying a niche between moors/grasslands and woodland, in heathlands and moorlands in Britain, where it is thought to influence succession through invading early-successional communities and controlling the colonisation of later successional species (Marrs *et al.* 2000). Although the persistent nature of bracken results in long-term stagnation of succession, making it look like there is for evermore, there are signs from long-term studies showing establishment of tree species in treeless bracken stands resulting in the restoration of the forest (Ouden 2002).

In its natural habitat, in the forest understory, it rarely reaches high densities. Large scale bracken dominance occurs only after deforestation (Figure 4.66), especially after fire. Being a species well adapted to fire, when it is already present in burned spots it proliferates and creates thick blankets. While it has been suggested that in this way it can assist the reestablishment of the area by preventing erosion, the exact effect of bracken in these situations it is quite ambiguous (Ouden 2002). Follow-up studies over 10-20 years periods in intense bracken infested areas have shown that there is no doubt that a dense bracken sward reduces colonisation by other species and it persists for long periods. *Pteridium aquilinum* is extremely difficult to eradicate, in fact almost impossible, and to sustain long-term reduction it is required continuous control treatments (Marrs *et al.* 2000). Those surveillances have shown that in general more frequent cutting treatments allow to shift to target community, in this case heathland and grassland (Alday *et al.* 2013). However, those desired communities[1] correspond to lower levels of succession, which in fact are maintained by periodic disturbance otherwise those areas are re-colonised by forest.

Figure 4.66 *Pteridium aquilinum* covering cleared areas. Paul da Serra, 2007 (AP; JP)

In Madeira Island *Pteridium aquilinum* was heavily cut in the past for livestock bedding and green manure (Silva & Menezes 1946a; CFF 1967) what, apart from contributing to its presence over forsaken fields (see figure 4.41), do not seem to have helped to restore native forest. Thus, there is no proof that controlling *P. aquilinum* will drive succession in the right direction, i.e. towards the late stages of climatophyllous vegetation series. Nowadays, its exploitation has decreased steered by agricultural abandonment, it is not consumed by herbivores due its phyto-toxicity

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[1] Heathlands and moorlands, are scrublands habitats, maintained by frequent disturbance, most of them of anthropogenic origin created by thousands of years of grazing, burning. Currently, those cultural landscapes, are managed by recreating the disturbance regime related to its origin.

and its dispersal was highly favoured by wildfires which frequency increased in last years. Those large and dense bracken stands can induce stagnation of succession for centuries but, because strategies used to control it depend upon the community to be achieved (Alday *et al.* 2013) measures to deal with this problem should not be taken without more in-depth local studies.

Plant communities that developed over forsaken agricultural fields are in accordance with vegetation model proposed by Capelo *et al.* (2004). However the great part of it correspond to seral stages, especially high-scrub communities, i.e. *Euphorbietum piscatoriae* (south coast), *Globulario salicinae-Ericetum arboreae* (north coast), and *Vaccinio padifoli-Ericetum maderincola* (inland). Recovery with more mature vegetation was seen more often in inland (*Clethro arborea-Ocoteetum foetentis*) than in north coast (*Semele androgynae-Apollonietum barbujanae*), and in this zone more than southern coastal areas (*Semele androgynae-Apollonietum barbujanae* and *Mayteno umbellatae-Oleetum maderensis*). It was possible to observe a successional pattern, as e.g.: Agricultural fields seen in older photographs depicting inland areas are currently more often covered with late successional stage (*Clethro arborea-Ocoteetum foetentis*) than early successional communities (*Vaccinio padifoli-Ericetum maderincola*), while forsaken fields still seen as farming land in the more recent historical photographs, have shown the inverse: greater abundance of immature seral stages and smaller quantity of the ones advancing towards the climax community.

Agriculture, as previously stated, it is one of the most damaging activities for native vegetation [see figure 4.62 (Kent 2012)]. Forsaken agricultural fields become depleted of native species seedbank, and physical and chemical soil properties were altered due to tens and in some cases hundreds of years under farming use. After abandonment, the fields that were not used to construction (which was frequent, especially in south coast) or maintained remnants of former perennial crops (e.g. neglected vineyards), were mainly invaded by exotic plants. Either because they were used to support farming activities (e.g. *Arundo donax)* or because they spread into those fields from the places where they were introduced (e.g. *Cardiospermum grandiflorum*), or even because people meant to shift to other crop (e.g. *Pinus pinaster*). Even so, spontaneous recovery of native vegetation occurred, in spite of the fact that those newly formed assemblages, even if dominated by native species, are always characterised by the presence of non-native species (see chaper 2)

Some issues could have contributed to smaller recovery of native vegetation over forsaken farmlands in southern areas than in north coast and inland: the time when land-clearing started, the length of time that the land was cultivated, the crop type that was grown in those fields, and the time when abandonment happened. Land clearance started first in south face[1] and in lower lying areas, since many of the higher grounds were still not cultivated[2] at the beginning of the nineteenth century making a difference of more than three hundred years of agricultural use. And, even when farming started out in the upper lands, fields were not used on a regular basis[3] and were the first to be

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[1] As stated by Silva & Menezes (1946c, p. 494) :"Como facilmente se acredita as explorações agrícolas e o correlativo desbravamento não começou na costa norte, nos anos mais próximos do descobrimento, tinham de sobra os primitivos povoadores, no sul da ilha, terras mais férteis e climas mais temperados em que exercitar a sua actividade" meaning: "As it is easy to believe clearance of forest to be farmed did not started in northen coast. In following years after the discovery those early settlers had a better climate and more fertile lands in the south to be cultivated".

[2] not only because they were less accessible and less inhabited but also due to the lack of irrigation water as was mentioned by Almeida (1817, p. 65) about the small village of Prazeres, located at more than 600 metres: "(…) Os terrenos estão em parte incultos (…) Pode produzir muito milho e trigo, porém tem falta de água (…)"meaning: Lands are in part not cultivted (…) wheat and corn can be grown but there is no water".

[3] As understood from the commentary made by Almeida (1817, p. 72), in relation to agriculture practices carried out in areas close to forest: "(…) e tem chegado a barbaridade dos povos desta freguesia a lançar fogo em grandes matas para cultivarem a batata, de cujo estrago só utilizam o primeiro ano" meaning: "people of this village [Santana] reaches to the point of committing such barbarous acts as setting fire to woods to grow potatoes, only for a year".

abandoned or converted into pine woodland, during emigrations cycles and shortage of farming labourers. More recently, after the *Circunscrição Florestal do Funchal* was created, agricultural lands close to forest perimeters were not allowed to be cultivated with perennial crops, as vines and fruit trees (CFF 1953-1969a). Recovery of native vegetation was thus facilitated by these circumstances contrarily to lower lands, which started to be cultivated earlier and on a permanent basis. Despite all that, regardless the location, it was the vicinity to native vegetation that determined regeneration, and the closer those fields were to source of propagules the greater was the recovery (Figure 4.67), being this aspect that certainly influenced the evolution of agricultural fields after abandonment.

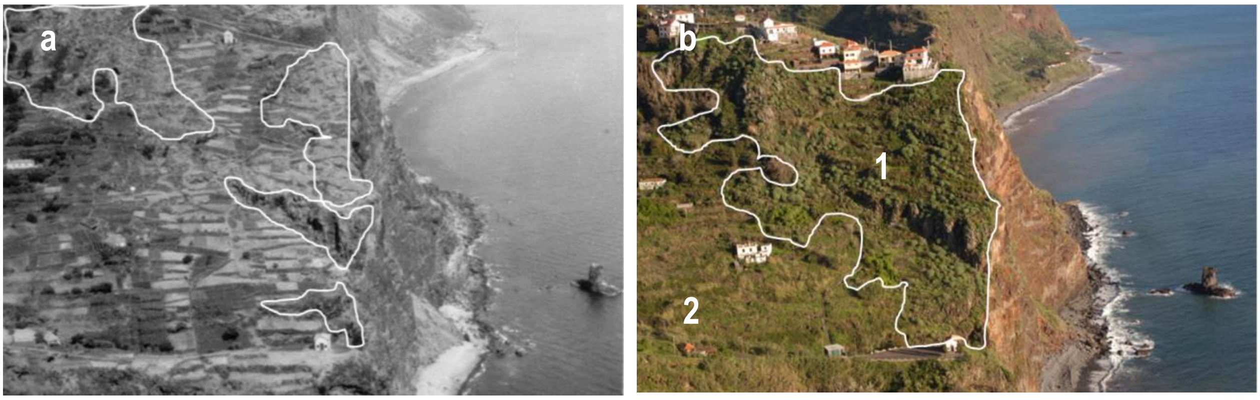

Figure 4.67 Community *of Euphorbia piscatoria* recovered in fields (1) interspersed in rock outcrops where vegetation of the seral stages already existed in the past. Left over lands located a bit farther are currently covered with exotics, e.g. *Arundo donax* and *Pennisetum purpureum* (2). Campanário, south coast in (a) early 1950s (by unknown photographer, DRF), and (b) in 2013 (AP, JP).

4.5 Conclusion

Historical photographs from the late nineteenth century and early twentieth century confirmed huge destruction of native vegetation in coastal and accessible inland areas and its replacement by exotic species.

The change that landscape suffered over more than one hundred years was higher in south coast than in inland and north coast, and it was bigger in last 75-50 years than during the period between 75-125 years. The majority of the landscape that has not significantly changed was already altered at the time of the historical photograph due construction and farming lands, classes that remained unchanged in those landscapes. On the other hand on landscape that undergone larger modification the change was mainly driven by agricultural abandonment and changes in vegetation, especially caused by the increase of exotic plants over those forsaken agricultural areas and over uncovered areas, which also have diminished. Another reason of landscape change was the increase of built up areas, especially in south coast, over former farming lands, clifftops, and stream banks.

Arundo donax and *Acacia meansii* were the exotic species that greatly spread into forsaken agricultural terraces all over the island: Some other exotic species also stood out throughout former farming lands, having more or less relevance in southern, northern or inland areas. Part of them were introduced to support farming activities (*A. donax, Brachiaria mutica, Penisetum purpureum*, *Cytisus spp.*), others spread into those fields from the places where they were introduced (*Cardiospermum grandiflorum*, *A. mearnsii*, *Solanum mauritianum, Ageratina adenophora, Pittosporum undulatum, Oxalis pes-caprae*, *Tropaeoleum majus, Podranea ricosaliana*), and others were planted to

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shift into less demanding crops (*Pinus pinaster* and *Eucalyptus globulus*). Cliffs, rocky outcrops, and rocky stream bed and banks were also greatly invaded by *Arundo donax* and *Acacia mearnsii*, as well as some other exotic species that also spread into those spaces as *Ageratina adenophora*, *Cardiospermum grandiflorum, Opuntia tuna*, *Podranea ricasoliana*.

The most common exotic tree seen in historical landscape was *Pinus pinaster* which replaced *Castanea sativa*, the predominant exotic tree up to the middle nineteenth century. *P. pinaster* started to be substituted in early twentieth century by *Eucalyptus globulus*, whose older stands almost disappeared. Current eucalyptus stands, as well as the remaining pinewoods, are being invaded by *Acacia mearnsii* and *Pittosporum undulatum*. Over time, some of the exotic that were once dominant become less relevant in the landscape. This does not mean that all exotics become less harmful as time goes by. These species that lost its predominance did not disappear completely, and some of the species that were early introductions as *Cytisus scoparius, Arundo donax,* and *Pittosporum undulatum* did not lose pervasive nature and are invading new areas preventing the regeneration of the native vegetation.

Recovery by native trees and shrubs in areas where it did not occur in the past was mainly seen over barren land areas and in areas carrying low sparse vegetation of less mature seral stages. Recovery also occurred in areas formerly occupied by exotic plants and agriculture, although in these two situations was far less due to adverse character of these land uses. In any case, recovery of native vegetation was firstly and foremost facilitated by close proximity of native vegetation refugee in save places. Spontaneous regeneration followed successional model proposed by Capelo *et al.* (2004), but recovery seen in these places mostly correspond to seral stages and findings pointed to a very slow recovery, i.e. more than 50 years to reach shade intolerant species that initiate the young forest. This slowness happens because past disturbances do not allow early stages to be faster, and ongoing disturbances (e.g. fire) retain succession in lower stages. These disturbances also have favoured *Pteridium aquilinum* which contributed to stagnation of the succession.

Larger areas containing quite preserved native vegetation were only seen in inland and slopes facing north coast, were it was seen in the past. Current native vegetation in spots often regarded as well conserved is undergoing little evolutionary change, heading towards unbalance between recovery and disturbance rates, and very vulnerable to exotic species encroachment. These shortcomings are evidence of low ecosystem resistance and demand additional protective measures.

Thus, as it was demonstrated, landscape photographs and Repeat Photography Techinique can be used for the evaluation of change and long-term vegetation dynamics. In Madeira Island context, although it can be considered a closed case in what concerns historical landscape, the technique and old images inhere employed can be used to explore other approaches. Moreover, the repeated photographs can be shortly repeated allowing to obtain data about short-term dynamics, also important to understand ecological mechanisms, or be repeated in the future to compose true time series.

5 Discussion

Madeira Island is an example of anthropic change over a very short time gap (600 years) when great disturbances as herbivory, frequent fires, and changes induced by agricultural practices occurred and disrupted natural balance of native flora that evolved in the absence those pressures. During this time human activity rescaled natural disturbance regime, to which native plants are adapted to, and introduced 'extrinsic disturbances'. Thus, it is difficult to know how much native vegetation was, is and will be resilient enough to survive to the synergistic effect of all those disturbances. It was proven that after alien disturbances are removed, even without exotic plants encroachment, plant succession can divert suffering modification in floristical composition and species richness (Lockwood *et al.* 1997; Fattorini & Halle 2004; Hobbs & Norton 2004; Lockwood & Samuels 2004). For instance, consequences of agricultural practices can last for a very long period of time, making it possible to recognise land that was formerly cultivated up to 130 years after abandonment, since it typically shows many common species and lacks rare ones (Dutoit *et al.* 2003). Therefore, it would not be out of place to wonder if native vegetation that recovered in each place corresponds to the exact original assemblage, i.e. the one that existed at the discovery time. Although the magnificence that was described could have been over exaggerated the fact that even after the great fire huge trees were largely exploited (see 1.2.2.2) corroborates the existence of a thick, lush forest at that time. May the native vegetation, even the less disturbed, have undergone change in face of so much disruption? Did those disturbances prevent regeneration of some native plants, at least the ill-adapted to resist, boosting the development of other vegetation types much impoverished and dominated by the more resistant species[1]? In fact, in addition to the lack of colossal sized trees abundance, current native vegetation become partly depleted. Some species that were abundant, became extremely rare (e.g *Juniperus* spp.), and some species became extinct (as *Frangula azorica*) (see p. 28), and possibly many others also disappeared before were known[2] (Jardim & Menezes de Sequeira 2008; Menezes de Sequeira *et al.* 2011a). However, although not being strictly identical it does not mean that is not worthy of protection. On the contrary it reinforces the importance of enhancing the protection of native vegetation, and to minimise man induced exogenous disturbances, given it is not guaranteed.

Areas of quite well-preserved native vegetation are found only in inland. Difficult access and agricultural unsuitability contributed to its preservation. Although current appearance of the forest located in inland (mainly communities within stink-laurel series) creates the perception of a well conserved forest, almost 'pristine', it cannot be accepted as such, for all foregoing reasons. Several spots do have in fact large old trees of shade tolerant species belonging to the most mature stage, and can be considered very close to what is considered an old-growth forest. However, great part of the area also considered as mature laurisilva forest it is in fact a very young forest, where the oldest and dominant trees are shade intolerant species (as *Erica* spp. and *Myrica faya*) or intermediate shade-tolerant (as *Laurus novocanariensis* and *Clethra arborea*), or even the first seral stage, which often attains to secondary forest

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[1] For instance, *Laurus novocanariensis* is the most common species in all laurel forests, and one of the native species that best recover in stands occupied by exotic species. Its dominance was explained by Arévalo *et al*. (1998) that pointed out the fact that although *L novocanariensis* (under *Laurus azorica*) being a shade tolerant species germinanting well in the understory it is also favoured by disturbance, occurring a positive effect of gaps on the densities of samplings and suckers of this species.

[2] *Freixo* (ash) was a tree wich logging was forbidden by Royal Warrant of D. João II, in 1493, because it was almost extinct at that time. According to Silva & Menezes (1984b, p. 57), it was a species that belonged in the past to the native forest but became very rare, existing only a few specimens planted in some *quintas* at that time. There is no information about the species, but it could probably be very similar to *Fraxinus excelsior* L. introduced for its wood.

character. In fact, inland areas were often described in mid-nineteenth century as still holding preserved original forest (see 1.2.2.2) but if particular attention is paid to paintings (see Figure 1.6.) and also to some descriptions[1], what was actually there was low vegetation, and vegetation growing in dense stands, revealing a young forest. Thus, in some inland areas there is no late seral forest but instead a second -growth forest, which has been retained in this state due to severe disruptions. Dendrochronological data of trees occurring in stink laurel forest corroborated this evaluation made through Repeat Photography, i.e. species that emerge during the intermediate phase as *Clethra arborea,* and during more mature stages, like *Ocotea foetens,* were younger than species present in early phases as *Myrica faya,* and *Laurus novocanariensis,* as well as species belonging to seral stages as *E. platycodon* subsp. *maderincola*, and *E. arborea*. Contrarily to this, an old-growth forest is dominated by old shade tolerant species, being the shade intolerant species, which emerge in canopy gaps, much younger (Figure 5.1-a). Only in areas resulting from huge disturbance a second growth forest emerges, being shade intolerant species older than shade tolerant trees (Figure 5.1-b).

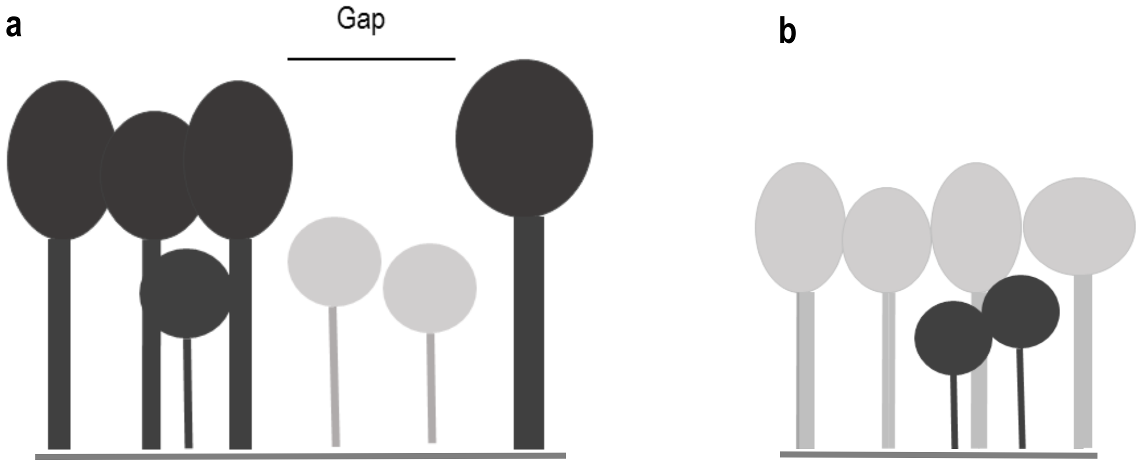

Figure 5.1 Stylised representation of an old-growth forest (a) and second-growth forest (b). Dark grey features represent shade-tolerant trees, and light grey features represent shade-intolerant trees.

Growth rates of woody taxa estimated in Chapter 3 and information of vegetation surveyed in Chapter 2 allowed to establish *tempus* of successional dynamics for two clymatophylous forests (Figure 5.2 and 5.3). This estimation have pointed almost eighty years after *Ocotea foetens*, main tree of stink-laurel forest, have conditions to growth as *tempus* needed to achieve the state of dynamic equilibrium (see Figure 5.3). This mean that in some spots of photographed area where oldest individual of *Ocotea foetens*, growing together with centennial laurels and heaths, is around 50 years the forest will need around 30 years to reach old-growth state, if not subjected to major disturbance. Another evidence that this forest has been under recurring disturbance is the fact that in some other sites of the same area seedlings of *Laurus novocanariensis* are starting to appear in a community of *Faial* (*urzal-faial*)*,* which developed over cleared areas seen in the historical photography (100-125 years ago). Given the *Tempus* estimated for some stages of succession this tardiness of reaching the mature forest can only been explained due to continuous disturbance.

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[1] "(…) cut through a forest of laurel, myrtle and other evergreens, growing so thickly together, that the whole forest seems one tangle mass of leaves."(De França 1854, pp. 104-105)].

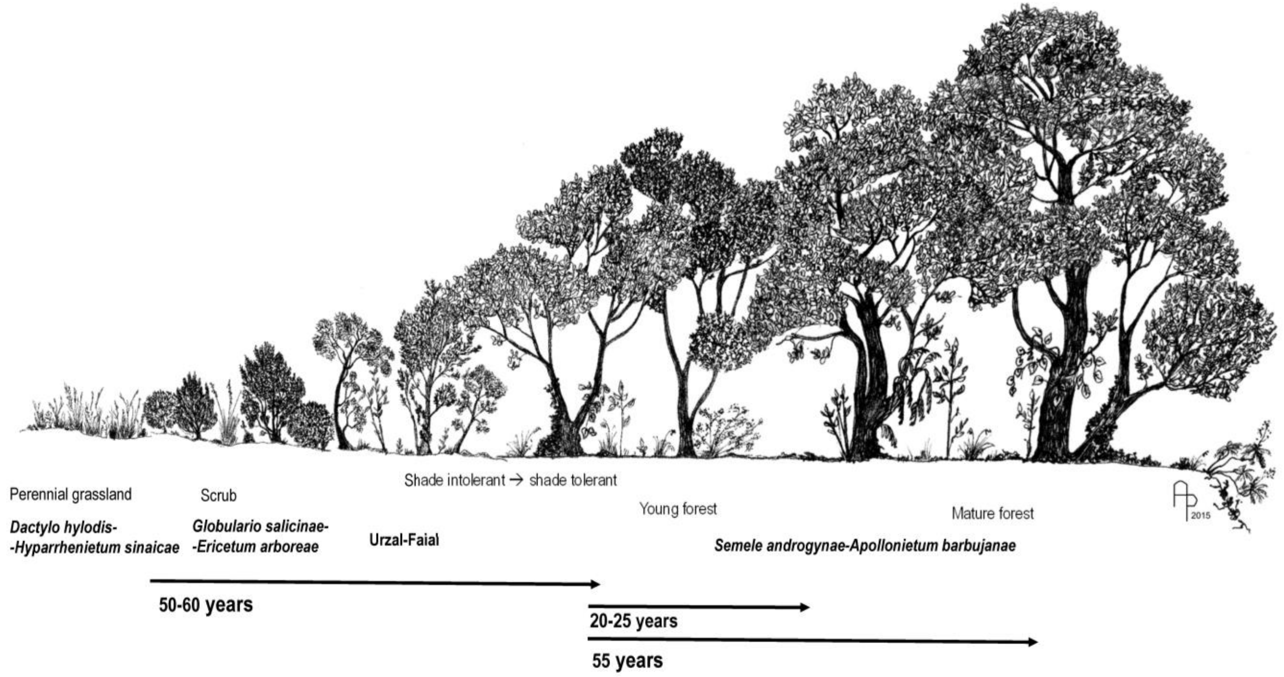

Figure 5.2 Diagram showing succession from perennial grassland to mature forest of *Semele androgynae-Apollonietum barbujanae*. *T*empus estimation for the successional dynamics indicates that it takes around 105-115 years from shrub stage to the mature state.

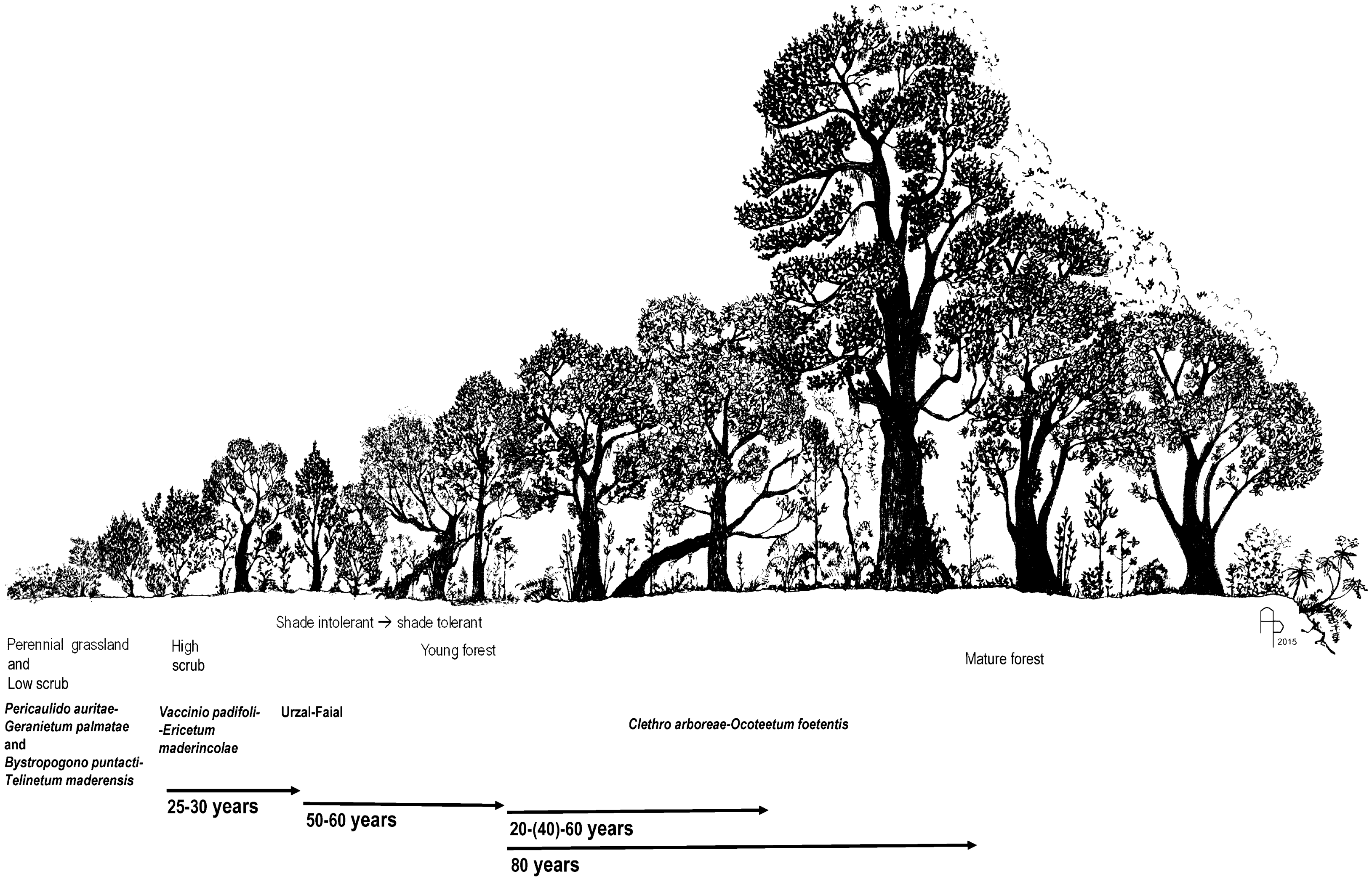

Figure 5.3 Diagram showing succession from perennial grassland to mature forest of *Clethro arboreae-Ocoteetum foetentis. Tempus* estimation for the successional dynamics indicates that it takes around 170 years from shrub stage to the mature state

As seen in Chaper 1, two major threats to native vegetation in upper lands were the exploitation of wood and grazing. Since early 1950s, when forest services were installed, logging in the native forest was no longer permitted, although felling trees to produce charcoal was authorised in a few places and under certain circumstances up to 1980s (CFF 1952-1980). Some of those records show that most of the places stopped being explored in early 1960s. However some areas seen in photographed areas (Ribeira da Janela Valley) were, up to mid-1970s, subjected to requests to collect firewood and to cut trees/bushes (mainly *Erica* sp.) to produce charcoal. These areas, still are recovering from that activity.

Grazing, that was one of the main responsible by forest destruction always found a great resistance from livestock breeders in every attempted to deal this problem (see 1.2.2.2, pp.19-20). It was finally resolved in 2003 when goats and sheep were removed from the hills, a measure that definitely contributed towards natural vegetation recuperation (Menezes de Sequeira *et al.* 2007). However, cattle was not removed, and in fact it has increased in last years, what supports the allegation made by Andrada (1990, p. 21) to show the enormous difficulty of local authorities to enforce rules established:

> "It was insufficiently considered the tenacity and way of being of Madeiran peasant who seeming to bind the determinations aiming to preserve for posterity the natural resources of everyone's interest, which must prevail over immediate interests of some individuals, always return to same practices, relapsing in reprehensible procedures of commonage exploitation which are passed down from generation to generation (…)"[1].

Although no data from local surveys was published, up until now, to evaluate the consequences of this situation, in Canary islands, studies have shown that in the availability of more palatable plants, like native ones, these are the ones that livestock eat (Nogales *et al*. 2006). Thus, species like *Cytisus* spp. which have a bitter taste are not grazed (Leblanc 2001) have been favoured in detriment of native vegetation, and it increased all over wastelands surrounding forest perimeters.

Wildfires in Madeira Island are not a recent disturbance (see 1.2.2. pp.16-17) and have encouraged the species that were able to survive them. Prior to settlement extremely rare natural fires may have happened, caused by, for instance, volcanic eruptions (Scott 2000). However, since 1425 most of the fires were and are of anthropogenic origin. Although historical records show that one huge fire (1593) was ignited by natural causes, probably lightning (Silva & Menezes 1946a), as the climate of Madeira Island (see 1.1) is more prone to winter storms than to dry thunderstorms during summer, lightning-related fires should be extremely rare. So, although a few other situations[2] can be responsible for naturally-caused fires (Babrauskas 2003) most of the them are not started by natural means but due to arson and to human carelessness. These two categories cover almost all fires that were either maliciously ignited to cause damage (as in 1919, see 2.1.2, p.19), or because they get out of hand and spread into the forest, as it happened in

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[1] Translated from text in Portuguese: "Só que foram insuficientemente ponderadas a pertinácia e maneira de ser do vilão madeirense que parecendo acatar as determinações no sentido de se preservarem para a posteridade bens naturais de interesse geral, que devem prevalecer aos interesses imediatos de alguns, voltam sempre à mesma, reincidindo no uso de processos condenáveis, transmitidos de pais a filhos, para exploração de baldios (…)" (Andrada 1990, p. 21)

[2] Spontaneous combustion of litter (under certain conditions of moister and temperature) and sparks from rocks falling down (Babrauskas 2003).

agricultural burns to clear fallow lands, illegal charcoal production and to clear land for pastures (see 1.2.2.2, pp. 19-22). Although the latter two do not have a role in present time fires they were important sources of disturbance in the past. Since later decades of the twentieth century, the two first felonies are the main cause of wildfires. They affect mainly exotic forest but now and then also reaches native forest, as fire scars detected in cores extracted to dendrochronological purposes proved. Their frequency had been boosted due the increase of pyrophile exotic plants as *Cytisus* spp. in upland, *Arundo donax*, *Acacia meansii*, and *Eucalyptus globulus* at bit lower altitudes (Figueiredo *et al.* 2008). These species, in other hand, took advantage of the disturbance to establish and to spread (Bell 1997; Duc *et al*. 2000; Leblanc 2001; Wilgen *et al*. 2001; Fernandes *et al*. 2005) as it was discussed earlier. So, given that wildfires are expected to occur more frequently, due to climatic changes anticipated in reasoned scenarios (Figueiredo *et al.* 2013 and references therein), exotic forest will be favoured more and more, hampering native forest recovery. Even if it is an exotic coverage that allow regeneration of native pants (as previously seen for *Eucalyptus globulus,* see also chapter 2), the fire crops the young individuals of mature stages, perpetuating earlier states of succession or stimulating pyrofilous species hindering full recovery of native forest (White & Jentsch 2004). Regrettably, this is a vicious cycle preventing native forest development: a forest with larger moister content (Capelo *et al.* 2004) which would create ecological conditions to prevent ignition and propagation of fire and therefore minimising hazard (Babrauskas 2003).

These two 'exotic disturbances' do not correspond at all to the type and regime that native forest become adapted. The native plants of Madeira Island are not adapted to fire, since natural wildfires would be rather rare and not a recurring phenomenon, as well as not adapted to herbivory, since no large herbivores existed in the island prior to settlement, favouring species better adapted to those perturbations. In addition, because destroyed areas are larger and subjected to higher frequency of disturbance, than natural phenomena that can occur in Madeira Island, the consequent disruption of the system integrity forces to move into alternative stable states. These alternative vegetation states are often resilient to colonisation by native species from the remaining pool (Lockwood *et al*. 1997; Lockwood & Samuels 2004), promoting the exotic vegetation.

Forests go through processes of establishment, maturing, and renewal. Forest renewal and survival of many species depend on disturbance, be it merely caused by toppling of a single old tree (fine scale gap dynamics) or as part of a natural disturbance regime. The latter is the disturbance type to which forest have adapted evolutionarily and rely on it to maintain biological diversity, its structure and processes, remaining in a state of dynamic mosaic (see chapter 2, p. 28-29). Disturbance is responsible for heterogeneity and patch formation, either at local scale or landscape level. Balance of the system occurs when the sum of all disturbed patches is small comparatively to the area and its frequency is low in relation to the time needed to recover. Studying the type of disturbance regime is of highest importance to understand regional traits of ecosystem functioning (White & Jentsch 2004).

However, as shown by Arévalo & Fernández-Palacios (1998), disturbance due to treefall do not affect significantly the dynamic of the laurel forest, and differences are not found between patterns of regeneration seen in those gaps and regeneration in the understory. In laurel forest context, fine-scale gap dynamics can be responsible for regeneration of the forest, but it is not the cause of maintenance of biological diversity, as it happens in other forest types. In Madeira Island native forest, another type of disturbance is responsible for *synusiae* where the xerophytic and heliophytic species of subseral communities are found or where neo-endemic caulirosetted phanerophytes are common (see chapter 2). Since Madeira Island terrain is of enormous steepness it is extremely landslide-prone.

Mass movement, especially during episodes of heavy precipitation is a type of disturbance that naturally affects steep slopes all over the island (Baioni 2011; Betâmio de Almeida & Oliveira 2011). As it was shown in some mountainous tropical rain forest, the occurrence of natural landslides, or at risk of slipping, is highly related to senescent forest reveling the effect of landslides as main responsible for the natural regeneration of the forest (Bussmann et al. 2008). Yet, although being this the disturbance regime to which the forest is adapted does not mean that it is completely resilient to this sort of perturbation. Same studies have shown that anthropogenic landslide were usually more extensive and break down forest into isolated patches. They tend, in this way, to create disconnected landscapes, which are reinforced by the fact that those clearings suffer slower succession processes than the natural situation and are more frequently invaded by exotic species.

In Madeira Island, frequency of landslide increased from the past into present. Although the main cause of this occurrence is heavy rainfall, it was intensify by human activity (Baioni 2011; Betâmio de Almeida & Oliveira 2011). The relationship between modifications caused by reduction in forest cover and damaging landslides[1] (Gray 1970) and flood events in Madeira Island was already pointed out by Almeida (1817), who drawn attention to incorrect agricultural practices with fire (see footnote p. 19) and the way that forest was being destroyed[2] as main causes of the flash flood and mudslides, which had happened before[3]. Although these events have mainly increased in areas subjected to anthropogenic occupancy (Baioni 2011) and covered with exotic vegetation (Menezes de Sequeira *et al.* 2011b), in natural forest also happened a rescaling of natural disturbance regime by making it larger, more frequent, and more intense (Menezes de Sequeira *et al.*2011a).

Not pointing out past actions, whose effects are still felt today, because cannot be amended, some current situations can be blamed for the modification of natural landslide regime within the native forest. Three issues can be considered as threats to this balance: (1) recurrent fires that often reach native forest, as demonstrated by fire scars seen in cores collected, which altering the soil properties create over-flow and increase erosion (DeBano 2000); (2) roads that were constructed in neighbouring areas of native forest, which generating runoff, and especially lateral redistribution, are responsible by severe erosion processes over the hillslopes (Luce 2002); (3) *levadas* built to bring water from the north to south face, which started to be constructed since the beginning of the settlement, although the largest ones were made, or rebuilt to carry larger water flow, in late nineteenth and twenty centuries (Siva & Menezes 1946a). They currently form an extensive network that enters deep into the native forest and when water flow increases, especially under severe weather conditions, it outflows far from rivulets where it should be drained. In the two latter cases the water cascades running over the forest ground causes soil loss and forest destruction. It creates larger clearings which, as seen above, are more prone to exotic invasions. Because roads and *levadas* go through the forest they are effective corridors to the invasion of non-native plants, increasing the probability of those unexpected clearings start a fragmentation process (White & Jentsch 2004) as seen above (Bussmann et al. 2008).

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[1] The two main reasons explaining why loss of forest cover increase the frequency of landslides are: deterioration of root systems and denuded soil reaching critical saturation much earlier (Gray 1970).

[2] In relation to this Almeida (1817 p. 53) wrote: "*As grandes cheias que sucessivamente tem havido têm a sua origem na destruição dos arvoredos e as montanhas que não há muitos anos vi cobertas de arvoredos, hoje as vejo reduzidas a um esqueleto*". Meaning: the great floods that repeatedly have happened are due to forest destruction, and mountains that were all covered by trees just a few years ago are now completely uncovered.

[3] This type of events that in Madeira are called by *aluvião* were often repeated throughout the time, leading to huge material damage and loss of human life. Since the first recorded in 1601, several other left their mark as in 1724, 1765, and 1803 (Carita 1982), and more recently 1941, 1991 (Baioni 2011), and also 2010, when this work was already ongoing (Menezes de Sequeira *et al.* 2011).

Thus, in light of the above, current native vegetation in spots often regarded as well conserved is undergoing little evolutionary change, heading towards unbalance between recovery and disturbance rates, and being very vulnerable to exotic species encroachment. These shortcomings are evidence of low ecosystem resilience (Levine *et al.* 2004) and demand additional protective measures (Menezes de Sequeira *et al.* 2007; Pupo-Correia *et al.* 2011).

Coastal vegetation, especially in south coast where natural vegetation corresponds mainly to sub-seral stages of the three vegetation series (madeira oleaster tree, marmulano-tree, and barbusano-tree) which mature stages are currently restrict to small patches that occur in very hardly accessible places all corresponding to highly threatened habitats and species due to population fragmentation and urban pressure, and native vegetation was largely replaced by exotics plants. Those southern areas are mostly not included both in Natura 2000 Net and the Natural Park of Madeira, and therefore are not legally protected. The fact that inland areas have quite well preserved native vegetation does not reduce the need for specific management of coastal vegetation, which correspond to distinct vegetation types (Capelo *et al.* 2004; Menezes de Sequeira *et al.* 2007). Native vegetation in north coast is also under pressure, although less pronounced than in southern areas. Nevertheless it is also a matter of concern because the photographed areas are part of UNESCO Biosphere Reserve area. Although fragments of native vegetation still remain (marmulano-tree and barbusano-tree series), and some resulting from regeneration, much of the vegetated landscape corresponds to exotic plants. Exotic species invasion of recent disturbed gaps anticipates that resilience of native vegetation will not be enough to avoid invasion. This means that beyond the threat that it represents to those remaining areas of natural vegetation it is also a menace to the biological diversity value attributed to these areas. Further exotic control programs must be implemented and follow a careful management orientation (Menezes de Sequeira *et al.* 2007).

As it was emphasised, at various points of this work, many measures aiming to prevent native forest devastation have been legislated since the settlement, and many others aiming afforestation with the view of stopping erosion and to avoid groundwater resources deterioration were also laid down. However, either due to people failing to abide those laws, or because the right measures were not always taken, as consequence of the needs and mentality of that time, led to pristine vegetation destruction and to a massive cover with exotic trees. With regard to the latter Silva & Menezes (1946b, pp.148-149) stated that:

> "In what concerns Madeira Island, we think that native flora should be the one to provide the species for reforestation. Using exotic species, as it has unfortunately advised, it is not only setting aside our natural resources, but also hampering forest improvement, which need no further demonstration. We do not question that species from other parts of the world are able to acclimatise in the mountains and inland valleys. However, we not see the need for using them when Madeiran flora has thirty two trees and tall shrubs better adapted to island grounds. Even if it was not our moral duty to conserve the forest species that still exist, the fact that they are fully a adapted to climate and soil would be sufficient reason to give preference to native species for forestry work."[1]

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[1] Translated from the original writen in Portuguese: "*Pelo que respeita à Madeira, entendemos que é a flora indígena que deve fornecer as espécies precisas para o repovoamento das serras. Preferir para o referido repovoamento as árvores exóticas às indígenas, como infelizmente tem sido aconselhado, é não só pôr de parte, sem motivo justificado, as riquezas florestais com que a natureza dotou a ilha, como também dificultar a realização dum melhoramento cuja utilidade não carece demonstração. Não pomos em dúvida que haja espécies oriundas de outras paragens susceptíveis de aclimatar-se na região montanhosa da Madeira, e em especial nos vales do interior; o que não vemos é necessidade de recorrer tão-somente a tais espécies para reconstruir as nossas florestas, quando temos nada menos de trinta e duas árvores e arbustos*

However, although Silva & Menezes (1946) early reference to the incorrect afforestation with exotics species in Madeira Island, they have been repeatedly introduced (Menezes de Sequeira *et al*., 2007) becoming a problem for nature conservation and also a major problem due to ecological, aesthetic, and economic impacts (Henderson *et al*., 2006). Relevés performed in stands dominated by exotic species, as for instance *of Arundo donax* and *Acacia mearnsii* have shown these assemblages as extremely low species rich communities, almost mono-specific. In addition, most of the other species present are non-native, some of them also highly invasive. Native species found are almost the common ones, and endemic taxa are generally absent (see Chapter 2).

In Madeira Island the exotic plants issue is not restricted to the fact that they prevent native vegetation reclamation and diminish biological diversity. Exotic species as *Cytisus scoparius*, and *Acacia mearnsii* increase risk of fire (Wilgen *et al.* 2001; Figueiredo *et al.* 2008; Figueiredo *et al.* 2010) and reinforce soil erosion, especially in harsh rainfall conditions as also seen in other places (DeBano 2000; Doerr & Thomas 2000; D'Antonio & Meyerson 2002). In Madeira Island this behavior is aggravated by geological and climatic conditions and these exotic plants happen to increase landslides, flash floods and mud flows (Menezes de Sequeira *et al.* 2011ba). Thus, their penetration in the forest inevitably entail serious hazards which, as previously discussed, enable other exotic species establishment or encourage native species as *Pteridium aquilinum* to become noxious, also blocking early successional phases and delaying forest recovery.

However, some naturalised exotic tree species, which were in times gone by the most dominant trees (*Castanea sativa* and *Pinus pinaster*), are currently much less extended than in the past and were, and still are, being replaced by other exotic species more recently introduced (as e.g. *Eucalyptus globulus*, *Acacia mearnsii*, and *Pittosporum undulatum*). Repeat photography has shown that older stands have almost disappeared and only stands seen in latest photographs largely maintain same coverage type. Some of those remaining “oldest stands” are in fact renewal, as shown by dendrochronology of specimens occurring in those stands which age by ring counting prove not being possible to be present in historical landscape (see point 3.3.4). This fact shows that even current coverage corresponds to the same cover type, it resulted from new plantations, or most probably due to renewal.

Although supremacy *Castanea sativa* and *Pinus pinaster* no longer exists they have not entirely disappeared, and continue to spontaneously emerge here and there. One may wonder whether if all naturalised exotic species will remain here forever. On the other hand, other species that were likewise introduced a long time ago did not lose their pervasive nature (as e.g. *Arundo donax* and *Cytisus scoparius*). So, it is not easy to forecast how exotic species is going to behaviour. For instance, *Acacia mearnsii, a*lthough not considered invasive in early 1990s (Andrada 1990)[1], expanded into forsaken agricultural fields, surrounding barren areas and former native scrubland proving to be a vigorous invader, as it is all over the world (Lowe *et al.* 2000). This circumstance supports several statements (Henderson *et al.* 2006; Richardson & Pysek 2006) about the difficulty to predict species invasiveness to take early preventing measures. It is possible to develop models to predict areas of potential conflict between invasive exotic

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adequados ao revestimento dos mais variados terrenos e altitudes da ilha. Quanto mesmo não fosse para nós um dever conservar religiosamente as essências espontâneas que nos restam, bastaria a circunstância de todas elas oferecerem um maior grau de adaptação ao solo e clima da ilha, para se lhes dar preferência nos revestimentos a executar.”

[1] Andrada (1990, p. 69) suggesting exploitation of *Acacia mearnsii* (under *Acacia molissima*) for tannin: “ *Acacia molissima Willd espécie esta que, não sendo de carácter infestante, tem bem mais interesse do que Acacia dealbata Link, infelizmente tão generalizada na freguesia do Monte, onde chega a constiuir uma praga.*” meaning: *Acacia molissima* Willd a species without pervasive nature much more interesting than *Acacia dealbata* Link, unfortunately so widespread at Mount where it is a plague.”

species and native vegetation, but if those exotic species are not in ecological balance projections of suitable area can be highly uncertain. Despite the uncertainty in terms of spatial predictions, a recent research by Figueiredo (2013) showed that it is possible to identify patterns on responses of exotic species, as *Acacia mearnsii* and *Pittosporum undulatum,* to future scenarios in Madeira Island. The projections have shown that suitable areas might expand upwards, increasing potential conflict with native vegetation, especially with *Mayteno umbellatae-Oleetum maderensis* and *Semele androgynae-Apollonietum barbujanae,* also affecting lower margins of *Clethro arboreae-Ocoteetum foetentis*. Moreover, reduction of suitable areas in lower lands will create empty niches giving newcomers an opportunity to establish and therefore increasing exotic coverage (Figueiredo 2013). Predicting plant invasiveness cannot be done with complete accuracy always existing the danger of declaring a plant to be low risk which become later on the worst environmental weed. Eradication it is now considered unattainable for a number of invasive species that are already too widespread, and many other will need huge effort to contain spread and limit further damage. So, not being possible to forecast invasive capacity of exotic species the best way to solve this problem is to restrain the entrance of alien plants to avert new invasions.

Even so it was it was possible native vegetation regeneration, as it was stated in chapters 2 and 4. Spontaneous recovery was more significant in cleared areas where land use allowed to conserve seed bank, trunks and roots that sprout (mainly related to grazing and firewood gathering reduction) and at the same time hampered afforestation with exotic trees, and were historical descriptions have shown that native vegetation still occurred in the neighbouring areas. These facts along with colonising strategies of the native plants (such as *Erica arborea, Erica platycodon* subsp. *maderincola, Euphorbia piscatoria, Globularia salicina, Myrica faya, Myrtus communis*) seem that gave a head start to the native tree-shrub vegetation in relation to the invading phanerophytes. However, despite the recovery that was observed in barren areas the threat of exotic plants encroachment can raise in the future as long as soil conditions became more evolved (Hobbs & Huenneke 1992; Hobbs & Humphries 1995; Henderson *et al.* 2006) or new uncovered areas, with deeper soils, will merge as consequence of frequent landslide events (Baioni, 2011).

Native vegetation recovery in areas formerly occupied by exotic plants was less significant. It was detected by Repeat Photography in areas with edaphic conditions adverse to such exotic species or in situations when the area was covered by an exotic plant able to generate a nurse effect. Although succession followed the model proposed by Capelo *et al*. (2004) it was rather slow. Since *tempus* of most mature phases of *Semele androgynae-Apollonietum barbujanae* (Figures 3.17 and 5.2) were very close to those found for similar forest in neighbour island of La Palma, it is possible to assume that earlier stages, in minor disturbance situation, will last the same. Thus, the fact that it takes longer clearly indicates issues slowing down as lack of propagules, adequate edaphic conditions (Sänger & Jetschke 2004; Temperton & Zirr 2004; Wagner 2004) and recurrent disturbance, mainly fire (White & Jentsch 2004) which often happens in this exotic forest. *Relevés* in very open woods of *Eucalyptus globulus* and dead pines stands (see chapter 2) have shown that recovery happened when they have spots of native vegetation nearby. However, those assemblages in spite of being very similar to native communities, which are supposed to develop, they are characterised by the presence of exotic plants and lack of rare species.

Recovery by native vegetation over former farming lands, as revealed by Repeat photography, occurred in forsaken lands which were farmed during less time, i.e. the ones that started to be cultivated much later and earlier abandoned, and also the ones that were not use to growth perennial crops. As seen in areas formerly covered with exotic species, forsaken agricultural areas that allowed native vegetation recovery were the ones close to safe sites holding native species of those communities. Relevés performed over abandoned agricultural terraces (see chapter 2) also showed that those assemblages were very close to the communities proposed by the vegetation model but contain more exotic species, and less endemic species than communities where propagules came from.

Thereby, passive restoration can be a viable approach, if diaspore sources exist in the neighbourhood and there is no limitation of time[1]. However as it was shown, most of the assemblages are highly invaded by exotic plants and cannot be left unattended. Clearing treatments are widely applied, but their effectiveness are not clearly tested and frequently stimulate secondary invasion of exotic species hindering restoration effort. So, intervention in these areas undergoing reclamation has to be undertaken with great caution and closely monitored (Bradshaw 2000; Sänger & Jetschke 2004). Active restoration by seed sowing and planting of cuttings should be only promoted whenever occur total destruction of natural landscape without possibility of spontaneous recovery of native vegetation or to slowly that little help might be needed. Even though it should be cautious taking into account that environmental conditions may have changed preventing native plants development (D'Antonio & Meyerson 2002; Bradshaw 2004). Restoration projects, in any case, must always use propagules from native plants of neighbourhood areas (Kaye 2001), and to attend to the vegetation model proposed by (Capelo *et al.* 2004).

5.1 Recommendations for restoration projects and conservation policies

Success of Madeira Island native vegetation depends upon strict conservation measures. Conclusions drawn from results of this study support recommendations, some made repeatedly thoughout times, and point to the need to follow them for more effective environmental management. In view of the foregoing some of those recommendations are summarised below:

1) prevent wildfires and disallow prescribed burning, since they will perpetuate exotic forest and hinder native vegetation regeneration, as native plants are not adapted to fire and exotic pyrofilous species are highly favoured;
2) implement policy measures regarding roads and *levadas,* since they act as corridors for the spread of non-native plants and are a main cause of the disturbance regime rescaling;
3) disallow any type of grazing practices in native vegetation areas or where it is the desired outcome, since native plants are not adapted to herbivory;
4) restrain the entrance of new alien plants, since it is difficult to predict their invasive capacity and are the main cause of biological diversity lost;
5) use active restoration only when spontaneous recovery is not a viable option;
6) implement restoration projects meeting the vegetation model proposed by Capelo *et al.* (2004) and using diaspores from nearest populations;
7) promote local studies monitoring invasive exotic species as well as native plants that become noxious before establishing further control and removal activities

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[1] According to Sänger & Jetschke (2004) whenever there is the possibility of spontaneous recovery and the time available for the restoration project it is not less than five to ten years, the best option is the natural succession process.

6 Main conclusions

Landscape change over almost 125 years was higher in last five decades than in preceding years, and more significantly in southern areas than in inland and north coast manly driven by farming abandonment, growth of building and increase of exotic vegetation coverage.

Pristine vegetation was greatly destroyed since early settlement. By the end of the nineteenth century native vegetation was highly devastated and most of the remaining greenery was a secondary forest of stink-laurel forest. Other forest types that should occupy lower lands, as oleester and barbusano-tree forests, and in upper lands, as Juniperus-heaths forest, were almost entirely lost. Antropogenic disturbances as grazing, frequent fires, agriculture, and exotic plants introduction, disrupted natural balance of native flora which evolved in the absence of those pressures. During this time natural disturbance regime (natural landslides) was rescaled which, along with those extrinsic disturbances, lead to forest fragmentation, and to floristical composition and species richness alteration. It also encouraged establishment of exotic species and induced native species as *Pteridium aquilinum* to become noxious, blocking early successional phases and delaying forest recovery.

Recovery by native vegetation in areas were it did not formerly existed happened but it was conditioned by former land use, existence of diaspores sources in close neighbourhood, and duration of disturbance. In places with less hemeroby, as in places currently under protection, it was detected higher recovery rate of lower seral stages. However, most mature stages are heading towards unbalance between recovery and loss, also being very vulnerable to exotic species encroachment. Recovery in areas formerly occupied by exotic plants and agriculture occurred but it was almost negligible. Although vegetation recovery followed successional model proposed by Capelo *et al.* (2004), attesting the model itself, it was very slow due to lack of favourable conditions and due to recurrent disturbances. Probable duration of the seral stages were obtained by growth rates of woody taxa estimated by dendrochronology which also supported the vegetation model. It was found that *Semele androgynae-Apollonietum barbujanae* takes around 105-115 years and *Clethro arboreae-Ocoteetum foetentis* takes around 170 years from the high scrub stage to the state of dynamic equilibrium.

Some of the exotic trees which were the dominant trees in the past (as *Castanea sativa* and *Pinus pinaster*) do not fill the landscape anymore, but are naturalised and have not completely vanished. *Eucalyptus globulus*, the current main tree of the exotic forest showed signs that same thing could happen, since older stands almost disappeared and were replaced by other cover type. Nevertheless, time-factor was not solely responsible for this situation since other species also introduced a long time ago, still are very invasive, as for instance *Arundo donax, Cytisus scoparius* and *Pittosporum undulatum*. *Acacia mearnsii* which was a more recent introduction, it is together with previous ones, a very strong presence in the landscape, and an environmental issue. Like these, many other exotic species have proved to be highly pervasive and responsible for loss of biological diversity, and one of the greatest threat to native vegetation preventing vegetation recovery. Some of them, like *Cytisus scoparius* and *Acacia mearnsii* entail serious hazards by increasing risk of fire and increasing the likelihood of landslides and mud flows, geological phenomena that due to orography/geology and human activity are likely to occur in Madeira Island.

Although some weaknesses were pointed out by some authors, in fact dendrochronology and repeated photography proved to be useful and dynamic tools to be used in historical ecology. It allows gathering information about landscape change, to reconstruct disturbance history, to research about intensity and frequency of disturbance events, and to investigate successional patterns. Combination of this two different approaches with information from historical records and vegetation surveys allows to make inferences that can be used to help conservation policies and ecological restoration decisions.

6.1 Future research perspectives

Several issues have been suggested in each chapter as future work proposals being set out together:

1) To develop further research aiming a better understand of successional pathways and causes of species turnover; i.e. to research on biotic interactions between plants, the role of mycorrhizae in each successional stage; the role of seed rain and seed bank in recolonisation of disturbed sites.

2) In dendrochronological field, future work may be directed to clarify rates of the initial growth of these species; to conduct more detailed studies about the alternation between growth and rest periods (which seem to be not triggered by temperature and water stress); to compare growth rates of species found in different bioclimates, to extend dendrochronological studies to less common native trees; to evaluate crossdating potential and built standard chronologies for each *taxa*.

3) In what concerns historical landscape, the technique and old images inhere employed can be used to explore other approaches. Moreover, the repeated photographs can be shortly repeated allowing to obtain data about short-term dynamics, also important to understand ecological mechanisms, or be repeated in the future to compose true time series.

7 References

Abbott RJ, James JK, Milne RI, Gillies ACM (2003) Plant introductions, hybridization and gene flow. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences,* 358(1434): 1123-1132.

Abdullah MG (Ed.) (2015a) Damião de Góis. Encyclopaedia Britannica. Retrieved 5th Jjune 2015, from http://www.britannica.com/EBchecked/topic/237187/Damiao-de-Gois

Abdullah MG (Ed.) (2015b) Luís de Camões. Portuguese poet. Encyclopaedia Britannica. Retrieved 5th June 2015, from http://www.britannica.com/EBchecked/topic/91028/Luis-de-Camoes

Abdullah MG (Ed.) (2015c) João de Barros. Portuguese historian. Encyclopaedia Britannica. 5th June 2015, from http://www.britannica.com/EBchecked/topic/54159/Joao-de-Barros

Abreu SR, Guerra L, Jesus Td, Vasconcelos L, Araújo MH (2004) *Prestrellos Photographos*. Secretaria Regional do Turismo e Cultura, Funchal.

Ackermann R (1821) *A History of Madeira with a series of twenty seven coloured engravings illustrative of the costumes, manners and occupation of the inhabitants of that island*. R. Ackermann, Strand, London.

Aguiar CFG (2000) *Flora e vegetação da Serra de Nogueira e do Parque Natural de Montesinho* Unpublished Doctoral Thesis, Universidade Técnica de Lisboa, Lisboa, Portugal.

Aigoin D, Devos N, Huttunen S, Ignatov M, Gonzalez-Mancebo J, Vanderpoorten A (2009) And if Engler was not completly wrong? Evidence for multiple evolutionary origins in the moss flora of Macaronesia. *Evolution,* 63(12): 3248-3257.

Alday JG, Cox ES, Pakeman RJ, Harris MPK, Duc MGL, Marrs RH (2013) Overcoming resistance and resilience of an invaded community is necessary for effective restoration: a multi-site bracken control study. *Journal of applied ecology,* 50: 156-167.

Almeida PD (1817) Descrição da ilha da Madeira, in: Carita R (1982) *Paulo Dias de Almeida e a descrição da ilha da Madeira*, Direcção Regional dos Assuntos Culturais (DRAC), Funchal, pp. 49-103.

Amaranthus MP, Trappe JM (1993) Effects of erosion on ecto- and VA-mycorrhizal inoculum potential of soil following forest fire in southwest Oregon *Plant and soil,* 150: 41-49.

Anderson MK (2001) The contribution of ethnobiology to the reconstruction and restoration of historic ecosystems, in: Egan D, Howell EA (Eds.), *Historical ecology handbook : a restorationist's guide to reference ecosystems*, (2 ed.), Society for Ecological Restoration International, Island Press, Washington, D.C, pp. 55-72.

Anderson PL (1914) *Pictoral Landscape-Photography*. (2ed.), Wilfred A. French, Boston.

Andrada EC (1965) *Circunscrição florestal do Funchal: dificuldades, perspectivas actuais e possibilidades*. Doc. Circunscrição Florestal do Funchal (Cx 519/1-2). Arquivo Regional da Madeira, Funchal, Portugal.

Andrada EC (1990) *Repovoamento Florestal no arquipélago da Madeira (1952-1975)*. Direcção Geral das Florestas,. Secretaria de Estado da Agricultura, Ministério da Agricultura, Pescas e Alimentação, Lisboa.

Antrop M (2005) From holistic landscape synthesis to transdiciplinary landscape management, in: Tress B, Tress G, Fry G, Opdam P (Eds.), *From landscape Research to Landscape Planning: Aspects of integration, Education and Application*, Springer, Dordrecht, pp. 27-50.

Araújo H (1990) Fotografia e Fotógrafos Madeirenses, in: CEHA/DRAC/MC/VCCE (Ed.), *Fotografia e fotógrafos insulares. Açores, Canárias e Madeira*, Centro de Estudos da História do Atlântico (Madeira)/ Direcção Regional dos Assuntos Culturais (Açores)/ El Museu Canario/ Vice Consejeria de Cultura y Educación (Canarias), Funchal, pp. 37-52.

Arevalo JR, Delgado JD, Fernandez-Palacios JM (2011) Regeneration of potential laurel forest under a native canopy and an exotic canopy, Tenerife (Canary Islands). *Forest Systems* 20(2): 255-256.

Arévalo JR, Fernández-Palacios JM (1998) Treefall gap characteristics and regeneration in the laurel forest of Tenerife. *Journal of vegetation Science* 9: 297-306.

Arévalo JR, Fernández-Palacios JM (2000) Seed bank analysis of tree species in two stands of the Tenerife laurel forest (Canary Islands. *Forest Ecology and Management,* 130: 177-185.

Arévalo JR, Delgado JD, Fernández-Palacios JM (2007) Variation in fleshy fruit fall composition in an island laurel forest of the Canary Islands. *Acta Oecologica,* 32(2): 152-160.

Arévalo JR, Fernández-Lugo S, Mallado M, Concepción Tdl (2015) Experimental management control of Opuntia dilleniiHaw. and Agave americana L. in Teno Rural Park,Canary Islands. *Plant Species Biology,* 30: 137-146.

Aristotle (2350 BP) On the Soul, translated by J.A. Smith Retrieved 2nd June 2015, Book III, from http://classics.mit.edu/Aristotle/soul.3.iii.html

"Aristotle" (2015) The Biography.com website. Retrieved 3rd June 2015, from http://www.biography.com/people/aristotle-9188415

Asherin AA, Mata SA (2001) Basic Tree-Ring Sample Preparation techniques for aging Aspen*,* Proceedings of the USDA Forest Service RMRS-P-18. pp. 347-351.

Athayde JM (1813) Diario da Visita que o Bispo de Meliapôr, Vigario Apostolico do Funchal, D. Fr. Joaquim de Menezes e Athayde, fez nas Igrejas da Costa de Cima, na Ilha da Madeira, em 1813. *Arquivo de marinha e ultramar: compilação do Inventário Madeira e Porto Santo*, (Vol. 2), Imprensa da Universidade de Coimbra, Coimbra, pp. 333-338.

Austin MP, Smith TM (1989) A new model for the continuum concept. *Vegetatio,* 83: 35-47.

Axelrod DI (1975) Evolution and Biogeography of Madrean-Tethyan Sclerophyll vegetation. *Annals of the Missouri Botanical Garden,* 62(2): 280-334.

Azevedo JS (1950) Rega e arborização das serras*,* Proceedings of the I Conferência da Liga para a Protecção da Natureza, 10-18 Abr 1950, Funchal, Portugal. in: LPN (Ed.), *Publicações da LPN* (IV), LPN e GEFPHM, Lisboa, pp. 100-104.

Azurara GE (1434-1448) Of how the Island of Madeira was peopled, and also the other Islands that are in that part (Beazley CR, Prestage E, Trans.) *The Chronicle of the Discovery and Conquest of Guinea*, (Vol. II), Hakluyt Society and Burt Franklin Publisher, New York, pp. 245-248.

Babrauskas V (2003) *Ignition Handbook*. Society of Fire Protection Engineers, Boston.

Baioni D (2011) Human activity and damaging landslides and floods on Madeira Island. *Natural Hazards and Earth System Sciences,* 11: 3035-3046.

Balée W, Erickson C (2006a) The Perspective of Historical Ecology, in: Balée W, Erickson C (Eds.), *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*, Columbia Univ. Press, New York, pp. 1-16.

Balée W, Erickson C (Eds.) (2006b) *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*. Columbia Univ. Press, New York.

Barkman JJ (1950) On the sessions of the Section Phytogeography, in : Sessions Botanical Congress Proceedings of the VIIth International Botanical Congress, Stockholm. pp. 146-148.

Barkman JJ, Doing H, Segal S (1964) Kritische Bemerkungen und Vorschlage zur quantitativen vegetationsanalyse. *Acta Botanica Neerlandica,* 13: 394-419.

Barrón E, Rivas-Carballo R, Postigo-Mijarra JM, Alcade-Olivares C, Vieira M, Castro L, Pais J, Valle-Hernández M (2010) The Cenozoic vegetation of the Iberian Peninsula: a synthesis. *Review of Paleobotany and Palynology,* 162: 382-402.

Basalla G (1967) The spread of western science. *Science,* 156: 611-622.

Bastian O (2001) Landscape Ecology – towards a unified discipline? *Landscape Ecology,* 16: 757-766.

Beavon M (2007) *Pollination and sispersal of the noxious vine Passiflora mollissima.* Unpublished MSc, University of Canterbury.

Bell G (1997) Ecology and management of Arundo donax, and approaches to riparian habitat restoration in Southern California, in: Brock JH, Wade M, Pysek P, Green D (Eds.), *Plant Invasions: Studies from North America and Europe.*, Blackhuys Publishers, Leiden, pp. 103-113.

Bergeron Y, Denneler B, Charron D, Girardin M-P (2002) Using dendrochronology to reconstruct disturbance and forest dynamics around Lake Duparquet, northwestern Quebec. *Dendrochronologia,* 20(1-2): 175-189.

Bermúdez AM, Fernández-Palacios JM, González-Mancebo JM, Patiño J, Arévalo JR, Otto R, Delgado JD (2007) Floristic and structural recovery of a laurel forest community after clear-cutting: A 60 years chronosequence on La Palma (Canary Islands). *Annals of Forest Science,* 64(1): 109-119.

Bertrand G (1968) Paysage et geographie physique globale. Esquisse méthodologique. *"Revue Geógraphique des Pyrénées et du Sud-Ouest,* 39(3): 249-272.

Bess HA, Haramoto FH (1972) Biological Control of Pamakani, *Eupatorium adenophorum* in Hawaii by Tephritid Gall Fly, *Procecidochares utilis*. 3. Status of the weed, fly and parasites of the fly in 1966-71 versus 1950-571. *Proceedings, Hawaiian Entomological Society,* XXI(2): 165-178.

Betâmio de Almeida A, Oliveira RP (Eds.) (2011) *Estudo de Avaliação do Risco de Aluviões na Ilha da Madeira* (Technical Report). Instituto Superior Técnico, Lisboa, Portugal

Bettencourt LCFA (2007) *A morfologia urbana da cidade do Funchal e os seus espaços públicos estruturantes* Unpublished master Thesis, Universidade Lusófona de Humanidades e Tecnologias.

Bierman P (2010) Clear-Cuting, Reforestation, and the coming of the intersate: Vermont's photographic Record of Landscape use and response, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 106-116.

Bierman PR, Howe J, Stanley-Mann E, Peabody M, Hilke J, Massey CA (2005) Old images record landscape change through time. *The Geological Society of America Today,* 15(4): 4-10.

Billamboz A (2003) Tree rings and wetland occupation in Sothwest Germany between 2000 and 500 BC: Dendroarqueology beyond dating in tribute to F.H. Schweingruber. *Tree-ring Research,* 59(1): 37-49.

Boesser EW (1951) Esboço sobre o endemismo e a colocação fitogeográfica da flora da Madeira. *Boletim Anual da Junta dos Lacticínios da Madeira,* Separata: 3-23.

Boland JM (2006) The importance of layering in the rapid spread of Arundo donax (giant reed). *Madroño,* 53(4): 303-312.

Bollschweiler M, Stoffel M, Schneuwly DM (2007) Dynamics in debris-flow activity on a forested cone- A case study using different dendroecological approaches. *Catena* 72: 67-78.

Bossuyt B, Hermy M (2001) Influence of land use history on seed banks in European temperate forest ecosystems: a review. *Ecography,* 24(2): 225-238.

Botosso PC, Mattos PPd. (2002). Conhecer a idade das árvores: Importância e Aplicação. Colombo, Brasil: EMBRAPA.

Bourassa SC (1991) *The Aesthetics of Landscape*. Belhaven Press, London.

Bowdich TE (1825) *Excursions in Madeira and Porto Santo, during the Autumn of 1823, while on his third voyage to Africa*. George B. Whittaker, London.

Bowman DMJS (2002) Measuring and Imagining: Exploring Centuries of Australian Landscape Change. Preface of the Special 50th anniversary issue. *Australian Journal of Botany,* 50(4): i-iii.

Boyer DE, Webb RH, Turner R (2010) Techniques of matching and archiving repeat photography used in the Desert Laboratory collection, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 12-23.

Braam RR, Weiss EEJ, Burrough PA (1987) Spacial and temporal analysis of mass movement using dendrochronology. *Catena,* 14: 573-584.

Bradshaw A (2000) The use of natural processes in reclamation-advantages and difficulties. *Landscape and Urban Planning,* 51: 89-100.

Bradshaw A (2004) The role of nutrients and the importance of function in the assembly of ecossystems, in: WTemperton V, R RH, Nuttle T, Halle S (Eds.), *Assembly Rules and Restoration Ecology. Bridging the gap between the theory and practice*, International Island Press, Washington, pp. 325-340.

Bramwell D (1972) Endemism in flora of the Canary Island, in: Valentine DH (Ed.), *Taxonomy, Phytogeography and Evolution*, Academic Press, London, New york, pp. 141-159.

Bramwell D, Bramwell Z (1974) *Wild flowers of the Canary Islands*. Cabildo Insular de Tenerife in association with Stanley Thornes Publishers, London.

Bramwell D, Bramwell Z (2001) *Flores Silvestres de las Islas Canarias*. (4ª ed.), Editorial Rueda, Madrid.

Bramwell D, Caujapé-Castells J (Eds.) (2011) *The Biology of the Island Floras*. Cambridge University Press, New York.

Briand CH, Brazer SE, Harter-Dennis JM (2006) Tree Rings and the Aging of Trees: A Controversy in 19th Century America. *Tree-Ring Research,* 62(2): 51-65.

Buch LV (1825) *Physicalische beschreibung der Canarischen Inseln*. Cedruckt in der Drckerei der koeniglichen Akademie der Wissenschaften, Berlin.

Bullock SH, Turner RM (2010) Plant Populations Fluxes in the Sonoran Desert shown by Repeat Photography, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 119-131.

Burton C, Michell JY, Cutter SL (2011) Evaluatind post-Katrina recovery in Mississipi using repeat photography. *Disasters,* 35(3): 488-509.

Bussmann RW, Wilcke W, Richter M (2008) Landslides as Important Disturbance Regimes – Causes and Regeneration, in: Beck E (Ed.), *Gradients in a Tropical Mountain Ecosystem of Ecuador*, Springer-Verlag, Berlin Heidelberg pp. 319-330.

Butler DR, DeChano LM (2001) Environmental change in Glacier National Park, Montana: an assessment through repeat photography from fire lookouts. *Physical Geography. ,* 22: 291-304. .

Büttner N (2006) *Landscape Painting. A History*. Abbeville Publishing Group, New York.

Byers A (1987) An Assessment of Landscape Change in the Khumbu Region of Nepal Using Repeat Photography. *Mountain Research and Development,* 7(1): 77-81.

Cadamosto L (1445-1455) Navegação Primeira de Luiz de Cadamosto *Collecção de Noticias para a História e Geografia das Nações Ultramarinas que vivem nos domínios Portuguezes, ou lhe são visinhas*, Portuguese translation published in 1812 by Academia Real das Sciencias, Lisboa, pp. 5-58.

Caetano M, Nunes V, Nunes A (2009) *CORINE Land Cover 2006 for Continental Portugal* (Relatório Técnico). Instituto Geográfico Português, Lisboa.

Cairns J, Heckman JR (1996) Restoration Ecology: The State of an Emerging Field. *Annu. Rev. Energy Environ,* 21: 167-189.

Caldwell BA (2006) Effects of invasive scotch broom on soil properties in a Pacific coastal prairie soil. *Applied Soil Ecology,* 32: 149-152.

Camacho JH (1920) *Notas para o estudo da rearborisação da ilha da Madeira*. Imprensa Libanio da Silva, Lisboa.

Camões Ld (1572) *Os Lusiadas*. Casa de Antonio Gonçalvez Impressor, com Privilegio Real e licença da Sancta Inquisição e do Ordinario, Lisboa.

Campelo F, Nabais C, Freitas H, Gutiérrez E (2006) Climatic significance of tree-ring width and intr-annual density fluctuations in *Pinus pinea* from a dry Mediterranean area in Portugal. *Ann. For. Sci,,* 64: 229-238.

Campos ÉPd, Vieira MF, Silva AFd, Martins SV, Carmo FMdS, Moura VM, Ribeiro ASdS (2009) Chuva de sementes em Floresta Estacional Semidecidual em Viçosa MC Brasil. *Acta Botanica Brasilica* 23(2): 451-458.

Capelo J, Costa JC, Lousã M, Fontinha S, Jardim R, Menezes de Sequeira M, Rivas-Martinez S (1999) Vegetação da Madeira (Portugal): I-Aproximação à tipologia fitossociológica. *Silvalusitana,* 7(2): 257-282.

Capelo J (2003) *Conceitos e métodos da Fitossociologia: Formulação Contemporânea e Métodos Numéricos de Análise da Vegetação*. Estação Florestal Nacional, Sociedade Portuguesa de Ciências Florestais, Lisboa.

Capelo J, Costa JC, Jardim R, Menezes de Sequeira M, Aguiar C, Lousã M (2003a) The vegetation of Madeira II: woody caulirosetted communities of evergreen forest clearings; Euphorbion melliferae all. nova. Notas do Herbário da Estação Florestal Nacional (LISFA): fasc. XVII. *Silva Lusitana,* 11(1): 111-113.

Capelo J, Costa JC, Jardim R, Menezes de Sequeira M, Rivas-Martinez S (2003b) The vegetation of Madeira VIII:Advances on the phytosociological survey of non-nitrophyllous vegetation of Madeira Archipelago. Notas do Herbário da Estação Florestal Nacional (LISFA): fasc. XVIII. *Silva Lusitana,* 11(2): 253-256.

Capelo J, Costa JC, Lousã M, Fontinha S, Jardim R, Menezes de Sequeira M, Rivas-Martinez S (2003c) The vegetation of Madeira: III- Diplazio caudati-Perseetum indici ass.nova and Rhamno gladulosi-Sambucetum lanceolati ass. nova: two new hygrophillic forest associations from Madeira Island. Notas do Herbário da Estação Florestal Nacional (LISFA). Fasc. XVII. *Silva Lusitana,* 1(11): 113-116.

Capelo J, Menezes de Sequeira M, Jardim R, Costa JC (2004) Guia da Excursão Geobotânica dos V Encontros ALFA 2004 à ilha da Madeira, in: Capelo J. A (Eds), A paisagem vegetal da Ilha da Madeira. *Quercetea,* 6: 5-46.

Capelo J, Menezes de Sequeira M, Jardim R, Mesquita S, Costa JC (2005) The vegetation of Madeira Island (Portugal). A brief overview and excursion guide. *Quercetea,* 7: 95-122.

Capelo J, Menezes de Sequeira M, Jardim R, Mesquita S (2007) Biologia e ecologia das florestas das ilhas (Madeira), in: Silva JS (Ed.), *Árvores e Florestas de Portugal*, (Vol. 6), Público, Comunicação Social SA e Fundação Luso-Americana para o Desenvolvimento, Lisboa, pp. 81-134.

Carine MA, Russell SJ, Santos-Guerra A, Francisco-Ortega J (2004) Relationships of the Macaronesian and Mediterranean floras: molecular evidence for multiple colonizations into Macaronesia and back-colonization of the continent in Convolvulus (Convolvulaceae). *Am. J. Bot.,* 91(7): 1070-1085.

Carita R (1982) *Paulo Dias de Almeida e a descrição da Ilha da Madeira*. DRAC, Funchal.

"Carl Linnaeus". Encyclopedia of World Biography (2004) Encyclopedia.com. Retrieved 30 Mar. 2015, from http://www.encyclopedia.com

Carlquist PDS (2015) Biography and publications. Retrieved 6th june 2015, from http://www.sherwincarlquist.com/biography-publications.html

Carlquist S (1962) A theory of Paedomorphosis in Dicotyledonous Woods. *Phytomorphology,* 12(1): 30-45.

Carlquist S (1966) Wood anatomy of Compositae: A Summary, with comments on factors controlling wood evolution. *Aliso,* 6(2): 25-44.

Carlquist S (1970a) Wood anatomy of Echium (Boraginaceae). *Aliso,* 7(2): 183-199.

Carlquist S (1970b) Wood anatomy of insular species of Plantago and the problem of raylessness. *Bulletin of the Torrey Botanical Club,* 97(6): 353-361.

Carlquist S (1970c) Wood anatomy of Hawaiian, Macaronesian, and other species of Euphorbia. *Botanical Journal of the Linnean Society,* 63: 181-193.

Carlquist S (1974) *Island Biology*. Columbia University Press, New York and London.

Carlquist S (1983) Intercontinental Dispersal. *Sonderbd. naturwiss. Ver. Hamburg,* 7: 37-47.

Carlquist S (2002) Wood and Bark anatomy of Myricaceae: relatioships, generic definitions, and ecological interpretations. *Aliso,* 21(1): 7-29.

Carrión JS, Fernández S (2009) The survival of the "natural potential vegetation"concept (or the power of tradition). *Journal of Biogeography,* 36: 2202-2203.

Carstensen R, Hocker K, Shephard M, Wittwer D (2010) Repeat Photography Methods. Retrieved December 28, 2013, from http://www.fs.fed.us/r10/spf/fhp/repeat_photo_se/techniques.php

Casteleiro JM (Ed.) (2001) *Dicionário da Língua Portuguesa Contemporânea, da Academia das Ciências* (Vol. 2). Editorial Verbo, Lisboa.

Caujapé-Castells J (2011) Jesters, red queens, boomerangs and surfers: a molecular outlook on the diversity of the Canarian endemic flora, in: Bramwell D, Caujapé-Castells J (Eds.), *The Biology of the Island Floras*, Cambridge University Press, New York, pp. 284-317.

Cayouette J (2011) Pierre Dansereau (1911-2011). *CBA/ABC Bulletin,* 45(1): 20-22.

CFF (1952-1965) *Plantas e Sementes usadas em arborização*. Doc. Circunscrição Florestal do Funchal (D-4-1-1-1). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1952-1973) *Planos e Relatórios de Trabalhos* Doc. Circunscrição Florestal do Funchal (Cx 519/1-2; Cx 520/1-2). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1952-1980) *Licenças para fabrico de carvão*. Doc. Circunscrição Florestal do Funchal (Cx 524/1 to 5). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1952-1981) *Sementes cedidas a particulares*. Doc. Circunscrição Florestal do Funchal (Cx 518/10). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1953-1965) *Plantas e sementes usadas em arborização*. Doc. Circunscrição Florestal do Funchal (Cx 357/2). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1953-1968) *Plantas e Sementes usadas em arborização*. Doc. Circunscrição Florestal do Funchal (Cxs 357/1,2; 358/2-10; D-4-1-1-1). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1953-1969a) *Licenças e pedidos de autorização de cultivo nos perímetros florestais*. Doc. Circunscrição Florestal do Funchal (Cx 519/2). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1953-1969b) *Elementos estatísticos relativos ao povoamento florestal*. Doc. Circunscrição florestal do Funchal (Cx 520/1). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1954-1972) *Planos e Relatórios de actividades relativas a arborizações* Doc. Circunscrição Florestal do Funchal (Cx 403/2). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1962-1964) *Planos e Relatórios de actividades relativas a arborizações nos perímetros florestais*. Doc. Circunscrição Florestal do Funchal (Cx 523). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1965-1968) *Plantas e sementes usadas em arborização*. Doc. Circunscrição Florestal do Funchal (Cx 358/2). Arquivo Regional da Madeira, Funchal, Portugal.

CFF (1967) *Licenças para colheita de feiteira*. Doc. Circunscrição Florestal do Funchal (Cx 524/9). Arquivo Regional da Madeira, Funchal, Portugal.

"Charles Babbage". Complete Dictionary of Scientific Biography (2008) Encyclopedia.com. Retrieved March 30, 2015 from http://www.encyclopedia.com/doc/1G2-2830905456.html

Cherubini P, Gartner ML, Tognetti R, Bräker OU, Schoch W, Innes JL (2003) Identification, measurement and interpretation of tree rings in woody species from mediterranean climates. *Biological revisions,* 78: 119-148.

Chiarucci A, Araújo MB, Decocq G, Beierkuhnlein C, Fernández-Palacios JM (2010) The concept of potential natural vegetation: an epitaph? *Journal of vegetation science,* 21: 1172-1178.

Chisholm H. (Ed.) (1911) Entry for 'Gonzalo Oviedo Y Valdes'. Encyclopedia Britanica.

Chisholm H (Ed.). (1911) Entry for 'Thomas Eduard Bowdich'. Encyclopædia Britannica (11th ed.).

Chytrý M (1998) Potential replacement vegetation: an approach to vegetation mapping of cultural landscapes. *Applied Vegetation Science,* 1: 177-188.

Clark K (1949) *Landscape into art*. John Murray (Publishers) Ltd, London.

Clark P, Hardegree S (2005) Quantifying vegetation change by Point Sampling Landscape Photography Time Series. *Rangeland Ecology & Management,* 58: 588-597.

Clark SL, Hallgren SW (2004) Age estimation of *Quercus marilandica* and *Quercus stellata*: applications for interpreting stand dynamics. *Canadian Journal of Forest Research* 34(6): 1353-1358.

Clark SL, Brosi SL, Schlarbaum SE, Grissino-Mayer HD (2008) Dendrochronology of two butternut *(Juglans cinerea*) populations in the southeastern United States. *Forest Ecology and Management* 255: 1772–1780.

Clement D (1999) *General Guidelines for Identifying and Evaluating Historic Landscapes* (Report). California Department of Transportation, Sacramento, California, USA.

Clements FE (1905) *Research Methods in Ecology*. The University Publishing Company, Lincoln.

Cockerell TDA (1928) Aspects of the Madeira Flora. *Botanical Gazette,* 85(1): 66-73.

Coelho JdV (2011) *Dendrocronologia: método matemático para determinação da idade das árvores.* Universidade Federal de Mato Grosso, Cuiabá.

Coffman GC (2007) *Factors Influencing Invasion of Giant Reed (Arundo donax) in Riparian Ecosystems of Mediterranean-type Climate Regions.* Unpublished Doctor of Philosophy in Environmental Health Sciences, University of California, Los Angeles.

Conceição A, Menezes de Sequeira M (2007) A Madeira e os Naturalistas do século XIX. in: Cap. III A chegada dos portugueses às ilhas - o antes e o depois (Madeira), in: Silva JS (Ed.), *Árvores e Florestas de Portugal*, Público, Comunicação Social SA e Fundação Luso-Americana para o Desenvolvimento, Lisboa, pp. 190-191.

Copenheaver CA, Pokorski EA, Currie JE, Abrams MD (2006) Causation of false ring formation in *Pinus banksiana*: A comparison of age, canopy class, climate and growth rate. *Forest Ecology and Management* 236: 348-355.

Cordeiro A (1717) História Insulana Lusitana. Livro Terceiro das Ilhas de Porto Santo, e Madeira. In: *Historia Insulana das Ilhas a Portugal Sugeitas no oceano occidental*, (Vol. I), Typ. do Panorama com Licença da Ordem da Companhia de Jesus, do Santo officio, do Ordinario e do Paço, Lisboa, pp. 89-132.

Corrêa MJ (1926) *Historia da descoberta das ilhas*. Imprensa da Universidade, Coimbra.

Corrêa MJ (1927) *A Ilha da Madeira. Impressões e notas archeológicas, ruraes, artísticas e sociais*. Imprensa da Universidade, Coimbra.

Cosgrove D (1984) *Social Formation and Symbolic Landscape*. Barnes and Nobles Books, New Jersey.

Costa JC, Aguiar C, Capelo JH, Lousã M, Neto C (1998) Biogeografia de Portugal Continental.

Costa JC, Capelo J, Jardim R, Menezes de Sequeira M, Espírito Santo D, Lousã M, Fontinha S, Aguiar C, Rivas-Martínez S (2004) Catálogo sintaxonómico e florístico das comunidades vegetais da Madeira e Porto Santo. *Quercetea,* 6: 61-185.

Crimmins MA, Crimmins TM (2008) Monitoring Plant Phenology Using Digital Repeat Photography. *Environmental Management,* 41: 949-958.

Crumley CL (1998) Foreword, in: Balée W (Ed.), *Advances in Historical Ecology*, Columbia University Press, New York, pp. ix-xiv.

Curtis RO (1967) Height-Diameter and Height-Diameter-Age Equations For Second-Growth Douglas-Fir. *Forest Science,* 13(365-375).

D'Antonio C, Meyerson LA (2002) Exotic Plant Species as Problems and Solutions in Ecological Restoration: A Synthesis. *Restoration Ecology,* 10(4): 703-713.

D'Cruz IA (1991) Garcia da Orta in Goa:pioneering tropical medicine. *BMJ,* 303: 1593-1594.

Dansereau P (1961) Études Macaronésiennes I. Géographie des Cryptogames vasculaires. *Agronomia lusitana,* 23(3): 151-181.

Dansereau P (1966) Études macaronésiennes III. La zonation altitudinale. *Naturalistee Canadien,* 93(1): 779-795.

Darwin C (1859) *The Origin of Species or The Preservation of Favoured Races in the Struggle for Life*. (5th ed.), John Murray, London.

Davis OK (2001) Palynology: an important tool for discovering historic ecosystems, in: Egan D, Howell EA (Eds.), *Historical ecology handbook : a restorationist's guide to reference ecosystems* (2 ed.), Society for Ecological Restoration International, Island PressIsland Press, Washington, D.C, pp. 229-255.

De França I (1854) *Journal of a visit to Madeira and Portugal*. (1969 *fac-simile* ed.), Junta Geral do Distrito Autónomo do Funchal, Funchal.

DeBano LF (2000) The role of fire and soil heating on water repellency in wildland environments: a review. *Journal of Hydrology,* 231-232: 195-206.

Debussche M, Lepart J, Dervieux A (1999) Mediterranean landscape changes: evidence from old postcards. *Global Ecology and Biogeography,* 8: 3-15.

DeRose RJ, Gardner RS (2010) Tecnique to improve visualization of elusive tree.ring boundaries in aspen (Populus tremuloides). *Tree-ring Research,* 66(1): 75-78.

Dionísio JA (1950) Valor medicinal da *Myrica faya* das nossa matas*,* Proceedings of the I Conferência da Liga para a Protecção da Natureza, Funchal, Portugal. in: LPN (Ed.), *Publicações da LPN* (IV), LPN e GEFPHM, Lisboa, pp. 115-118.

Doerr SH, Thomas AD (2000) The role of soil moisture in controlling water repellency: new evidence from forest soils in Portugal. *Journal of Hydrology,* 231-232: 134-147.

Domingues MA, Barreto DO, Castro NP, Figueira PG (2008) *Árvores monumentais e emblemáticas da Madeira*. Direcção Regional de Florestas, SRARN, Funchal.

Downey PO (2000) Broom (Cytisus scoparius (L.) Link) and fire: management implications. *Plant Protection Quarterly,* 15(4): 178-183.

Duc MGL, Mitchell RJ, Goddardt D, Patersons S, Pakeman RJ (2000) The Ecology of Bracken: Its Role in Succession and Implications for Control. *Annals of Botany,* 85(Supplement B): 3-15.

Dukes JS, Mooney HA (2004) Disruption of ecosystem processes in western North America by invasive species. *Revista Chilena de Historia Natural,* 77: 411-437.

Dutoit T, Buisson E, Roche P, Alard D (2003) Land use history and botanical changes in the calcareous hillsides of Upper_Normandy (north-western France): new implications for their conservation management. *Biological Conservation,* 115: 1-19.

Dwyer JP, Cutter BE, Wetteroff JJ (1995) A dendrochronological study of black and scarlet oak decline in the Missouri Ozarks. *Forest Ecology and management* 75: 69-75.

Eastman JR (2001) *Idrisi 32 release2. Guide to GIS and Image Processing*. (Vol. 1), Graduate School of Geography, Clark University, Worcester.

Edmonds M (2001) The pleasures and pitfalls of written records, in: Egan D, Howell EA (Eds.), *The Historical Ecology Handbook: A Restoration Guide To Reference Ecossystems*, (2 ed.), Society for Ecological Restoration International. Island Press, Washington, pp. 73-93.

Egan D, Howell EA (Eds.) (2001) *The Historical Ecology Handbook: A Restoration Guide To Reference Ecossystems*, (2 ed.). Society for Ecological Restoration International. Island Press, Washington, D.C.

Elliot GP, Baker WL (2004) Quaking aspen (Populus tremuloides Michx) at treeline: a century of change in the Juan Mountains, colorado, USA. *Journal of Biogeography,* 31: 733-745.

Fairchild D (1907) Madeira, on the way to Italy. *The National Geography Magazine,* XVIII(12): 751-771.

Farag-Miller M, Miller K, Kirkpatrick JB (2013) Determining the accuracy of historical landscape paintings. *Geographical Research,* 51(1): 49-58.

Fattorini M, Halle S (2004) The dynamic environmental filter model: how do filters effects change in assembly communities after distrurbance?, in: Temperton VM, Hobbs R, Nuttle T, Halle S (Eds.), *Assembly Rules and restoration ecology. Briging the gap between theory and practice*, Society for Ecological Restoration. International Island Press, Washington, pp. 96-114.

Fernandes P, Botelho H, Rego F (2005) A Piroecologia do Pinheiro Bravo. *Silva Lusitana,* 13(2): 233-248.

Fernández-Palacios JM (2009) Relictualismo en islas oceánicas. El caso de la laurisilva macaronésica, in: Real R, Márquez AL (Eds.), *Biogeografia: Scientia Biodiversitatis*, Universidadd de Málaga, Málaga, pp. 13-24.

Fernández-Palacios JM (2011) The islands of Macaronesia, in: Serrano ARM, Borges PAV, Boieiro M, Oromí P (Eds.), *Terrestrial arthropods of Macaronesia. Biodiversity, ecology and evolution.*, Sociedade Portuguesa de Entomología, Lisboa, pp. 1-30.

Fernández-Palacios JM, de Nascimento L, Otto R, Delgado JD, García-del-Rey E, Arévalo JR, Whittaker RJ (2011) A reconstruction of Palaeo-Macaronesia, with particular reference to the long-term biogeography of the Atlantic island laurel forests. *Journal of Biogeography,* 38(2): 226-246.

Ferreira-Fedele L, Filho MT, Botosso PC, Giannotti E (2004) Periodicidade do crescimento de Esenbeckia leiocarpa (guarantã) em duas áreas da região Sudeste do Estado de São Paulo. *Scentia Florestalis,* 65: 141-149.

Ferreira AJD, Coelho COA, Walsh RPD, Shakesby RA, Ceballos A, Doerr SH (2000) Hydrological implications of soil water-repellency in Eucalyptus globulus forests, north-central Portugal. *Journal of Hydrology,* 231-232: 165-177.

Figueiredo A, Pupo-Correia A, Menezes de Sequeira M (2008) The potential contribution of Cytisus sp. to changes on fire regime under future scenarios at Madeira Island. Paper presented at the *VII Encontro ALFA "Fitossociologia aplicada ao ordenamento e gestão do território"*, 24-27 de Julho de 2008, Coimbra.

Figueiredo A, Menezes de Sequeira M (2010) Posição serial dos urzais-faiais nas séries de vegetação da Ilha da Madeira. Paper presented at the *VIII Encontro Internacional da Associação Lusitana de Fitossociologia (ALFA)*, 13-16 september, Fundação Calouste Gulbenkian, Lisboa, Portugal

Figueiredo A, Pupo-Correia A, Campar Almeida A, Menezes de Sequeira M (2010) Current and potencial distribution for Acácia Mill species at Madeira Island and implications to diversity. Paper presented at the *International Symposium FloraMac2010*, 23-25 September 2010, University of the Azores, Ponta Delgada.

Figueiredo A (2013) *Assessing impacts from future climatic scenarios on the distribution of flora and vegetation at Madeira Island.* Doctoral thesis presented to Universidade de Coimbra, Portugal.

Fogerty JE (2001) Oral history: a guide to its creation and use in: Egan D, Howell EA (Eds.), *Historical ecology handbook : a restorationist's guide to reference ecosystems*, (2 ed.), Society for Ecological Restoration International, Island PressIsland Press, Washington, D.C, pp. 101-120.

Fonseca L, Lopes A, Cardoso J, Pestana M, Abreu F, Nunes N, Mota M, Abrantes I The pinewood nematode, Bursaphelenchus xylophilus, in Madeira Island. Abstract book, Proceedings of the 30th International Symposium of European Society of Nematologists, Vienna. pp. 176.

Formagio A, Masetto T, Vieira M, Z´rate N, Costa W, Trevizan L, Sarragiotto M Allelopathy potential of Tropaeolum majus L. on picão-preto seeds germination and initial seedling growth. *Ciencia Rural- Online,* CR5342: 1-7.

Forman RTT, Godron M (1981) Patches and Structural Components For a Landscape Ecology. *Bioscience,* 31(10): 733-740.

Forster G (1777) *A Voyage Round The World, In His Britannic Majesty's Sloop, Resolution, commanded by Capt. James Cook, during the Years 1772, 3, 4, and 5.* (Vol. Book I), London.

Foucault B (1999) Notes phytosociologiques sur la végétation observée lors du voyage à Madère de la Sociétè botanique de France. *Journal Botanique de la Société botanique de France,* 11: 21-28.

Foxcroft LC, Richardson DM, Wilson JRU (2008) Ornamental Plants as Invasive Aliens: Problems and Solutions in Kruger National Park, South Africa. *Environmental Management,* 41: 32-51.

Foxcroft LC, Pyšek P, Richardson DM, Editors PG (Eds.) (2013) *Plant invasions in protected areas. Patterns, problems and challenges*. Springer Dordrecht

Frutuoso G (1589) *Saudades da Terra*. Reprint edition (1968) by Rodrigues JBO (Ed), Instituto Cultural de Ponta Delagada, Ponta Delgada.

Fuller D (1932) The Plant community of the Earth: Review of Pflanzengesellschaften der Erde by Eduard Rübel (1930). *Ecology,* 13(1): 88-91.

Galopim-de-Carvalho AM, Brandão JM (1991) *Geologia do arquipélago da Madeira*. Museu Nacional de História Natural Lisboa.

Garcia MG (2000) *Introduction to 2th edition of "Madeira: illustrated by Andrew Pickens: with a description of the island*. Edições de Arte Lda, Lisboa.

Gardener DE, Hodges CS (1995) Pathogens from the Azores, Madeira, and Canary Islands as biocontrol agents of *Myrica faya* (Myricaceae) in Hawaii*,* Proceedings of the 1st Symposium of "Fauna & Flora of the Atlantic Islands", Funchal, Portugal. *Boletim Municipal do Funchal* (Sup. nº 4-A), Câmara Municipal do Funchal, Funchal, pp. 319-323.

Garraty J, Jackson K (1973) Frederic Edward Clements in: Garraty JA (Ed.), *Dictionary of American Biography*, (Vol. Supplement 3), American Council of Learned Societies. Scribner, New York, pp. 1941-1945.

Géhu J-M, Rivas-Martinez S (1981) Notions fondamentales de phytosociologie*,* Proceedings of the Berichte Internationalen Symposien der Internationalen Vereinigung für Vegetationskunde, Vaduz, Liechtenstein. in: Dierschke H (Ed.), J. Cramer, Germany, pp. 5-33.

Geldmacher J, Hoernle K, Bogaard Pvd, Duggen S, Werner R (2005) New 40Ar/ 39Ar age and geochemical data from seamounts in the Canary and Madeira volcanic provinces: Support for the mantle plume hypothesis. *Earth and Planetary Science Letters,* 237 85– 101

geographie-studieren.de (2015) Biographie von Carl Troll. Retrieved 15th April 2015, from http://geographie-studieren.de/beruehmte-geographen/carl-troll

Giovanzana TH (1999) On a Grand Scale: Landscape Photography. *(detail),* 6(2): 16-20.

Gleadow R, Walke J Realising predictions about *Pittosporum undulatum,* Proceedings of the Fifth Victorian Weed Conference-Invasive plants and animals, contrasts and connections 13-15 May 2014, Victoria. pp. 20-26.

Góis FF (1977) *Aspectos económico-sociais do meio rural madeirense-Coletânia de escritos* Câmara Municipal de São Vicente, Funchal.

Gomes AMA (1957) *Medição dos arvoredos*. A Terra e o Homem, Livraria Sá da Costa, Lisboa.

Gonçalves ÂB, Nunes RS (1990) *Ilhas de Zargo (Adenda)*. Câmara Municipal do Funchal, Funchal.

Gonçalves GV (2008) *Dendrocronologia no Alto de S. Bento, em Évora: Curva de calibração para datações no âmbito da arqueologia.* Universidade de Évora, Évora.

Goodland T, Healey JR (1997) *The effect of Pittosporum undulatum on the native vegetation of the Blue Mountains of Jamaica*. U.K. Overseas Development Administration and the U.K. Department of the Environment Darwin Initiative programme, Bangor.

Grabham M (1934) *Plants seen in Madeira. A handbook of botanical information for visistors and intending residents*. London.

Grabham MC (1926) *The Garden interests of Madeira*. William Clowes & Sons, London.

Grau HR, Easdale TA, Paolini L (2003) Subtropical dendroecology- dating disturbances and forest dynamics in northwester Argentina montane ecosystems. *Forest Ecology and Management,* 177: 131-143.

Graves AB (2004) Pre-Medieval Landscapes in Medieval Court Romance. *Assemblage,* (8), 1-17. Retrieved from http://www.assemblage.group.shef.ac.uk/issue8/graves.html

Gray DH (1970) Effects of forest clear-cutting on the stability of natural slopes. *Bulletin of the Association of Engineering Geologists* 7: 45-66.

Grissino-Mayer HD (2003) A Manual and Tutorial for the Proper use of an Increment Borer. *Tre-Ring Research,* 59(2): 63-69.

Gruell G (2010) Foreword, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Applications in the Natural Sciences*, Island Press, Washington, pp. xiii-xviii.

Gutsell SL, Johson EA (2002) Accurately ageing trees and examining their height-growth rates: implications for interpreting forest dynamics. *Journal of Ecology,* 90: 153-166.

Haber W (1980) Nachrufe. *Ber. Bayer. Bot. Ges.,* 51: 145-148

Hall F (2001) *Ground-based photographic monitoring, General Technical Report PNW-GTR-503*. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland.

Haller BJ (2007) *Landscape description in Homer's Odissey* Unpublished Doctoral Dissertation, University of Pittsburg, United States of America.

Hanks TC, J LB, Webb R (2010) Virtual Repeat Photography, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington,

Hannan C, Herman JL (Eds.) (2008-2009) *Connecticut Biographical Dictionary*. State History Publications, Hamburg.

Hansen A (1968) Floristiche Beobachtungen auf der Inseln Madeira. *Bocagiana,* 15: 1-11.

Hansen A (1971) Contributions to the Flora of Madeira. *Bocagiana,* 27: 1-14.

Harcourt EV (1851) *A sketch of Madeira*. Jonh Murray, London.

Hart RH, Laycock WA (1996) [Repeat phography on range and forest lands in the Western United States]. *Journal of Range Management,* 49: 60-67.

Hartshorne R (1939) *The Nature of Geography*. The Science Press Company, Lancaster.

Hastings JR, Turner RM (1965) *The changing mile*. University of Arizona Press, Tucson.

Heer O (1857) Ueber die fossilen Pflanzen von St.Jorge in Madeira. *Neue Denkschriften der allgemeinen Schweizerischen Gesellschaft für die gesamten Naturwissenschaften,* v. Band IV: 1-40.

Helama S, Lindholm M, Timonen M, Eronen M (2004) Detection of climate signal in dendrochronological data analysis: a comparison of tree-ring standardization methods. *Theoretical and Applied Climatology,* 79(3): 239-254.

Henderson S, Dawson TP, Whittaker RJ (2006) Progress in invasive plants research. *Progress in Physical Geography,* 30(1): 25-46.

Hendrick LE, Copenheaver CA (2009a) Using Repeat Landscape Photography to Assess Vegetation Change in Rural Communities of the Southern Appalachian Mountains in Virginia, USA. *Mountain Research and Development,* 29(1): 21-29.

Hendrick LE, Copenheaver CA (2009b) Using Repeat Landscape Photography to Assess Vegetation Changes in Rural Communities of the Southern Appalachian Mountains in Virginia, USA. *Mountain Research and Development* 29(1): 21-29.

Hengesch G (1985) Josef Schmithüsen 1909–1984, in: forum für Politik, Gesellschaft und Kultur. *Ausgabe,* 77(42-44).

Herrera AM, Dudley TL (2003) Reduction of riparian arthropod abundance and diversity as a consequence of giant reed (Arundo donax) invasion. *Biological Invasions,* 5(3): 167-177.

Higgs E (2003) *Nature by design: people, natural process, and ecological design*. Massachusetts Institute of Technology, The MIT Press, Cambridge, Massachusetts.

Hill RL, Gourlay AH, Fowler SV (2011) The biological control program against gorse in New Zealand*,* Proceedings of the X International Symposium on Biological Control of Weeds, 4-14 July 1999, Montana State University, Montana.

Hobbs RJ, Huenneke LF (1992) Disturbance, Diversity, and Invasion: Implications for Conservation. *Conservation Biology,* 6(3): 324-337.

Hobbs RJ, Humphries SE (1995) An Integrate Aproach to the Ecology and management of Plant Invasions. *Conservation Biology,* 9(4): 761-770.

Hobbs RJ, Norton DA (2004) Ecological filters, Thresholds, and Gradients in Resistante to Ecosystem Reassembly, in: Temperton VM, Hobbs RJ, Nuttle T, Halle S (Eds.), *Assembly Rules and Restoration Ecology: Bridging the Gap Between Theory and Pratice*, Island Press, Washington, pp. 72-95.

Hoffman MT, Rohde RF, Duncan J, Kaleme P (2010) Repeat Photography, Climate Change and Long Term Population Dynamics of Tree Aloes in Southern Africa, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 134-142.

Hoffman MT, Toold SW (2010) Using Fixed-point Photography, Field Surveys, and GIS to Monitor Environmental Change: an example from Riemvasmaak, South africa, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 46-56.

Holmes RL (1983) Computer-assisted quality in tree-ring dating and Measurement. *Tree-ring Bulletin,* 43: 69-78.

Honrado J, Gonçalves J, Lomba A, Vicente J (2012) Ecologia da paisagem e biodiversidade: da investigação à gestão e conservação. *Ecologi@* 5: 36-51.

Howe N (2011) Landscape versus Region – Part I, in: Agnew J, Duncan JS (Eds.), *Human Geography*, Blackwell Publishing Ltd, Chichester, pp. 114-129.

Howell J (2003) Pittosporum undulatum as a case study for native species that change range – how to avoid inappropriate responses? *Cunninghamia,* 8(1): 153-155.

Hunter ML, Jacobson GL, Webb T (1988) Paleoecology and the Coarse-Filter Approach to Maintaining Biological Diversity. *Conservation Biology,* 2(4): 375-385.

Ingegnoli V (2002) *Landscape Ecology: A Widening Foundation*. Spriger, Berlin.

Ismail BS, Tan PW, Chuah TS (2015) Assessment of the Potential Allelopathic Effects of Pennisetum purpureum Schumach. on the Germination and Growth of Eleusine indica (L.) Gaertn. *Sains Malaysiana,* 44(2): 269-274.

Jackson JB (1984) *Discovering Vernacular Landscape*. Yale University Press, New Haven & London.

Jardim AF (1914) *Madeira, the pearl of the Atlantic. The modern Eden, an Ideal Winter Resort*. The Madeira Commercial Bureau, London.

Jardim R, Francisco D (2005) *Flores da Ilha da Madeira*. Centralivros, Lisboa.

Jardim R, Menezes de Sequeira M, Capelo J (2007) Espécies florestais das ilhas (Madeira), in: Silva JS (Ed.), *Árvores e Florestas de Portugal*, (Vol. 6), Público, Comunicação Social SA e Fundação Luso-Americana para o Desenvolvimento, Lisboa, pp. 255-295.

Jardim R, Menezes de Sequeira M (2008) As Plantas Vasculares (Pteridophyta e Spermatophyta) dos Arquipélagos da Madeira e das Selvagens, in: Borges PAV, Abreu C, Aguiar AF, Carvalho P, Fontinha S, Jardim R, Melo I, Oliveira P, Menezes de Sequeira M, Sérgio C, Serrano ARM, Sim-Sim M, Vieira P (Eds.), *Listagem dos fungos, flora e fauna terrestres dos arquipélagos da Madeira e Selvagens*, Direcção Regional do Ambiente da Madeira and Universidade dos Açores, Funchal, Madeira, and Angra do Heroísmo, pp. 157-178.

Kalliovirta J, Tokola T (2005) Functions for Estimating Stem Diameter and Tree Age Using Tree Height, Crown Width and Existing Stand Database Information. *Silva Fennica,* 39(2): 227–248.

Kaufmann V (2012) The evolution of rock glacier monitoring using terrestrial photogrammetry: the example of Äußeres Hochebenkar rock glacier (Austria). *Austrian Journal of Earth Sciences* 105(2): 63-67.

Kay CE (2003) *Long term vegetation change on Utah's Fishlake National Forest: A study in Repeat Photography*. Utah State University Logan.

Kaye TN (2001) Common Ground and Controversy in Native Plant Restoration: the SOMS Debate, Source Distance, Plant Selections, and a restoration-Oriented Definition of Native*,* Proceedings of the Native Plant Propagation and Restoration Strategies, Nursery Technology Cooperative and Western Forestry and Conservation Association. in: Haase DL, Rose R (Eds.),

Keddy P (1992) Assembly and Response Rules: two goals to predictive community ecology. *Journal of Vegetation Science,* 3: 157-164

Kellner CL (2014) Alexander von Humbolt. German explorer and naturalist. Encyclopaedia Britannica. Retrieved 15th April 2015, from http://www.britannica.com/EBchecked/topic/276083/Alexander-von-Humboldt

Kent M, Coker P (1992) *Vegetation description and analysis. A pratical aproach.*, Belhaven Press, London.

Kent M (2012) *Vegetation Description and Data analysis. A pratical aproach*. (2nd ed.), Wiley-Blackwell, Oxford.

Kim S-c, McGowen MR, Ludinsky P, Barber JC, Mort ME, Santos-Guerra A (2008) Timing and Tempo of Early and Sucessive Adaptative radiations in Macaronesia. *PlosOne,* 3(5): e2139.

Kipfmuller KF, Swetnam TW (2001) Using Dendrochronology to Reconstruct the History of Forest and Woodland Ecosystems, in: Egan D, Howel EA (Eds.), *The Historical Ecology Handbook. A Restoration Guide to Reference Ecosystems*, (2nd (2005) ed.), Society for ecological Restoration International, Island Press, Washington D.C, pp. 199-228.

Klaver C (2007) *Inseparable friends in life and death: Heinrich Kuhl (1797 - 1821) and Johan Conrad van Hasselt (1797 - 1823), students of prof. Theo van Swinderen*. Barkhuis, Eelde.

Klett M (2010) Three Methods of Presenting Repeat Photograhs, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 32-45.

Kondraskov P, Schütz N, Rudolph B, Schmidt B, Menezes de Sequeira M, Guerra AS, Reyes-Betancort A, Thiv M (2012) Laurel Forest-a relict vegetation type? Paper presented at the *FloraMac2012*, 5-8 Sept, Funchal.

Krause KEL (2005) *Identificación de periodos de supresión y liberación en las especies Tepa [Laurelia philippiana (Losser)] y Olivillo [Aextoxicon punctatum (R. Et Pav.)] en dos bosques multietáneos de la Provincia de Valdivia.* Unpublished Thesis of Titulo de Ingeniero Forestal, Universidad Austral de Chile, Valdivia, Chile.

Kuhl H (1826) On the vegetable productions of the Island of Madeira. *Edindurgh Journal of Science,* IV: 119-124.

Kull CA (2005) Historical Landscape repeat photography as a tool for land use change research. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography,* 59: 253-268.

Kwa C (2005) Alexandre von Humboldt's Invention of the Natural Landscape. *The European Legacy,* 10(2): 149-162.

Lafay B, Burdon JJ (2006) Molecular diversity of rhizobia nodulating the invasive legume Cytisus scoparius in Australia. *Journal of Applied Microbiology,* 100(6): 1228-1238.

Laska G (2001) The disturbance and vegetation dynamics: a review and an alternative framework. *Plant Ecology,* 157: 77-99.

Lawson DM, Giessow JA, Giessow JH (2005) *The Santa Margarita River Arundo donax Control Project: Development of Methods and Plant Community Response* (USDA Forest Service Gen. Tech. Rep. PSW-GTR-195). Santa Margarita River A. donax Control Project,

Leblanc JW (2001) Getting a Handle on Broom. *ANR Comunication. University of California,* 8049: 1-9.

Lens F, Davin N, Smets E, Arco Md (2013) Insular woodiness on the Canary Islands: a remarkable case of convergent evolution. *International Journal of Plant Sciences,* 174(7): 992-1013.

Léon WJ (2002) Anatomia xilematica caulinar 14 espécies de la Familia lauraceae. *Revista Florestal Venezolana,* 46(1): 15-25.

"Leonardo da Vinci". Encyclopedia of World Biography (2004) Encyclopedia.com. Retrieved 29 Mar 2015 from http://www.encyclopedia.com

Levesque LM (2005) *Investigating Landscape Change and Ecological Restoration: An Integrated Approach Using Historical Ecology and Geographical Information Systems in Waterton Lakes National Park, Alberta.* Unpublished Master of Science thesis, University of Victoria, Victoria, Canada.

Levine JM, Adler PB, Yelenik SG (2004) A meta- analysis of biotic resistance to exotic plant invasions. *Ecology letters,* 7: 975-989.

Lewis D (2010) Catle, Repeat photography, and Changing vegetation in the Victoria River District, Northern territory, Australia, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 197-210.

Lillesand TM, Kiefer RW (1994) *Remote Sensing and Image Interpretation*. (3rd Edition ed.), John Wiley and Sons, New York.

Liutsko L (2008) *What trees tell us. Dendrochronological and statistical analysis of the data.* Unpublished PhD Thesis, University of Barcelona, Barcelona, Spain.

Lockwood J, Samuels CL (2004) Assembly models and the pratice of restoration, in: Temperton VM, Hobbs R, Nuttle T, Halle S (Eds.), *Assembly Rules and restoration ecology. Briging the gap between theory and practice*, Society for Ecological Restoration. International Island Press, Washington, pp. 55-70.

Lockwood JL, Powell RD, Nott MP, Pimm SL (1997) Assembling Ecological Communities in Time and Space. *Oikos,* 80(3): 549-553.

Loetsch F, Haller KE (1973) *Forest Inventory*. (Vol. I), Verdagsgesellscaft, Munich.

Loidi J, Arco MD, Paz PLPd, Asensi A, Garretas BD, Costa M, Gonzélez Td, Fernández-González F, Izco J, Penas Á, Salvador-Rivas-Martínez, Sánches-Mata D (2010) Understanting properly the "potential natural vegetation" concept. *Journal of Biogeography,* 37: 2209-2215.

Lomba Â, Torres J, Alves H, Honrado J (2004) GIS applied to landscape valuation and management in coastal areas. Paper presented at the *Littoral 2004*, 20-22 September, Aberdeen, Scotland, UK.

Lopez L, Villalba R, Peña-Claros M (2012) Determining the annual periodicity of growth rings in seven tree species of a tropical moist forest in Santa Cruz, Bolivia. *Forest Systems,* 21(3): 508-514.

Loutfy MHA (2009) Wood anatomy and its implications on the taxonomy of Apollonias NEES (Lauraceae). *Feddes Repertorium* 120(1-2): 75-90.

Lowe RT (1857) *A Manual Flora of Madeira and the adjacent Islands of Porto Santo and Desertas* (Vol. I-Part 1), John Van Voorst, London.

Lowe RT (1872) *A Manual Flora of Madeira and the adjacent Islands of Porto Santo and Desertas*. (Vol. II), John Van Voorst, London.

Lowe S, Browne M, Boudjelas S, Poorter MD (2000) *100 of the World's Worst Invasive Alien Species A selection from the Global Invasive Species Database*. The Invasive Species Specialist Group (ISSG), Auckland.

Luce CH (2002) Hydrological processes and pathways affected by forest roads: what do we still need to learn? Invited Commentary. *Hydrological Processes,* 16: 2901-2904.

MacArthur RH, Wilson EO (1967) *The Theory of Islands Biogeography*. Princeton University Press, Princeton.

Macaulay J (1841) On the Vegetation and Botany of the Island of Madeira, in: Farlow WG (Ed.), *Transactions and Proceedings of the Botanical Society of Edinburgh*, (Vol. II), Maclachlan, Stewart, and Co., Edinburgh, pp. 71-74.

Mackey BG, Soule ME, Nix HA, Recher HF, Lesslie RG, William JE, Woinarski JCZ, Hobbs RJ, Possingham HP (2007) Applying landscape ecological principles to regional conservation: the WildCountry Project in Australia, in: Wu J, Hobbs RJ (Eds.), *Key Topics in Landscape Ecology*, pp. 192-213.

Macpherson H, Minca C (2006) Landscape, embodiment and visual impairment: an exploration of the limits of landscape knowledge. Paper presented at the *10th International Seminar "Cultural Landscapes in the 21st century"*, 11-16 April 2005, Newcastle-upon-Tyne, England.

Madeira M, Furtado A, Jeanroy E, Herbillon AJ (1994) Andisols of Madeira Island (Portugal). Characteristics and classification. *Geoderma,* 62: 363-383.

Mai D (1989) Development and regional differentiation of the European vegetation during the Tertiary. *Plant Systematics and Evolution,* 162: 79-91.

Mai DH (1987) Development and regional differentiation of the European vegetation during the Tertiary. *Plant Systematics and Evolution,* 162: 79-91.

Makhzoumi J, Pungetti G (2005) *Ecological Landscape Design and Planning*. (2ed.), Tailors & Francis e-Library, London.

Malato-Beliz J (1983) Considerations sur la protection de la flore e la vegetation à Madere*,* Proceedings of the II Congresso Internacional Pró Flora Macaronésica, 19-25 Jun 1977, Funchal.

Malde HE (1973) Geologic bench marks by terrestrial photography. *Journal of Research of the United Stated Geological Survey,* 1: 193-206.

"Malpighi" Complete Dictionary of Scientific Biography (2008) Encyclopedia.com. Retrieved March 29, 2015, from http://www.encyclopedia.com/doc/1G2-2830902791.html

Manier DJ, Laven RD (2002) Changes in landscape patterns associated with the persistence of aspen (Populus tremuloides Michx.) on the western slope of the Rocky Mountains, Colorado. *Forest Ecology and Management,* 167(1-3): 263-284.

Maringer J, Wohlgemuth T, Neff C, Pezzatti GB, Conedera M (2012) Post-fire spread of alien plant species in a mixed broad-leaved forest of the Insubric region. *Flora,* 207: 19-29.

Marques CAG (2013) *Paleobotânica da Ilha da Madeira: Inventário e Revisão da Macroflora Fóssil de São Jorge e Porto da Cruz* Unpublished MSc, Faculdade de Ciências da Universidade de Lisboa, Universidade de Lisboa, Portugal.

Marrs R, Duc M, Mitchell R, Goddardt D, Patersons S, Pakeman R (2000) The Ecology of Bracken: Its Role in Succession and Implications for Control. *Annals of Botany,* 85(B): 3-15.

Martinelli N (2004) Climate from dendrochronology: latest developments and results. *Global and Planetary Change,* 40(1-2): 129-139.

Mata J, Munhá J (2004) Madeira Island alkaline lava spinels: petrogenetic implications. *Mineralogy and Petrology,* 81: 85-111.

Mattos PPd, Braz EM, Hess AF, Salis SM (2011) *A dendrocronologia e o manejo florestal sustentável em florestas tropicais* Embrapa Florestas, Colombo.

Maxwell RS, Wixom JA, Hessl AE (2011) A comparision of two tecniques for measuring and crossdatind tree rings. *DEndrochronologia,* 29: 237-243.

McAuliffe JR, Scuderi LA, McFadden LD (2006) Tree-ring record of hillslope erosion and valley floor dynamics: Landscape responses to climate variation during the last 400yr in the Colorado Plateau, northeastern Arizona. *Global and Planetary Change,* 50: 184-201.

McBride JR (1983) Analysis of tree rings and Fire Scars to establish fire history. *Tree-Ring Bulletin,* 43: 51-67.

McCarthy DP, Luckman BH, Kelly PE (1991) Sampling Height-Age Error Correction for Spruce Seedlings in Glacial Forefields, Canadian Cordillera. *Arctic and Alpine Research,* 23(4): 451-455.

McClaran M (2003) A century of vegetation change on the Santa Rita Experimental Range, in: McClaran MP, Ffolliott PF, Edminster CB (Eds.), *Santa Rita Experimental Range: 100 years (1903 to 2003) of accomplishments and contributions*, Proc. RMRS-P-30, USDA Forest Service, Rocky Mountain Research Station, Ogden, pp. 16-33.

McClaran MP, Browning DM, Huang C-Y (2010) Temporal Dynamics and Spatial Variability in Desert Grassland Vegetation, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 145-166.

McGraw DJ (2000) Andrew Ellicott Douglass and the Big Trees: The Giant Sequoia was fundamental to the development of the science of dendrochronology—tree-ring dating. *American Scientist,* 88(5): 440-447.

McIntosh R (1975) H. A. Gleason - "Individualistic Ecologist" 1882-1975. *Bulletin of the Torrey Botanical Club* Retrieved 5, 102, from http://www.jstor.org/stable/2484142?seq=1#page_scan_tab_contents

Meagher M, Houstan D (1998) *Yellowstone and the Biology of Time Photographs across a century*. University of Oklahoma Press, Norman.

Meinig DW (1976) The beholding eye.Ten versions of the same scene. *Landscape Architecture,* 66: 47-54.

Mello FMd (1660) Descobrimento da ilha da Madeira Anno 1420. Epanaphora Amorosa, In: *Epanaphoras de varia historia portugueza a ElRey Nosso Senhor D. Afonso VI em Cinco Relações De Sucessos Pertencentes a este Reino*, Henrique Valente de Oliveira Impressor delRey Nosso Senhor, Lisboa, pp. 312-348.

Melo LS (1978) *Vicentes Photographos*. Ilha Tur, Funchal.

Melo LS, Farrow SE (1983) *Impressões da Madeira antiga*. Editorial Eco do Funchal, Funchal.

Menezes CA (1894) *Catálogo das Phanerogamicas da Madeira e Porto Santo não indicadas na Flora destas ilhas do Rev. Richard Thomas Lowe*. Funchal,

Menezes CA (1914) *Flora do Archipelago da Madeira (Phanerogamicas e Cryptogamicas Vasculares)*. Funchal.

Menezes de Sequeira M, Jardim R, Capelo J (2007) A chegada dos portugueses às ilhas - o antes e o depois (Madeira), in: Silva JS (Ed.), *Árvores e Florestas de Portugal*, (Vol. 06), Público, Comunicação Social SA e Fundação Luso-Americana para o Desenvolvimento, Lisboa, pp. 165-194.

Menezes de Sequeira M, Santos-Guerra A, Jarvis CE, Oberli A, Carine MA, Maunder M, Francisco-Ortega J (2010) The Madeiran plants collected by Sir Hans Sloane in 1687, and his descriptons. *Taxon,* 59(2): 598-612.

Menezes de Sequeira M, Capelo J, Jardim R, Pupo A (2011) Comments on the Vascular Flora of Madeira: history, recent advances and relations with other Macaronesian archipelagos*,* Proceedings of the International Conferences on Islands Biodiversity Jardín Botánico Canario "Viera y Clavijo"–Unidad Asociada CSIC, 14-18 March 2011, 14-18 March 2011, Gran Canaria.

Menezes de Sequeira M, Pupo-Correia A, Figueiredo A (2011a) Deslizamentos na Madeira - história recente de uma conjunção deletéria de factores. Paper presented at the *V Jornadas Florestais da Macaronésia*, 8 a 11 de Fevereiro de 2011, Funchal.

Menezes de Sequeira M, Pupo-Correia A, Figueiredo A (2011b) *O Papel do Coberto Vegetal In A. Betâmio de Almeida & R. Proença de Oliveira (Eds.) Estudo de Avaliação do Risco de Aluviões na Ilha da Madeira* (Technical Report). Instituto Superior Técnico, Funchal.

Mesquita S, Capelo J, Sousa Jd (2004) Bioclimatologia da Ilha da Madeira: abordagem numérica, in: Capelo J. A (Eds), A paisagem vegetal da Ilha da Madeira. *Quercetea,* 6(47-59).

Mesquita S, Capelo J, Jardim R, Menezes de Sequeira M (2007) Distribuição das principais manchas florestais (Madeira), in: Silva JS (Ed.), *Árvores e Florestas de Portugal*, (Vol. 6), Público, Comunicação Social SA e Fundação Luso-Americana para o Desenvolvimento, Lisboa, pp. 323-335.

Metzger JP (2001) O que é a ecologia de Paisagens? *Biota Neotropica* 1(1): 1-9.

Mikulinskij SR, Markova LA, Starostin BA (1981) Alphonse de Candolle (1806-1893). *Systematic Botany,* 6(2): 192-194.

Miller JR, Hobbs RJ (2007) Habitat Restoration—Do We Know What We're Doing? *Restoration Ecology,* 15(3): 382-390.

Mitchell DS (1996) Interactions between national and local strategies for the management of aquatic weeds. *Hydrobiologia,* 340: 153-156.

Mochiutti S, Higa AR, Simon AA (2008) Phytosociology of the arboreal and natural regeneration strata in a black-wattle (Acacia mearnsii De Wild.) plantation in the region of Semideciduis Seasonal Forests of Rio Grande do Sul. *Ciência Florestal,* 18(2): 207-222.

Morales D, Jiménez S, González-Rodríguez A, Cermák J (2002) Laurel forests in Tenerife, Canary Islands. I Xylem structure in stems and petioles of Laurus azorica trees. *Trees - Structure and Function,* 16(8): 529-537.

Moreira J, (Coord) (2015) *IFRAM2-2º inventário florestal da Região Autónoma da Madeira*. Technical Report. Secretaria Regional do Ambiente e dos Recursos Naturais, Direção Regional de Florestas e Conservação da Natureza, Funchal, Portugal.

Moseley RK (2006) Historical Landscape Change in Northwestern Yunnan, China: Using Repeat Photography to Assess the Perceptions and Realities of Biodiversity Loss. *Mountain Reserach and Development,* 26(3): 214-219.

Motulsky HJ, Christopoulos A (2003) *Fitting models to biological data using linear and nonlinear regression. A practical guide to curve fitting*. GraphPad Software Inc, San Diego, USA

Mucina L (2010) Floristic-phytosociological approach, potential natural vegetation, and survival of prejudice. *Lazaroa,* 31: 173-182.

Mullett TL Ecological Aspects of Sweet pittosporum (Pittosporum undulatum Vent.): Implications for Control and Management, Proceedings of the Eleventh Australian Weeds Conference, Melbourn.

Mullin JM (1994) Oxalidaceae, in: Press JR, Short M (Eds.), *Flora of Madeira*, HMSO, London, pp. 192-193.

Munroe JS (2003) Estimates of Litle Ice Age Climate Iferred Through Historical Rephotography, Northern Uinta Mountains, U.S.A. *Artic, Antartic, and Alpine Research,* 35(4): 489_498.

Murray CJ (2004) *Encyclopedia of the Romantic Era 1760-1850*. (Vol. 1 and 2), Fitztoy Dearborn, New York and London.

Natividade JV (1953) *Madeira a Epopoeia rural*. Junta Geral do distrito Autónomo do Funchal, Funchal.

Neves CMB (1950) Discurso de encerramento, Proceedings of the I Conferência da Liga para a Protecção da Natureza, 10-18 Abr 1950, Funchal, Portugal. in: LPN (Ed.), *Publicações da LPN* (IV), LPN e GEFPHM, Lisboa, pp. 125-129.

Neves HC, Valente AV, Faria BF, Silva IGd, Marques JC, Gouveia NA, Silva PGd, Oliveira PJ (1996) *Laurissilva da Madeira. Caracterização quantitativa e qualitativa*. Parque Natural da Madeira. SRAFP (Secretaria Regional de Agricultura, Florestas e Pescas., Funchal.

Neves HC (2000) *Laurissilva da Madeira - Measures for the Management and Conservation of the Laurissilva Forest of Madeira (code45.62*)* (LIFE97 NAT/P/004082).

Nicolson M (1987) Alexander Von Humboldt, Humboldtian science and the origins of the sutdy of vegetation. *History of Science,* 25: 167-194.

Noble IR, Slatyer RO (1980) The use of vital attributes to predict successional changes in plant communities subjected to recurrent disturbances. *Vegetatio,* 43: 5-21.

Nogales M, Rodrígues-Luengo JL, Marrero P (2006) Ecological effects and distribution of invasive non-native mammals on the Canary Islands. *Mammal Rev.,* 36(1): 49-65.

Norgate GlG (1912) *James Macaulay. Dictionary of National Biography*. (Vol. 2), Elder &Co., London.

Norton DA, Ogden J (1987) Dendrochronology: A review with emphasis on New Zealand Applications. *New Zealand Journal of Ecology,* 10: 77-95.

Norton DA, Ogden J (1992) Problems with the use of tree rings in the study of forest population Dynamics, in: Cook ER, Kairiukstis LA (Eds.), *Methods of Dendrochronology: Applications in the Environmental Sciences*, Kluwer Academic Publishers, Dordrecht, pp. 284-288

Norton DA (1998) *Impacts of tree coring on indigenous trees*. Department of Conservation, Wellington.

Nyssen J, Haile M, Monroe N, Poesen J, Grove ATD, Decken J (2010) Repeat Photography Chanllengers Received Wisdom on Land Degradation in the Northern Etiopian Highlands, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 186-197.

Ogden J (1981) Dendrochronological Studies and the Determination of Tree Ages in the Australian Tropics. *Journal of Biogeography,* 8(5): 405-420.

Oliveira P, Marrero P, Nogales M (2002) Diet of the endemic Madeira laurel pigeon and fruit resource availability: a study using microhistological analyses. *The Condor,* 104(4): 811-822.

Ollerton J, Watts S, Connerty A, Lock J, Parker L, Wilson I, Schuller A, Nattero J, Cocucci A, Izhaki I, Geets S, Pauw A, Stout J (2012) Pollination ecology of the invasive tree tobacco Nicoiana glauca: comparisons across native and non-native ranges. *journal of Pollination Ecology,* 9(12): 85-95.

Onaindia M, Ametzaga-Arregi I, Sebastián MS, Mitxelena A, Rodríguez-Loinaz G, Peña L, Alday JG (2013) Can understorey native woodland plant species regenerate under exotic pine plantations using natural succession? *Forest Ecology and Management,* 308: 136-144.

Otto R, Krüsi BO, Kienast F (2007) Degradation of an arid coastal landscape in relation to land use changes in Southern Tenerife (Canary Islands). *Journal of Arid Environments,* 70(3): 527-539.

Ouden Jd (2002) *The role of Braken (Pteridium aquilinum) in forest dynamics.* Unpublished Doctoral Thesis, Wageningen University, Netherlands.

Paiva J (2007) Soutos e Castiçais, in: Silva JS (Ed.), *Árvores e florestas de Portugal*, (Vol. 5), Público, Comunicação Social SA e Fundação Luso-Americana para o Desenvolvimento, Lisboa, pp. 31-37.

Patón D, Azocar P, Ovar JT (1998) Growth and productivity in forage biom ass in relation to the age assessed by dendrochronology in the evergreen shrub Cistus ladanifer (L.) using different regression models. *Journal of Arid Environments,* 38: 221-235.

Paul GS, Yavitt JB (2010) Tropical Vine Growth and the Effects on Forest Succession: A Review of the Ecology and Management of Tropical Climbing Plants. *The Botanical Review*.

Pedrotti F (2013) *Plant and Vegetation Mapping*. Geobotany Studies. Basics, Methods and Case Studies, Springer-Verlag, Berlin.

Pereira ECN (1989) *Ilhas de Zargo*. Cópia literal das edições de 1940, 1957, 1968, Vol. II (4ª ed.), Câmara Municipal do Funchal, Funchal.

Pereira JA (1950) Protecção às nossas florestas. *Frutas da Madeira,* X(2): 17.

Pereira O (2011) A emigração na História da Madeira*,* Proceedings of the Conference "A emigração na História da Madeira", 12 de Dezembro 2011, Funchal. in: Vieira A (Ed.), CEHA, pp. 2-4.

Pessoa F (1983) Le Parc Naturel de Madére et le management biophysique du territoire*,* Proceedings of the II Congresso Internacional Pró Flora Macaronésica, 19-25 Jun 1977, Funchal.

Pheloung PC (1995) *Determining the weed potential of new plant introductions to Australia* (A report on the development of a Weed Risk Assessment System). Agriculture Protection Board, Western Australia.

Pickard J (2002) Assessing vegetation change over a century using repeat photography. *Australian Journal of Botany,* 50: 409-414.

Picken A (1840) *Madeira illustrated by Andrew Piken: with a description of the island*. (2 ed.), in 2000 by Edições de arte Lda. Originally published by James Macaulay, London.

Pierson TC (2007) Dating young geomorphic surfaces using age of colonizing Douglas fir in southwestern Washington and northwestern Oregon, USA. *Earth Surface Processes and Landforms,* 32(6): 811-831.

Pissinati MC, Archela RS (2009) Geosystem, territory and landscape - method of study of the rural landscape from de Bertrand´s viewpoint. *Geografia,* 18(1): 5-27.

Pitta CAM (1889) *Madère Station Médicale Fixe*. Ancienne Librarie Germer Baillière et C^{ie}, Paris.

PlantExplorers.com (2015) Joseph Banks (1743-1820) “The Explorer” Part I Retrieved 25th April 2015, from https://www.plantexplorers.com/explorers/biographies/banks/joseph-banks-01.htm

prabook (2015) Erik Sjögren. Botanist, educator Retrieved 6th june 2015, from http://prabook.org/web/person-view.html?profileId=148927

Prach K, Řehounková K (2006) Vegetation succession over broad geographical scales: which factors determine the patterns? *Preslia,* 78: 469-480.

Prada S, Menezes de Sequeira M, Figueira C, Prior V, Silva MOd (2009) Fog precipitation and rainfall interception in the natural forests of Madeira Island (Portugal). *Agricultural and Forest Meteorology,* 149: 1179–1187.

Prada S, Menezes de Sequeira M, Figueira C, Prior V, Silva MOd (2010) Response to "Comment on fog precipitation and rainfall interception in the natural forests of Madeira Island (Portugal). *Agricultural and Forest Meteorology,* 150: 1154-1157.

Prada SN, Serralheiro A (2000) Stratigraphy and evolutionary model of Madeira Island. *Bocagiana,* 200.

Prada SN, Silva MOd (2001) Fog precipitation on the Island of Madeira (Portugal). *Environmental Geology,* 41: 384-389.

Press JR (1993) Introduced plants and their effects on the flora of Madeira. *Boletim do Museu Municipal do Funchal,* Sup.Nº2: 243-248.

Press JR (1994) Compositae (Asteraceae), in: Press JR, Short MJ (Eds.), *Flora of Madeira*, HMSO, London, pp. 381-382.

Press JR, Short MJ (Eds.) (1994) *Flora of Madeira*. HMSO, London.

Pupo-Correia A (2007) *História Recente da Paisagem Vegetal da Madeira. Utilização de recursos fotográficos antigos e recentes como elementos comparativos.* Unpublished MSc Thesis, Universidade da Madeira, Funchal.

Pupo-Correia A, Menezes de Sequeira M (2007) Fotografias históricas como documentos da alteração da paisagem vegetal da Madeira, in: Cap. III A chegada dos portugueses às ilhas - o antes e depois (Madeira), in: Silva JS (Ed.), *Árvores e florestas de Portugal*, (Vol. 6), Público, Comunicação Social SA e Fundação Luso-Americana para o Desenvolvimento, Lisboa, pp. 192-194.

Pupo Correia A, Figueiredo A, Aranha J, Menezes de Sequeira M (2008) Spacial spread of Cytisus spp.-The contribution of quantitative assessment obtained by Repeat Photography. Paper presented at the *VII Encontro ALFA "Fitossociologia aplicada ao ordenamento e gestão do território"*, 24-27 de Julho de 2008, Coimbra.

Pupo-Correia A, Figueiredo A, Aranha JT, Menezes de Sequeira M (2010a) Evolução da invasão por Arundo donax L. (Poaceae) na Ilha da Madeira e os seus efeitos sobre a biodiversidade vegetal. Paper presented at the *VIII Encontro Internacional da Associação Lusitana de Fitossociologia - "Novas Perspectivas da Fitossociologia"*, 13-16 de Setembro 2010, Fundação Calouste Goulbenkian, Lisboa.

Pupo-Correia A, Figueiredo A, Aranha JT, Menezes de Sequeira M (2010b) *Arundo donax* L. (Poaceae) in Madeira Island: Invasiveness and impact on biodiversity". Paper presented at the *International Symposium FLORAMAC 2010*, University of the Azores, Ponta Delgada.

Pupo-Correia A, Aranha JT, Menezes de Sequeira M (2011a) Photographs from tourist activity: a source to assess vegetation change using repeat landscape photography. *Journal of Tourism and Sustainability,* 1(1): 13-17.

Pupo-Correia A, Figueiredo A, Aranha J, Menezes de Sequeira M (2011b) Paisagem Vegetal da Madeira: Regressão, estase ou evolução? . Paper presented at the *V Jornadas Florestais da Macaronésia*, 8 a 11 de Fevereiro de 2011, Funchal.

Pupo-Correia A, Menezes de Sequeira M, Aranha J (2015) Dendrocronology as a useful tool to study native woody species of Madeira Island. Paper presented at the *International Symposium FLORAMAC*, 23-27 de março de 2015, Las Palmas de Gran Canaria.

Pupo-Correia A, Menezes de Sequeira M, Aranha JT (2014) Landscape repeat photography: Solutions to improve efficiency of a useful tool for vegetation research*,* Proceedings of the FloraMac 2012, 5 to 8 Setembro de 2012, University of Madeira, Funchal. in: Capelo J (Ed.), (Número especial), Silva Lusitana, pp. 107-120.

Pyšek P, Chocholoušková Z, Pyšek A, Jarošík V, Chytrý M, Tichý L (2004) Trends in species diversity and composition of urban vegetation over three decades. *Journal of Vegetation Science* 15: 781-788.

Quinn L, Holt J (2008) Ecological correlates of invasion by *Arundo donax* in three southern California riparian habitats. *Biological Invasions,* 10(5): 591-601.

Quinn LD, Holt JS (2009) Restoration for Resistance to Invasion by Giant Reed (*Arundo donax*). *Invasive Plant Science and Management,* 2(4): 279-291.

Ramos AP, Caetano MF, Rocha M, Belchior S, Lima A (2013) Doenças e pragas que condicionam o uso de palmeiras em espaços verdes. *APH Revista da Associação Portuguesa de Horticultura,* 112: 37-40.

Read R, Graham R (2002) *Aerial Survey*. Whittles Publishing, Caithness.

Real Academia de Ciências Exactas Fisicas y Naturales (2015) Relación de académicos desde el año 1847 hasta el 2003. Retrieved 22nd May 2015, from http://www.rac.es/ficheros/doc/00186

Reithmaier T (2001) Maps and Photograps, in: Egan D, E A Howell (2 ed.). Society for Ecological Restoration International. Island Press W, D.C. (Eds.), *The Historical Ecology Handbook: A Restoration Guide To Reference Ecossystems,*, (2 ed.), Society for Ecological Restoration International. Island Press, Washington, D.C., pp. 121-127.

Rejmánek M, Richardson DM (1996) What attributes make some plant species more invasive? *Ecology,* 77(6): 1655-1661.

Rhemtulla JM, Hall RJ, Higgs ES, Macdonald E (2002) Eight years of change: vegetation in the montane ecoregion of Jasper National Park, Alberta, Canada. *Canadian Journal of Forest Research,* 32: 2010-2021.

Ricardo RP, Câmara EMS, Ferreira MAM (1995) *Carta de solos da ilha da Madeira*. CEP(IICT), ISA (UTL), CPUTL e DRA (Madeira), Lisboa.

Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ (2000) Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions,* 6(2): 93-107.

Richardson DM, Pysek P (2006) Plant invasions: merging the concepts of species invasiveness and community invasibility. *Progress in Physical Geography,* 30(3): 409-431.

Rieger JP, Kreager DA (1989) *Giant reed (Arundo donax): a climax community of the riparian zone* (General Technical Report PSW-110). USDA Forest Service, San Diego.

Rivas-Martinez S (1976) Sinfitosociología, una nueva metodologia para el estudio del paisaje vegetal. *Anal. Instit. Bot. Canavilles,* 33: 179-188.

Rivas-Martinez S (2002) Review of definitions: Phytosociologic, bioclimatic and biogeographic terms, notions and units. Retrieved 24th March 2014, from http://www.globalbioclimatics.org/book/review.htm

Rivas-Martinez S (2005) Notions on dynamic-catenal phytosociology as a basis of landscape science. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology: Official Journal of the Societa Botanica Italiana,* 139(2): 135-144.

Rivas-Martínez S, Sánchez-Mata D, Costa M (1999) Wordwide Bioclimatic Classification System *Itenera Geobotanica,* 12: 5-316

Rogers GF, Malde HE, Turner RM (1984) *Bibliography of repeat photography for evaluating landscape change*. University of Utah Press, Salt Lake City.

Rohlf FJ (2009) *NYSYSpc:numerical taxonomy system (Version 2.21c)*. Exeter Software: Setauket, New York, USA.

Rolston H (1998) Technology versus nature: what is natural? *Ends and means. Journal of the University Centre for Philosophy, Technology & Society,* 2(2): 3-14.

Ross LC, Lambdon PW, Hulmeb PE (2008) Disentangling the roles of climate, propagule pressure and land use on the current and potential elevational distribution of the invasive weed Oxalis pes-caprae L. on Crete. *Perspectives in Plant Ecology, Evolution and Systematics,* 10: 251-258.

Rozas V (2003) Tree age estimates in Fagus sylvatica and Quercus robur: testing previous and improved methods *Plant Ecology,* 167: 193-212.

Rozas V (2005) Dendrochronology of pedunculate oak (*Quercus robur* L.) in an old-growth pollarded woodland in northern Spain: tree-ring growth responses to climate. *Ann. For. Sci.,* 62(3): 209-218.

Salas-Pascual M, Naranjo A, Fernández-Lugo S-, Arévalo JR (2011) Effects of Oxalis pes-caprae on ecological aspects of the potential thermofilous canarian forest, Proceedings of the "Plantas invasoras resistencias a herbicidas y detección de malas hierbas. XIII Congreso de la Sociedad Española de Malherbología, 22-24 November 2011, La Laguna.

Sanderson J, Harris LD (2000) Brief History of Lanscape Ecology, in: Sanderson J, Harris LD (Eds.), *Landscape Ecology: A Top Down Approach* Lewis Publishers, Boca Raton, pp. 3-18.

Sänger H, Jetschke G (2004) Are assembly rules apparent in the regeneration of former Uranium Mining site?, in: Temperton VM, Hobbs R, Nuttle T, Halle S (Eds.), *Assembly Rules and Restoration Ecology. Bridging the gap between the theory and practice*, International Island Press, Washington, pp. 305-324.

Santos J (1905) A ilha da Madeira. *Serões,* 4: 297-308.

Santos Simões CN (1969) Introduction *Journal of a Visit to Madeira and Portugal*, Junta Geral do Distrito Autónomo do Funchal, Funchal, pp. 19-30.

Santos TMHd (2010) *Landscape and Phytosociology of the Paiva River's Hydrological Basin.* Unpublished Doctoral Thesis, Universidade Técnica de Lisboa, Lisboa, Portugal.

Sayn-Wittgenstein L (1978) *Recognition of trees on aerial photographs*. Canadian forest Service, Ottawa.

Schinker MG, Hanse N, Spieker H (2003) High-frequency densiometry-a new method for the rapid evaluation of wood density variations. *AIAWA Journal,* 24(3): 231-239.

Schmitt AK, Danišík M, Aydar E, Sen E, Ulusoy I, Lovera O (2014) Identifying the Volcanic Eruption Depicted in a Neolithic painting at Çatalhöyük, Central Anatolia, Turkey. *PLoS ONE* 9(1): e84711.

Schweingruber FH, Poschlod P (2005) Growth Rings in Herbs and Shrubs: life span, age determination and stem anatomy. *Forest Snow and Landscape Research,* 79(3): 195-415.

Schweingruber FH (2007) *Wood structure and Environment*. Springer-Verlag Berlin Heidelberg, Heidelberg.

Schweingruber FH, Börner A, Schulze E-D (2011) *Atlas of stem anatomy in herbs, shrubs and trees*. (Vol. 1), Springer-Verlag Berlin, Heidelberg.

Scott A (2000) The Pre-Quaternary history of fire. *Palaeogeography Palaeoclimatology Palaeoecology,* 164: 281.

Sequeira MB (1913) *Argumento a favor da Arborisação obrigatória das serras da ilha da Madeira*. Typographia "Esperança", Funchal.

Sharma PD (2009) *Ecology and Environment*. Rakesh Kumar Rastogi, New Deli.

Sheppard PR, Means JE, Lassoie JP (1988) Cross-Dating Cores as a Nondestructive Method for Dating Living, Scared Trees. *Foest Science,* 34(3): 781-789.

Shier RA (2003) Trajectoria do conceito de paisagem na geografia. *RA'EGA. O espaço geográfico em análise,* 7: 79-85.

Short MJ (1994) Sapindaceae. Cardiospermum L., in: JR P, MJ S (Eds.), *Flora of Madeira*, HMSO, London, pp.211-212.

Short MJ (1994) Tropaeolaceae, in: Press JR, Short MJ (Eds.), *Flora of Madeira*, HMSO, London, pp. 200.

Silva CMN, Silva L, Oliveira N, Geraldes P, Hervías S (2011) Control of giant reed *Arundo Donax* on Vila Franca do Campo Islets, Azores, Portugal. *Conservation Evidence,* 8: 93-99.

Silva FA (1946) *O Revestimento Florestal do Arquipélago da Madeira*. Comércio do Funchal, Funchal.

Silva FA, Menezes CA (1946a) *Elucidário Madeirense*. (1998 *fac-simile* ed. Vol. II), Direcção Regional dos Assuntos Culturais (DRAC), Funchal.

Silva FA, Menezes CA (1946b) *Elucidário Madeirense*. (1998 *fac-simile* ed. Vol. I), Direcção Regional dos Assuntos Culturais (DRAC), Funchal.

Silva FA, Menezes CA (1946c) *Elucidário Madeirense*. (1998 *fac-simile* ed. Vol. III), Direcção Regional dos Assuntos Culturais (DRAC), Funchal.

Silva I, Ferreira P, Gonçalves AL, Fernandes A (1985) *A Madeira e o Turismo. Pequeno Esboço histórico*. Secretaria Regional do Turismo e Cultura. Direcção Regional dos Assuntos Culturais (DRAC), Funchal.

Silva L, Tavares J (1995) Phenological cycles of *Myrica faya* (Myricaceae) in the Azores Islands, Proceedings of the 1st Symposium of "Fauna & Flora of the Atlantic Islands", Oct 1993, Funchal, Portugal. *Boletim do Museu Municipal do Funchal* (Sup. nº 4-B), Câmara Municipal do Funchal, Funchal, pp. 671-679.

Silva L, Land EO, Luengo JR, Borges P, Oliveira P, Jardim R (2008a) Invasive alien species in: Silva L, Land EO, Luengo JR (Eds.), *Invasive Terrestrial Flora & Fauna of Macaronesia. TOP 100 in Azores, Madeira and Canaries*, ARENA, Ponta Delgada, pp. 159-165.

Silva L, Land EO, Luengo JLR (Eds.) (2008b) *Invasive Terrestrial Flora & Fauna of Macaronesia. TOP 100 in Azores, Madeira and Canaries*. ARENA, Ponta Delgada.

Silveira ABd, Madeira J, Ramalho R, Fonseca P, Prada S (2010) *Notícia explicativa da carta geológica da ilha da Madeira na escala 1:50000.* Secretaria Regional do Ambiente e Recursos Naturais, Região Autónoma da Madeira e Universidade da Madeira, Funchal.

Sit V, Poulin-Costello M (1994) *Catalogue of curves for curve fitting. Biometrics Information. Handbook nº 4*. Forest Science Research Branch. Ministry of Forests, Province of British Columbia.

Sjögren E (1972) Vascular plant communities of Madeira. *Boletim do Museu Municipal do Funchal,* XXVI (114): 45-125.

Sjögren E (2000) Aspects on the biogeography of Macaronesia from a botanical point of view. *Arquipélago. Life and marine Sciences,* 2(A): 1-9.

Smith W (Ed.) (1813-1893) *A Dictionary of Greek and Roman biography and mythology*. Litle, Brown and co., Boston.

Soares JN (1882) *Chorographia da Madeira*. By author, Lisboa.

Sokal RR, Rohlf FJ (1981) *Biometry. Principals and Practice of Statistics in Biological Research*. (Second ed.), W. H.- Freeman and Company, New York.

Sousa AB (1946) *Plano de arborização do Montado do Barreiro*. Relatório apresentado a 27 de Abril 1929 à Comissão Administrativa da CMF, Câmara Municipal do Funchal, Funchal.

Sousa FC (2008) Voyages in Romantic Madeira. Quinta da Cruzes Museum Web page. Retrieved 17 April 2014, from http://mqc.gov-madeira.pt/pt-PT/Coleccoes/pintura/ContentDetail.aspx

Sousa JJA (1994) *A História Rural da Madeira*. Direcção Regional dos Assuntos Culturais (DRAC), Funchal.

Speer JH, Orvis KH, Grissino-Mayer HD, Kennedy LM, Horn SP (2004) Assessing the dendrochronological potential of Pinus occidentalis Swartz in the Cordillera Central of the Dominican Republic. *The Holocene,* 14(4): 563-569.

Speer JH (Ed.) (2010) *Fundamentals of tree-ring research*. University of Arizona Press, Tucson.

Srinivasan M, kalita R, Gurung I, Bahattacharjee A, Antony P, Krishnan S, Gleeson S (2012) Seedling germination success and survival of the invasive shrub Scotch broom (Cytisus scoparius) in response to fire and experimental clipping in the montane grasslands of the Nilgiris, south India. *Acta Oecologica,* 38: 41-48.

Start AN, Handasyde T (2002) Using photographs to document environmental change: the effects of dams on the riparian environment of the lower Ord River. *Australian Journal of Botany* 50: 465-480.

Stern WL (1954) Comparative anatomy of xylem and phylogeny of Lauraceae. *Tropical Woods,* 100: 1-73.

Stoffel M (2006) A review of studies dealing with tree rings and rockfall activity: The role of dendrogeomorphology in natural hazard research. *Natural Hazards Earth System Sciences,* 39(1): 51-70.

Stoffel M, Bollschweiler M (2008) Tree-ring analysis in natural hazards research – an overview. *Natural Hazards Earth System Sciences,* 8(187-202): 187-202.

Sullivan M (1980) *Chinese Landscape Painting*. (Vol. II), University of California Press, Berkley and Los Angeles.

Sunding P (1979) Origins of the Macaronesian flora, in: Bramwell D (Ed.), *Plants and Islands*, Academic Press, London, pp. 13-40.

Taffin C (2014) Bailleul : décès du professeur Géhu, fondateur du conservatoire botanique et renommé dans le monde entier. *La Voix du Nord* Retrieved 24th May 2015, from http://www.lavoixdunord.fr/region/bailleul-deces-du-professeur-gehu-fondateur-du-ia

Temperton VM, Zirr K (2004) Order of arrival and availability of safe sites: An example of their importance for plant community assembly in stressed ecossystems, in: Temperton VW, Hobbs RJ, Nuttle T, Halle S (Eds.), *Assembly Rules and Restoration Ecology Bridging the Gap Between Theory and Pratice*, Society for Ecological Restoration. Island Press Washington, pp. 285-304.

The British Museum Web page (2015) Sir Hans Sloane. Retrieved 5th Jun 2015, from http://www.britishmuseum.org/about_us/the_museums_story/sir_hans_sloane.aspx

"Theophrastus". Complete Dictionary of Scientific Biography (2008) Encyclopedia.com. Retrieved March 29, 2015, from http://www.encyclopedia.com

Thomas S, Dines T (2010) *Invasive non-native plants. what's the big beal*. Plantlife, Plantlife, Wiltshire.

tidsskriff.dk (1946) Studiet af Geografi ved Kobenhavs Universitet af Professor M. Vahl. *Geografisk Tidsskriff,* 48: 1-7.

Tingbrand P (2011) Daniel Solander. The Botanist and Nature's Argonaut. Solanderföreningen (The Solander Society). Retrieved 5th june 2015, from http://www.danielsolander.se/esolan.htm

Tomazello-Filho M, Lisi CS, Hansen N, Cury G (2004) Anatomical features of increment zones in different tree species in the State of São Paulo Brazil. *Scientia Forestalis,* 66: 46-55.

Touchan R, Hughes MK (1999) Dendrochronology in Jordan. *Journal of Arid Environments,* 42(4): 291-303.

Trueba JJG (2012) Carl Troll e a Geografía del Paisaje: Vida, Obra e traducción de un texto fundamental. *Boletin de la Associación de Geógrafos Españoles,* 59: 431-434.

Turland NJ (1994) Leguminosae [Fabaceae], in: JR P, MJ S (Eds.), *Flora of Madeira*, HMSO, London, pp. 149-192.

Turner MG, Gardner RH, O'Neill RV (2001) *Landscape Ecology in Theory and Practice. Pathern and Process*. Springer-Verlag, New York.

Turner MG (2005a) Landscape Ecology: What is the state of Science? *Annual Review of Ecology and systematics,* 36: 319-344.

Turner MG, Gardner RH (Eds.) (1991) *Quantitative Methods in Landscape Ecology: The analyis and Interpretation of Landscape Heterogeneity*. Springer_Verlag New York, New York.

Turner RH, Ochung HA, Turner JB (1998) *Kenya's changing landscape*. The University Arizona Press, Tucson.

Turner RM, Robert H. Webb, Bowers JE, Hastings JR (2003) *The Changing Mile Revisited: An Ecological Study of Vegetation Change with Time in the Lower Mile of an Arid and Semiarid Region* University of Arizona Press, Tucson, Arizona.

Turner RM (2005b) Vegetation in transition: The Southwest's dynamic past century. *USDA Forest Service Proceedings* 36: 223-228.

Turner RM, Webb RH, Esque Tc, Rogers GF (2010) Repeat Photography and Low Elevation Fire Responses in the Southwestern United States, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 223-244.

Twining AC (1883) "On the growth of timber — Extract of a letter from Mr. Alexander C. Twining, to the Editor, dated Albany, April 9, 1833,". *The American Journal of Science,* 24: 391-393.

Urban DL, O'Neill RV, Herman Shugart J (1987) Landscape Ecology. *BioScience,* 37(2): 119-127.

Vahl M (1904) *Madeiras Vegetation*. PhD Thesis presented to University of Copenhagen, published by Gyldensalke Boghandel, Nordisk Forlag, Kristiania, Copenhagen, Denmark.

Vale T (2001) Landscape change, global change, and the wisdom of Roy Bedichek. *Physical Geography,* 22(4): 277-290.

Vale TR (2002) The Pre-European Landscape of the United States: Pristine or Humanized?, in: Vale TR (Ed.), *Fire, Native Peoples and The Natural Landscape*, Island Press, Washington, pp. 1-39.

Vanderpoorten A, Rumsey FJ, Carine MA (2007) Does Macaronesia exist? Conflicting signal in the Bryophyte and Pteridophyte Floras. *American Journal of Botany* 94(4): 625-639.

Vargas P (2007) Are Macaronesian islands refugia of relict plant lineages?: a molecular survey *Pylogeography of Southern European Refugia: Evolutionary Perspectives on the Origins and Conservation of European Biodiversity*, Springer, Dordrecht.

Veblen TT, Lorenz DC (1991) *The Colorado Front Range. A century of Ecological Change* University of Utah Press, Salt Lake City.

Veblen TT (2010) Disturbance and Vegetation Dynamics in the Southern Adean Region of Chile and Argentina in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 167-185.

Vellend M. (2014) The community Concept. Oxford Bibliographies Online posted to http://www.oxfordbibliographies.com/view/document/obo-9780199830060/obo-9780199830060-0011.xml

Verdaguer D, Sala A, Vila M (2010) Effect of environmental factors and bulb mass on the invasive geophyte Oxalis pes-caprae development. *Acta Oecologica*: 92-99.

Vieira A (1999) *Do Éden à Arca de Noé. O Madeirense e o Quadro Natural*. Centro de Estudos de História do Atlântico, Secretaria Regional do Turismo e Cultura, Funchal.

Vieira A (2014a) Do Eden à arca de noé. Descoberta e reinvenção do meio Natural nas ilhas atlânticas. CEHA Web Page. Retrieved 2nd April 2014, from http://http://www.madeira-edu.pt/Portals/31/CEHA/avieira/edennoe

Vieira A (2014b) A fortuna das Afortunadas. CEHA Web Page. Retrieved 19th April 2014, from http://www.madeira-edu.pt/Portals/31/CEHA/avieira/fortunaafortunadas

Vieira DSL (2006) Paisagens e imaginário: Contribuições teóricas para uma história cultural do olhar. *Fénix, Revista de História e Estudos Culturais,* 3(3): 1-14.

Vieira R (2002) Flora da Madeira. Plantas Vasculares Naturalizadas do Arquipélago da Madeira. *Boletim do Museu Municipal do Funchal (História Natural),* Sup. 8: 5-281.

Vieira RMS (1992) *Flora da Madeira. O interesse das plantas endémicas macaronésicas*. Colecção Natureza e Paisagem 11, Serviço Nacional de Parques Reservas e Conservação da Natureza, Lisboa.

Vilà M, Bartomeus I, Gimeno I, Traveset A, Moragues E (2006) Demography of the Invasive Geophyte Oxalis pes-caprae Across a Mediterranean Island. *Annals of Botany,* 97: 1055-1062.

Villalba R, Boninsegna JA, Holmes R (1985) *Cedrela angustifolia* and *Juglans australis*: two new species useful in dendrochronology. *Tree-ring bulletin,* 45: 25-35.

Villar L, Monserrat P (2007) In Memoriam: Le Professeur Oriol de Bolòs *Le Mond Des Plantes* 494: 8-9.

Visconde do Porto da Cruz AFB (1949) *Notas e Comentários para a História Literária da Madeira: 1420-1820*. (Vol. 1), By Author, Funchal.

Visconde do Porto da Cruz AFB (1950) O problema florestal do arquipélago da Madeira, Proceedings of the I Conferência da Liga para Protecção da Natureza, 10-18 Abr, Funchal, Portugal. in: LPN (Ed.), *Publicações da LPN* (IV), LPN e GEFPHM, pp. 105-114.

Vogel JC, Fuls A, Visser E (2001) Radiocarbon adjustments to the dendrochronology of a yellowwood tree. *South African Journal of Science,* 97: 164-166.

Wagner L (Ed.) (1885 *ca.*) *Souvenir da Ilha da Madeira*, Sepia tinted chromolithograph views. Leopoldo Wagner, Lisboa.

Wagner M (2004) The roles of seed dispersal ability and seedling salt tolerance in community assembly of a severey degraded site, in: Temperton VW, Hobbs RJ, Nuttle T, Halle S (Eds.), *Assembly Rules and Restoration Ecology Bridging the Gap Between Theory and Pratice*, Society for Ecological Restoration, Island Press, Washington, pp. 266-284.

Walker LR (1990) Germination of an invading tree species (Myrica faya) in Hawaii. *BIOTROPICA,* 22(2): 140-145.

Wallace AR (1878) *Tropical Nature and other Essays.*, reprinted in 1895 in: Natural Selection and Tropical Nature Essays on Descritive and Theorethical Biology. Macmillan, London.

Way DA, Oren R (2010) Differential responses to changes in growth temperature between trees from different functional groups and biomes: a review and synthesis of data. *Tree Physiology,* 30: 669-688.

Webb PB, Berthelot S (1840) *Histoire Naturelle des iles Canaries*. (Vol. Tome III), Béthune Éditeur, Paris.

Webb RH (1996) *Grand Canyon: A century of change. Rephotography of the 1889-1890 Stanton Expedition.* The University of Arizona Press, Tucson.

Webb RH, Turner RM, Boyer DE (2010a) Introduction: A brief History of Repeat photography in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 3-11.

Webb RH, Boyer DE, Turner RM (Eds.) (2010b) *Repeat Photography Methods and Aplications in the Natural Sciences*. Island Press, Washington.

Wells TS (1880) Notes of an Easter holiday trip to Madeira. *The British Medical Journal,* May 1880: 767-768.

West CJ (2002) Eradication of alien plants on Raoul Island, Kermadec Islands, New Zealand, in: Veitch CR, Clout MN (Eds.), *Turning the tide: the eradication of invasive species*, IUCN Publications Servives Unit, Auckland, pp. 365-373.

Western D (2010) People, Elephants, and habitat: Detecting a Century of Change using Repeat Photography, in: Webb RH, Boyer DE, Turner RM (Eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. 212-222.

White J (1998) *Estimating the Age of Large and Veteran Trees in Britain*. Forestry Commission Information Note 12. Surrey, Unted Kingdom.

White PS, Jentsch A (2004) Disturbance, Succession and community assembly in terrestrial plants communities, in: Temperton VM, Hobbs R, Nuttle T, Halle S (Eds.), *Assembly Rules and Restoration Ecology. Bridging the gap between the theory and practice*, International Island Press, Washington, pp. 342-366.

Whittaker RH (1956) Vegetation of Great Smoky Mountains. *Ecological Monographs,* 26(1): 1-80.

Wilgen Bv, Richardson D, Higgins S (2001) Integrated control of invasive alien plants in terrestrial ecosystems. *Land Use and Water Resources Research,* 1(5): 1-6.

Williams M, Lowenthal D, Denevan WM (2014) *To Pass On a Good Earth. The Life and Work of Carl O. Sauer*. University of Virginia Press, Charlottesville.

Williams PA, Winks C, Rijke W (2003) Forest processes in the presence of wild ginger (*Hedychium gardenerianum*). *New Zeland Journal of Ecology,* 27(1): 45-54.

Wilson RJS, Hopfmuller M (2001) Dendrochronological investigations of Norway spruce along an elevational transect in the Bavarian Forest, Germany. *Dendrochronologia,* 19(1): 67-19.

Witkowski ETF, Garner RD (2008) Seed production, seed bank dynamics, resprouting and long-term response to clearing of the alien invasive Solanum mauritianum in a temperate to subtropical riparian ecosystem. *South African Journal of Botany,* 74: 476-484.

Worbes M (1999) Annual growth rings, rainfall-dependent growth and long-term growth patterns of tropical trees from the Caparo Forest Reserve in Venezuela. *Journal of Ecology,* 87: 391-403.

Worbes M, Staschel R, Roloff A, Junk WJ (2003) Tree ring analysis reveals age structure, dynamics and wood production of natural forest stand in Cameroon. *Forest Ecology and Management,* 173: 105-123.

Worbes M (2004) Tree-ring Analysis. 1-13. Retrieved from
http://www.extranet.elsevier.com/homepage_about/mrwd/arch/Sample_Article.pdf

Wotherspoon SH, Wotherspoon JA (2002) The evolution and execution of plan for invasive weed eradication and control, Rangioto Island, Hauraki Gulf, New Zeland, in: Veitch C, Clout M (Eds.), *Turning the tide: the eradication of invasive species*, IUCN Publications Servives Unit, Auckland, pp. 381-388.

Wu J, Hobbs RJ (2007a) Landscape ecology: the state of the science, in: Wu J, Hobbs RJ (Eds.), *Key Topics in Landscape Ecology*, Cambridge University Press, Cambridge, pp. 271-287.

Wu J (2013) Key concepts and research topics in landscape ecology revisited: 30 years after the Allerton Park workshop. *Landscape Ecology,* 28: 1-11.

Wu J, Hobbs RJ (Eds.) (2007b) *Key Topics in Landscape Ecology*. Cambridge University Press, Cambridge.

Xiong L, Okada N, Fujiwara T (2000) The dendrochronological potential of ten species in the three Gorges Reservoir region of China. *IAWA journal,* 21(2): 181-196.

Yamaguchi DK, Brunstein FG (1991) Special Sanding films and sandpapers for surfacing narrow-ring increment cores. *Tree-ring Bulletin,* 51: 43-46.

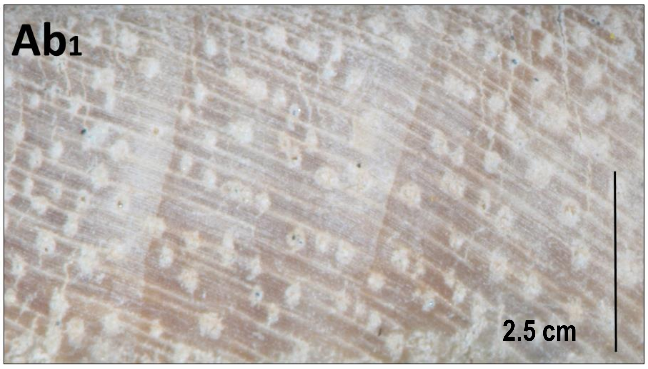
Zier JL, Baker WL (2006) A century of vegetation change in the San Juan Mountains, Colorado: An analysis using repeat photography. *Forest Ecology and Management,* 228: 251-262.

Zimmermann H, Granata G (2002) Insect pests and diseases, in: Nobel PS (Ed.), *Cacti. Biology and Uses*, University of California Press, Berkley, Los Angeles, London, pp. 235-254.

8 Appendices

8.1 Appendix 1 Growth rings and age estimation of more common woody species of Madeiran forests based on height and diameter.

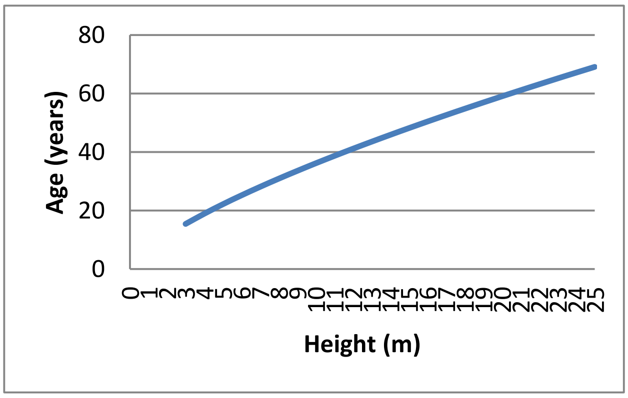
Apollonias barbujana subsp. *barbujana*

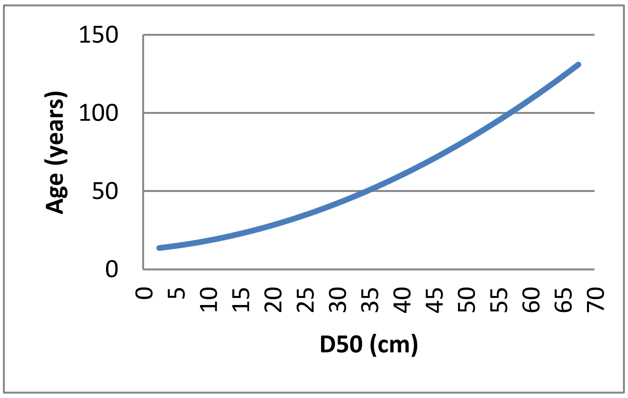


	Model	R2adj	RMSE
Age = 0,0206 D50^2 + 0,3635 D50 + 12,593	Quadratic	0.7050	2.11
Age = 7,116 Alt^{0,7063}	Potencial	0.4990	6.91
Age = 5.55684+0.618967*D_50+1.600449*Height	Potencial	0.6180	6.29

Age estimation by combination of diameter at 50 cm and total height for *Apollonias barbujana* subsp. *barbujana*

	Height (m)	1	2	3	4	5	6	7	8	9	10	11	13	15	17	19	21	23	25
D_50 (cm)	Age (year)	7	12	15	19	22	25	28	31	34	36	39	44	48	53	57	61	65	69
1	13	8	9	11	13	14	16	17	19	21	22	24	27	30	33	37	40	43	46
3	14	9	10	12	14	15	17	18	20	22	23	25	28	31	34	38	41	44	47
5	15	10	12	13	15	17	18	20	21	23	25	26	29	33	36	39	42	45	49
8	16	12	13	15	17	18	20	21	23	25	26	28	31	34	37	41	44	47	50
10	18	13	15	17	18	20	21	23	25	26	28	29	33	36	39	42	45	49	52
13	20	15	16	18	20	21	23	24	26	28	29	31	34	37	41	44	47	50	53
15	23	16	18	20	21	23	24	26	28	29	31	32	36	39	42	45	48	52	55
18	25	18	20	21	23	24	26	28	29	31	32	34	37	40	44	47	50	53	56
20	28	20	21	23	24	26	28	29	31	32	34	36	39	42	45	48	52	55	58
23	31	21	23	24	26	27	29	31	32	34	35	37	40	43	47	50	53	56	59
25	35	23	24	26	27	29	31	32	34	35	37	39	42	45	48	51	55	58	61
28	38	24	26	27	29	31	32	34	35	37	39	40	43	47	50	53	56	59	63
30	42	26	27	29	31	32	34	35	37	39	40	42	45	48	51	55	58	61	64
33	46	27	29	30	32	34	35	37	38	40	42	43	46	50	53	56	59	62	66
35	51	29	30	32	34	35	37	38	40	42	43	45	48	51	54	58	61	64	67
38	55	30	32	34	35	37	38	40	42	43	45	46	50	53	56	59	62	66	69



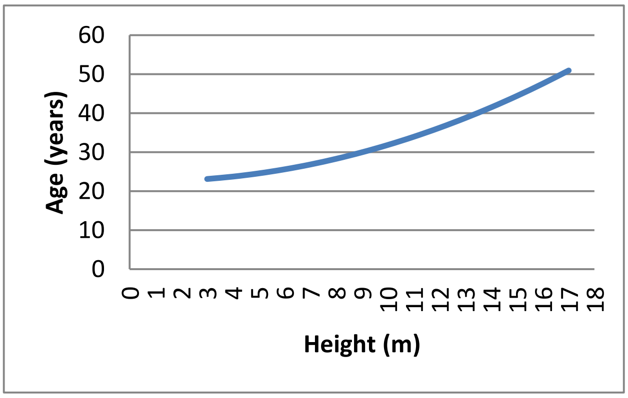


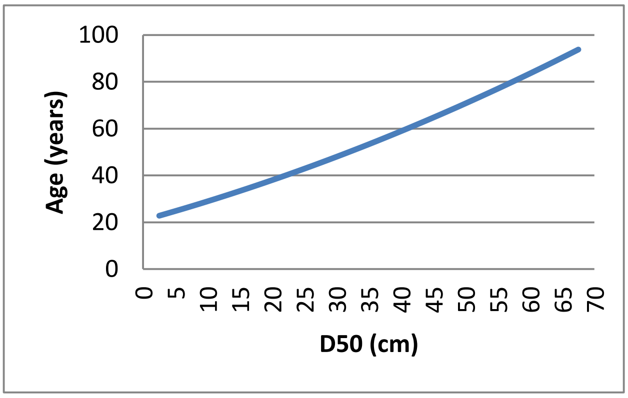
Clethra arborea

	Model	R2adj	RMSE
Age = 14.376*LN(D_50)-2.3918	Logarithm	0.7894	6.24
Age = 7.4612+2.3802*Height+0.0076*Height^2	Quadratic	0.7450	6.35
Age = 12.68283+0.558273*D_50+1.134843*Height		0.7060	6.71

Age estimation by combination of diameter at 50 cm and total height for *Clethra arborea*

	Height (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
D_50 (cm)	Age (year)	10	12	15	17	20	22	24	27	29	32	35	37	40	42	45	47	50
2	3	15	16	17	18	19	20	21	23	24	25	26	27	28	29	31	32	33
3	11	15	16	17	19	20	21	22	23	24	25	27	28	29	30	31	32	33
5	21	17	18	19	20	21	22	23	25	26	27	28	29	30	31	32	34	35
8	27	18	19	20	21	23	24	25	26	27	28	29	30	32	33	34	35	36
10	31	19	21	22	23	24	25	26	27	28	30	31	32	33	34	35	36	38
13	34	21	22	23	24	25	26	28	29	30	31	32	33	34	36	37	38	39
15	37	22	23	24	26	27	28	29	30	31	32	34	35	36	37	38	39	40
18	39	24	25	26	27	28	29	30	32	33	34	35	36	37	38	39	41	42
20	41	25	26	27	28	30	31	32	33	34	35	36	37	39	40	41	42	43
23	42	26	28	29	30	31	32	33	34	35	37	38	39	40	41	42	43	45
25	44	28	29	30	31	32	33	35	36	37	38	39	40	41	43	44	45	46
28	45	29	30	31	33	34	35	36	37	38	39	41	42	43	44	45	46	47
30	47	31	32	33	34	35	36	37	39	40	41	42	43	44	45	46	48	49
33	48	32	33	34	35	37	38	39	40	41	42	43	44	46	47	48	49	50
35	49	33	34	36	37	38	39	40	41	42	44	45	46	47	48	49	50	52
38	50	35	36	37	38	39	40	42	43	44	45	46	47	48	50	51	52	53
40	51	36	37	38	40	41	42	43	44	45	46	47	49	50	51	52	53	54
43	52	38	39	40	41	42	43	44	45	47	48	49	50	51	52	53	55	56





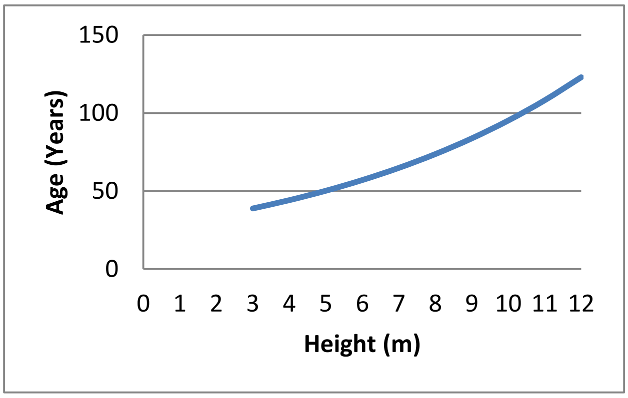
Erica arborea

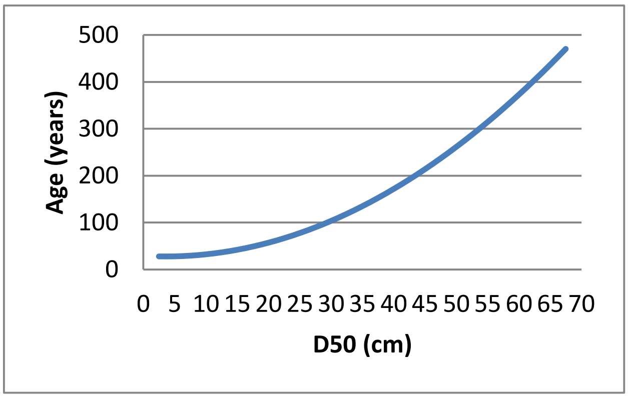
$\text{Age} = 0.6085*D\_50^{1.5577}$
$\text{Age} = 9.4853*\text{EXP}(0.2574*\text{Height})$
$\text{Age} = 1.834584*D\_50+1.769484*\text{Height}+0.005568*(D\_50^{2}*\text{Height})$

Modelo	R2adj	RMSE
Quadratic	0.5979	11.00
Exponential	0.4800	4.56
	0.6360	10.340

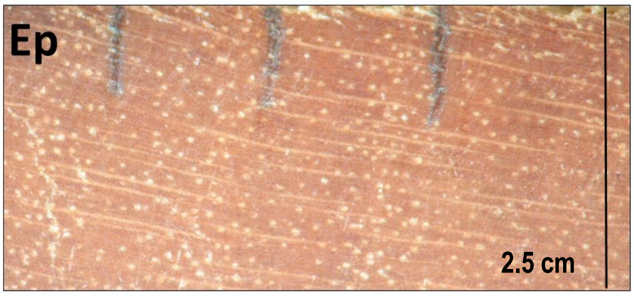
Age estimation by combination of diameter at 50 cm and total height for *Erica arborea*

	Height (m)	1	2	3	4	5	6	7	8	9	10
D_50 (cm)	Age (year)	12	16	21	27	34	44	57	74	96	124
3	3	6	8	10	12	14	15	17	19	21	23
5	7	11	13	15	17	19	21	23	24	26	28
8	14	16	18	20	22	24	26	28	30	33	35
10	22	21	23	25	28	30	32	35	37	39	42
13	31	26	28	31	33	36	39	41	44	47	49
15	41	31	34	37	40	43	46	49	52	55	58
18	53	36	39	43	46	49	53	56	60	63	67
20	65	41	45	49	53	57	61	65	69	73	77
23	78	46	50	55	60	64	69	73	78	83	87
25	92	51	56	62	67	72	77	83	88	93	98
28	106	56	62	68	74	80	86	92	98	104	110
30	122	62	69	75	82	89	96	103	109	116	123
33	138	67	75	83	90	98	106	113	121	128	136
35	155	73	81	90	99	107	116	124	133	142	150
38	172	78	88	98	107	117	126	136	146	155	165





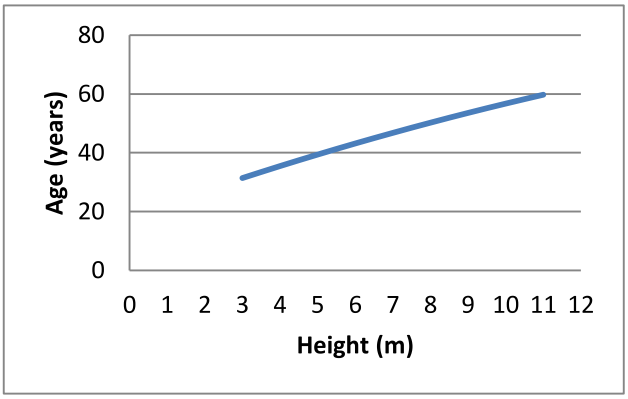
Erica platycodon subsp. *maderincola*

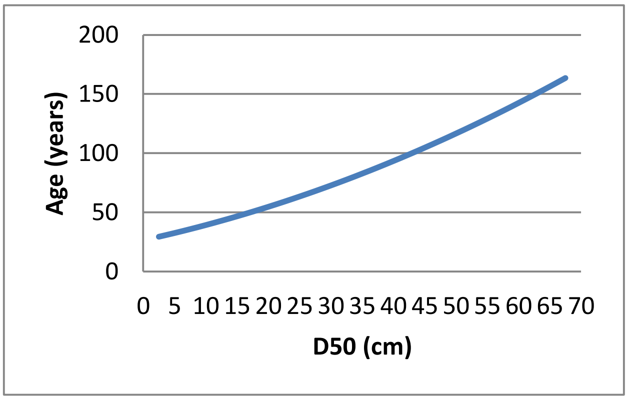


	Model	R2adj	RMSE
$Age = -0.0038*D\_50^{2}+1.6904*D\_50+22.845$	Quadratic	0.6616	7.02
$Age = -0.1706*Height^{2}+6.8575*Height+7.4305$	Quadratic	0.2701	7.13
$Age = 0.85438*D\_50+5.446121*Height$	Combined Variable	0.4441	8.42

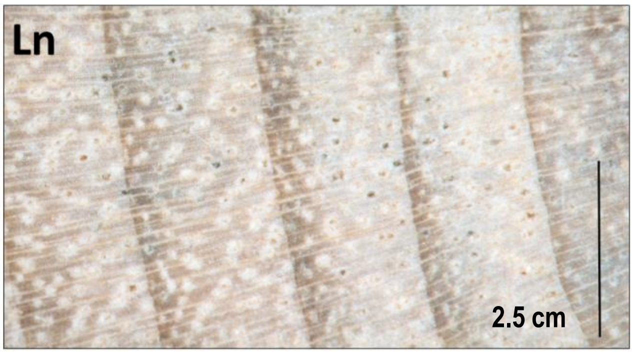
Age estimation by combination of diameter at 50 cm and total height for *Erica platycodon* subsp. *maderincola*

	Height (m)	1	2	3	4	5	6	7	8	9	10	11	12
D_50 (cm)	Age (year)	14	20	26	32	37	42	47	51	55	59	62	65
2,5	27	8	13	18	24	29	35	40	46	51	57	62	67
5,0	31	10	15	21	26	32	37	42	48	53	59	64	70
7,5	35	12	17	23	28	34	39	45	50	55	61	66	72
10,0	39	14	19	25	30	36	41	47	52	58	63	68	74
12,5	43	16	22	27	32	38	43	49	54	60	65	71	76
15,0	47	18	24	29	35	40	45	51	56	62	67	73	78
17,5	51	20	26	31	37	42	48	53	59	64	69	75	80
20,0	55	23	28	33	39	44	50	55	61	66	72	77	82
22,5	59	25	30	36	41	46	52	57	63	68	74	79	85
25,0	63	27	32	38	43	49	54	59	65	70	76	81	87
27,5	66	29	34	40	45	51	56	62	67	73	78	83	89
30,0	70	31	37	42	47	53	58	64	69	75	80	86	91
32,5	74	33	39	44	50	55	60	66	71	77	82	88	93
35,0	77	35	41	46	52	57	63	68	73	79	84	90	95
37,5	81	37	43	48	54	59	65	70	76	81	87	92	97
40,0	84	40	45	51	56	61	67	72	78	83	89	94	100
42,5	88	42	47	53	58	64	69	74	80	85	91	96	102
45,0	91	44	49	55	60	66	71	77	82	87	93	98	104
47,5	95	46	51	57	62	68	73	79	84	90	95	100	106
50,0	98	48	54	59	65	70	75	81	86	92	97	103	108
52,5	101	50	56	61	67	72	78	83	88	94	99	105	110
55,0	104	52	58	63	69	74	80	85	91	96	101	107	112





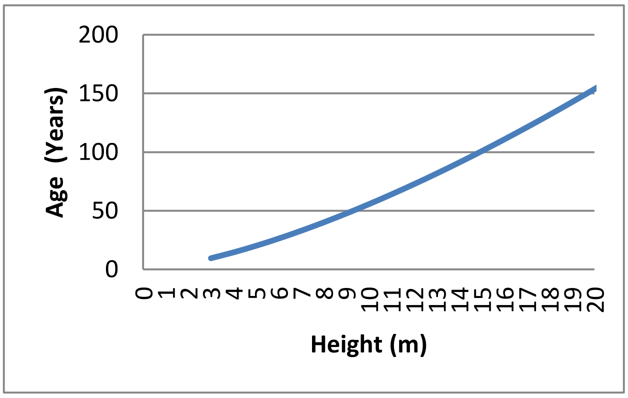
Laurus novocanariensis

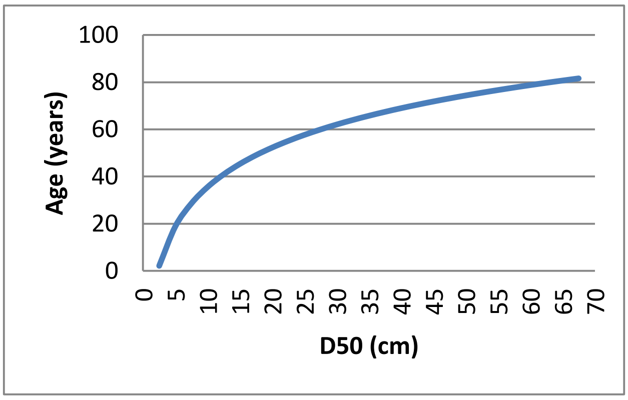


	Model	R2adj	RMSE
Age = 7.9263*D_50$^{0.6198}$	Potencial	0.7198	8.71
Age = 2.8535*Height$^{1.2724}$	Potencial	0.6987	10.32
Age =2.089462*D_50+1.397429*Height		0.7821	7.43

Table 8.1 Age estimation by combination of diameter at 50 cm and total height for *Laurus novocanariensis*

	Height (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
D_50(cm)	Age (year)	3	7	12	17	22	28	34	40	47	53	60	67	75	82	90	97	105	113	121	129
0,5	5	2	4	5	7	8	9	11	12	14	15	16	18	19	21	22	23	25	26	28	29
2,5	14	7	8	9	11	12	14	15	16	18	19	21	22	23	25	26	28	29	30	32	33
5,0	21	12	13	15	16	17	19	20	22	23	24	26	27	29	30	31	33	34	36	37	38
7,5	28	17	18	20	21	23	24	25	27	28	30	31	32	34	35	37	38	39	41	42	44
10,0	33	22	24	25	26	28	29	31	32	33	35	36	38	39	40	42	43	45	46	47	49
12,5	38	28	29	30	32	33	35	36	37	39	40	41	43	44	46	47	48	50	51	53	54
15,0	42	33	34	36	37	38	40	41	43	44	45	47	48	50	51	52	54	55	56	58	59
17,5	47	38	39	41	42	44	45	46	48	49	51	52	53	55	56	58	59	60	62	63	65
20,0	51	43	45	46	47	49	50	52	53	54	56	57	59	60	61	63	64	66	67	68	70
22,5	55	48	50	51	53	54	55	57	58	60	61	62	64	65	67	68	69	71	72	74	75
25,0	58	54	55	56	58	59	61	62	63	65	66	68	69	70	72	73	75	76	77	79	80
27,5	62	59	60	62	63	64	66	67	69	70	71	73	74	76	77	78	80	81	83	84	85
30,0	65	64	65	67	68	70	71	72	74	75	77	78	79	81	82	84	85	86	88	89	91
32,5	69	69	71	72	73	75	76	78	79	80	82	83	85	86	87	89	90	92	93	94	96
35,0	72	75	76	77	79	80	82	83	84	86	87	89	90	91	93	94	95	97	98	100	101
37,5	75	80	81	83	84	85	87	88	90	91	92	94	95	97	98	99	101	102	104	105	106
40,0	78	85	86	88	89	91	92	93	95	96	98	99	100	102	103	105	106	107	109	110	112
42,5	81	90	92	93	94	96	97	99	100	101	103	104	106	107	108	110	111	113	114	115	117
45,0	84	95	97	98	100	101	102	104	105	107	108	109	111	112	114	115	116	118	119	121	122
47,5	87	101	102	103	105	106	108	109	110	112	113	115	116	117	119	120	122	123	124	126	127
50,0	90	106	107	109	110	111	113	114	116	117	118	120	121	123	124	125	127	128	130	131	132



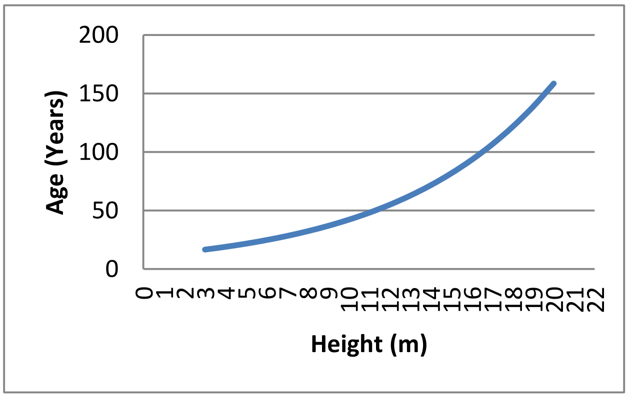


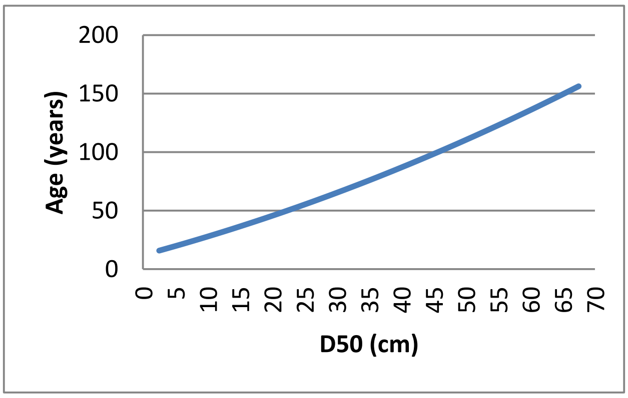
Myrica faya

	Model	R2adj	RMSE
$Age = 0.0037 * D\_50^2 + 1.8258 * D\_50 + 8.2891$	Quadratic	0.729	9.58
$Age = 0.307 * Height^2 + 0.6743 * Height + 7.3465$	Quadratic	0.678	11.93
$Age = 6.006387 + 0.839753 * D\_50 + 0.399259 * Height + 0.085428 * D\_50 * Height$		0.737	9.68

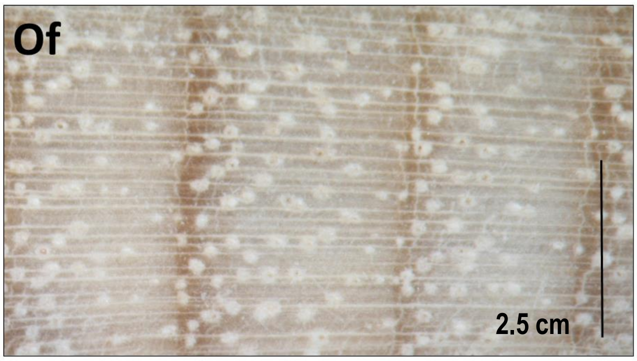
Age estimation by combination of diameter at 50 cm and total height for *Myrica faya*

	Height (m)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
D_50 (cm)	Age (year)	10	12	15	18	22	27	32	38	45	52	60	68	77	87	97	108	119	131	144
2,5	13	9	10	11	11	12	12	13	14	14	15	15	16	17	17	18	19	19	20	20
5,0	18	12	13	14	14	15	16	17	18	18	19	20	21	22	23	23	24	25	26	27
7,5	22	14	15	16	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
10,0	27	17	18	19	21	22	23	24	26	27	28	29	31	32	33	34	36	37	38	39
12,5	32	19	21	22	24	25	27	28	30	31	33	34	36	37	39	40	41	43	44	46
15,0	37	22	24	25	27	29	30	32	34	35	37	39	40	42	44	45	47	49	51	52
17,5	41	24	26	28	30	32	34	36	38	40	42	43	45	47	49	51	53	55	57	59
20,0	46	27	29	31	33	35	38	40	42	44	46	48	50	52	54	57	59	61	63	65
22,5	51	30	32	34	37	39	41	43	46	48	50	53	55	57	60	62	64	67	69	71
25,0	56	32	35	37	40	42	45	47	50	52	55	57	60	62	65	68	70	73	75	78
27,5	61	35	37	40	43	46	48	51	54	57	59	62	65	68	70	73	76	79	81	84
30,0	66	37	40	43	46	49	52	55	58	61	64	67	70	73	76	79	82	85	87	90
32,5	72	40	43	46	49	52	56	59	62	65	68	71	75	78	81	84	87	90	94	97
35,0	77	42	46	49	52	56	59	63	66	69	73	76	79	83	86	90	93	96	100	103
37,5	82	45	48	52	56	59	63	66	70	74	77	81	84	88	92	95	99	102	106	110
40,0	87	47	51	55	59	62	66	70	74	78	82	85	89	93	97	101	104	108	112	116
42,5	93	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	110	114	118	122
45,0	98	52	57	61	65	69	73	78	82	86	90	95	99	103	107	112	116	120	124	129
47,5	103	55	59	64	68	73	77	82	86	90	95	99	104	108	113	117	122	126	131	135
50,0	109	57	62	67	71	76	81	85	90	95	99	104	109	113	118	123	127	132	137	141





Ocotea foetens



Age= 0.0259*D_50^2+1.0587*D_50+19.85

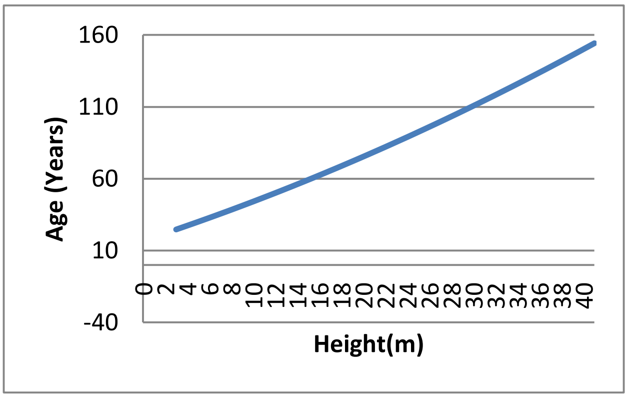
Age= 0.0204*Height^2+2.5129*Height+16.959

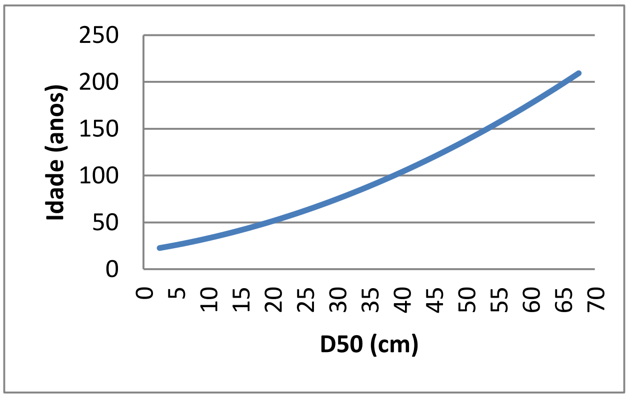
Age = 9.122718+2.097722*D_50+0.66863*Height

Model	R2adj	RMSE
Quadratic	0.8907	7.96
Quadratic	0.6835	13.00
Potential	0.8931	7.56

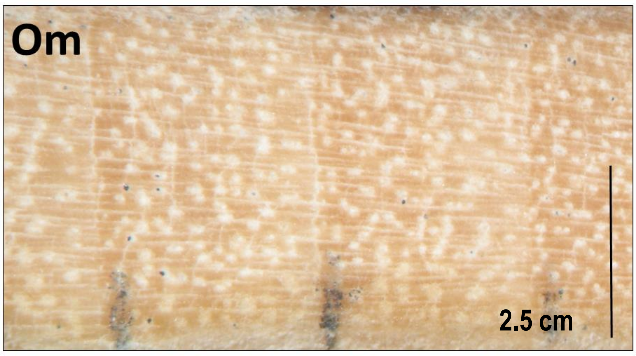
Age estimation by combination of diameter at 50 cm and total height for *Ocotea foetens*

	Height (m)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
D_50 (cm)	Age (year)	22	27	33	38	44	50	56	62	69	75	82	89	96	103	111	118	126	134	142	150	158
1	21	13	14	15	17	18	19	21	22	23	25	26	27	29	30	31	33	34	35	37	38	39
2,5	23	16	17	18	20	21	22	24	25	26	28	29	30	32	33	34	36	37	38	40	41	42
5,0	26	21	22	24	25	26	28	29	30	32	33	34	36	37	38	40	41	42	44	45	46	48
7,5	29	26	28	29	30	32	33	34	36	37	38	40	41	42	44	45	46	48	49	50	52	53
10,0	33	31	33	34	35	37	38	39	41	42	43	45	46	47	49	50	51	53	54	56	57	58
12,5	37	37	38	39	41	42	43	45	46	47	49	50	51	53	54	55	57	58	59	61	62	63
15,0	42	42	43	45	46	47	49	50	51	53	54	55	57	58	59	61	62	63	65	66	67	69
17,5	46	47	49	50	51	53	54	55	57	58	59	61	62	63	65	66	67	69	70	71	73	74
20,0	51	52	54	55	56	58	59	60	62	63	64	66	67	68	70	71	72	74	75	76	78	79
22,5	57	58	59	60	62	63	64	66	67	68	70	71	72	74	75	76	78	79	80	82	83	84
25,0	63	63	64	66	67	68	70	71	72	74	75	76	78	79	80	82	83	84	86	87	88	90
27,5	69	68	69	71	72	73	75	76	78	79	80	82	83	84	86	87	88	90	91	92	94	95
30,0	75	73	75	76	77	79	80	81	83	84	85	87	88	89	91	92	93	95	96	97	99	100
32,5	82	79	80	81	83	84	85	87	88	89	91	92	93	95	96	97	99	100	101	103	104	105
35,0	89	84	85	87	88	89	91	92	93	95	96	97	99	100	101	103	104	105	107	108	109	111
37,5	96	89	90	92	93	94	96	97	98	100	101	102	104	105	107	108	109	111	112	113	115	116
40,0	104	94	96	97	98	100	101	102	104	105	106	108	109	110	112	113	114	116	117	118	120	121
42,5	112	100	101	102	104	105	106	108	109	110	112	113	114	116	117	118	120	121	122	124	125	126
45,0	120	105	106	108	109	110	112	113	114	116	117	118	120	121	122	124	125	126	128	129	130	132
47,5	129	110	111	113	114	115	117	118	119	121	122	123	125	126	127	129	130	131	133	134	136	137
50,0	138	115	117	118	119	121	122	123	125	126	127	129	130	131	133	134	135	137	138	139	141	142
55,0	156	126	127	129	130	131	133	134	135	137	138	139	141	142	143	145	146	147	149	150	151	153
60,0	177	136	138	139	140	142	143	144	146	147	148	150	151	152	154	155	156	158	159	160	162	163
65,0	198	147	148	149	151	152	153	155	156	158	159	160	162	163	164	166	167	168	170	171	172	174
70,0	221	157	159	160	161	163	164	165	167	168	169	171	172	173	175	176	177	179	180	181	183	184
75,0	245	168	169	170	172	173	174	176	177	178	180	181	182	184	185	187	188	189	191	192	193	195
80,0	270	178	180	181	182	184	185	186	188	189	190	192	193	194	196	197	198	200	201	202	204	205
85,0	297	189	190	191	193	194	195	197	198	199	201	202	203	205	206	207	209	210	211	213	214	216
90,0	325	199	201	202	203	205	206	207	209	210	211	213	214	215	217	218	219	221	222	223	225	226
95,0	354	210	211	212	214	215	216	218	219	220	222	223	224	226	227	228	230	231	232	234	235	236
100,0	385	220	222	223	224	226	227	228	230	231	232	234	235	236	238	239	240	242	243	244	246	247
105,0	417	231	232	233	235	236	237	239	240	241	243	244	245	247	248	249	251	252	253	255	256	257
110,0	450	241	243	244	245	247	248	249	251	252	253	255	256	257	259	260	261	263	264	265	267	268





Olea maderensis

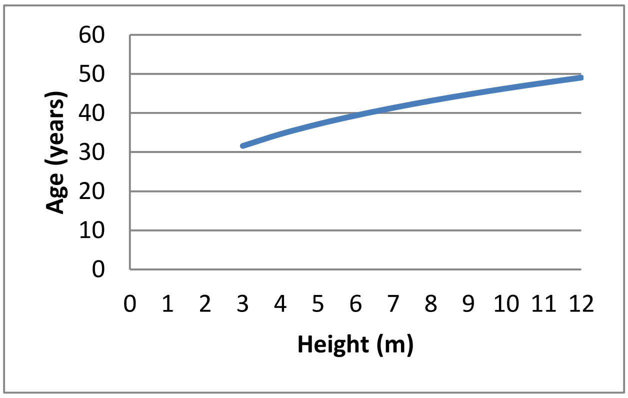


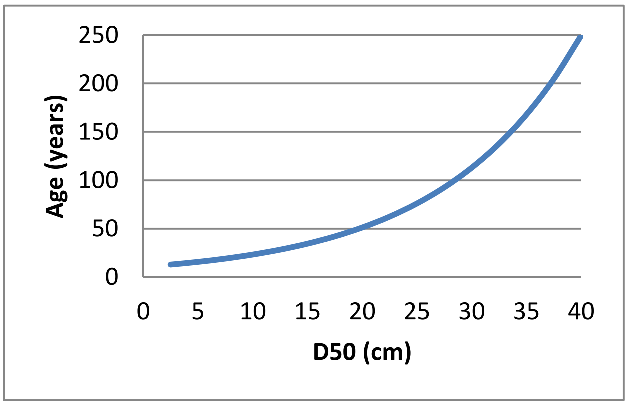
$\text{Age} = 22.286 * \text{Height}^{0.3176}$
$\text{Age} = 10.448 * \text{EXP}(0.0793 * \text{D\_50})$
$\text{Age} = 6{,}9071\ (\text{D\_50\^{}2 Height})^{0{,}2329}$

Model	R2adj	RMSE
Exponential	0.5389	9.20
Potential	0.2096	4.94
Potential	0.3323	11.522

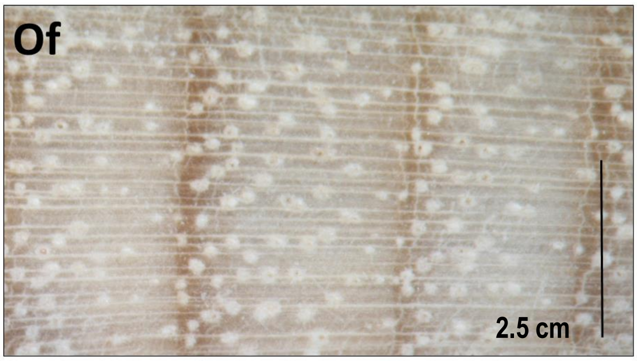
Table 8.2 Age estimation by combination of diameter at 50 cm and total height for *Olea maderensis*

	Height (m)	1	2	3	4	5	6	7	8	9	10
D_50 (cm)	Age (year)	22	28	32	35	37	39	41	43	45	46
2,5	13	11	12	14	15	15	16	17	17	18	18
5,0	16	15	17	19	20	21	22	23	24	24	25
7,5	19	18	21	23	24	26	27	28	29	29	30
10,0	23	20	24	26	28	29	31	32	33	34	35
12,5	28	22	26	29	31	33	34	35	36	37	38
15,0	34	24	29	31	34	35	37	38	40	41	42
17,5	42	26	31	34	36	38	40	41	43	44	45
20,0	51	28	33	36	39	41	42	44	45	47	48
22,5	62	29	35	38	41	43	45	46	48	49	50
25,0	76	31	36	40	43	45	47	49	50	52	53





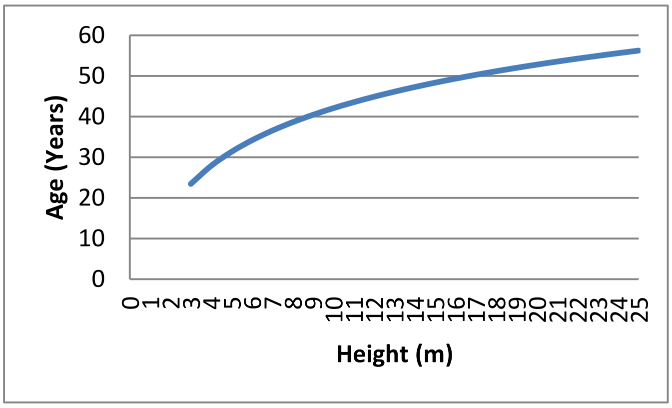
Persea indica

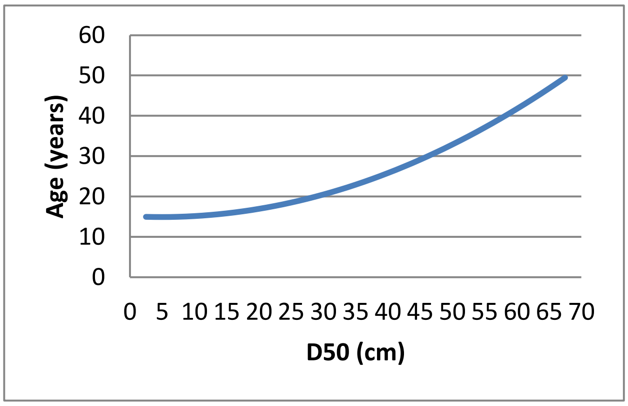


	Model	R2adj	RMSE
Age = $0{,}0088\ D\_50^2 - 0{,}0849\ D\_50 + 15{,}112$	Quadratic	0.3713	3.20
Age= $15{,}47\ \ln(\text{Height}) + 6{,}4189$	Logarithm	0.4093	11.9
Age = $0.253904\ D\_50 + 1.992551\ \text{Height}$	Combined Variable	0.5404	9.9

Table 8.3 Age estimation by combination of diameter at 50 cm and total height for *Persea indica*

	Height (m)	2	4	6	8	10	12	14	16	18	20	22
D_50 (cm)	Age (year)	17	28	34	39	42	45	47	49	51	53	54
2,5	15	5	9	13	17	21	25	29	33	37	40	44
5,0	15	5	9	13	17	21	25	29	33	37	41	45
7,5	15	6	10	14	18	22	26	30	34	38	42	46
10,0	15	7	11	14	18	22	26	30	34	38	42	46
12,5	15	7	11	15	19	23	27	31	35	39	43	47
15,0	16	8	12	16	20	24	28	32	36	40	44	48
17,5	16	8	12	16	20	24	28	32	36	40	44	48
20,0	17	9	13	17	21	25	29	33	37	41	45	49
22,5	18	10	14	18	22	26	30	34	38	42	46	50
25,0	18	10	14	18	22	26	30	34	38	42	46	50
27,5	19	11	15	19	23	27	31	35	39	43	47	51
30,0	20	12	16	20	24	28	32	36	39	43	47	51
32,5	22	12	16	20	24	28	32	36	40	44	48	52
35,0	23	13	17	21	25	29	33	37	41	45	49	53
37,5	24	14	17	21	25	29	33	37	41	45	49	53
40,0	26	14	18	22	26	30	34	38	42	46	50	54
42,5	27	15	19	23	27	31	35	39	43	47	51	55
45,0	29	15	19	23	27	31	35	39	43	47	51	55
47,5	31	16	20	24	28	32	36	40	44	48	52	56
50,0	33	17	21	25	29	33	37	41	45	49	53	57
55,0	37	18	22	26	30	34	38	42	46	50	54	58
60,0	42	19	23	27	31	35	39	43	47	51	55	59
65,0	47	20	24	28	32	36	40	44	48	52	56	60
70,0	52	22	26	30	34	38	42	46	50	54	58	62
75,0	58	23	27	31	35	39	43	47	51	55	59	63
80,0	65	24	28	32	36	40	44	48	52	56	60	64
85,0	71	26	30	34	38	42	45	49	53	57	61	65



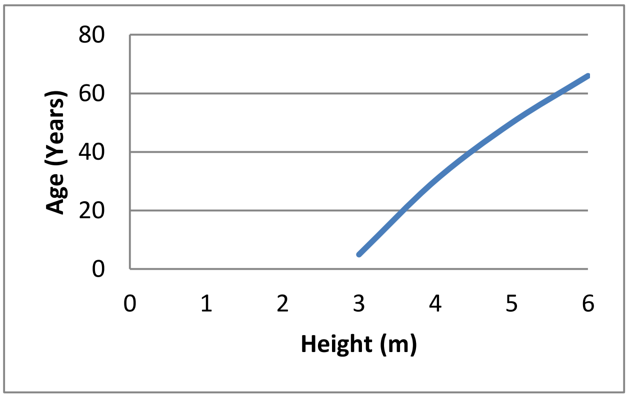


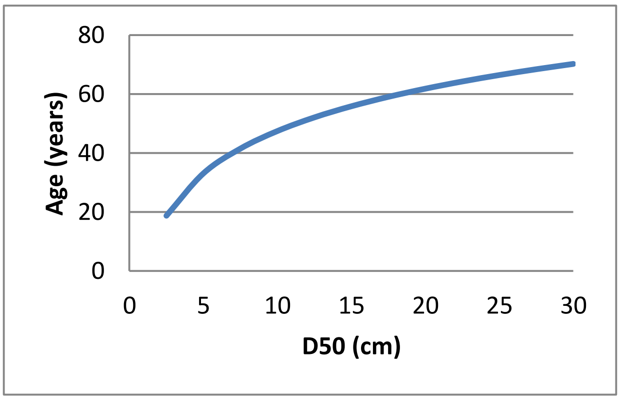
Vaccinium padifollium

	Model	R2adj	RMSE
Age = 20.717ln(D_50) - 0.2068	Logarithm	0.8492	2.811
Age = 2.3427*EXP(0.6355*Height)	Logarithm	0.7930	2.803
Age =8.3529*(D_50^2*Height)$^{0.2916}$		0.7330	3.376

Table 8.4 Age estimation by combination of diameter at 50 cm and total height for *Vaccinium padifolium*

	Height (m)	1	2	3	4	5
D_50 (cm)	Age (year)	4	8	16	30	56
1,1	2	9	11	12	13	14
2,5	19	14	17	20	21	23
5	33	21	26	29	32	34
7,5	42	27	33	37	41	43
10	47	32	39	44	48	51





8.2 Appendix 2: Detailed characterisation of land cover classes

Note: Designations light grey highlighted correspond to the 143 classes of the higher level of classification (sixth level).

1.1. Level 1

Land Cover Classes

Code	Designation	Description
First Level (Code_1)		
1	**Construction**	Various types of built structures (housing, industrial, roads). No distinction was made within this class. From this to sixth level the codes were as following: 11; 111; 1111; 11111; 111111.
2	**Agriculture**	Cultivated areas (second level).
3	**Vegetation**	Areas almost entirely covered by vegetation (second level).
4	**Bare ground**	Areas without vegetation cover (second level).
5	**Water**	Areas covered by water, snow. No distinction was made within this class. From this to sixth level the codes were as following: 51; 511; 5111; 51111; 511111.
6	**Non-sampled**	Features that were not used for comparison as ocean, sky, background (very distant landscapes), and unmatched areas between old and new photo. No distinction was made within this class. From this to sixth level the codes were as following: 61; 611; 6111; 61111; 611111.

1.2. Level 2 and Level 3 of Agriculture Classes

Agriculture Cover Classes

Code	Designation	Description
Second Level (Code_2)		
21	**Unidentified/varied agriculture**	Fields with highly diverse agriculture or cultivation type not clearly recognised identified by terraces. No distinction was made within this class. From this to sixth level the codes were as following: 211; 2111; 21111; 211111.
22	**Permanent cropland**	Lands cultivated with plants which last for many seasons (third level).
23	**Seasonal cropland**	Lands cultivated with seasonal crops or short-term semi-permanent cultivations (third level).
24	**Set-aside land**	Set-aside land (third level).
Third Level (Code_3)		
221	**Permanent crops - Orchards**	No distinction was made within this class. From this to sixth level the codes were as following: 2211; 22111; 221111.
222	**Permanent crops - Vineyards**	No distinction was made within this class. From this to sixth level the codes were as following: 2221; 22211; 222111.
223	**Permanent crops - Banana tree plantations**	No distinction was made within this class. From this to sixth level the codes were as following: 2231; 22311; 223111.
231	**Seasonal crops - Vegetables crops**	No distinction was made within this class. From this to sixth level the codes were as following: 2311; 23111; 231111.
232	**Seasonal crops - Cereals crops**	No distinction was made within this class. From this to sixth level the codes were as following: 2321; 23211; 232111.
233	**Seasonal crops -Sugar cane plantations**	No distinction was made within this class. From this to sixth level the codes were as following: 2331; 23311; 233111.
241	**Set-aside land - Forsaken fields**	Abandoned fields with remnants of former crops. No distinction was made within this class. From this to sixth level the codes were as following: 2411; 24111; 241111.
242	**Set-aside land - Fallow agricultural land**	Fields looking recently abandoned surrounded by farmland. No distinction was made within this class. From this to sixth level the codes were as following: 2421; 24211; 242111.

1.3. Level 2, 3, 4, 5, and 6 of Vegetation Classes

Vegetation Cover Classes		
Code	**Designation**	**Description**
Second Level (Code_2)		
31	**Forest vegetation**	Areas with trees (third level).
32	**Non-forest vegetation**	Areas with smaller plants (shrubs and herbs) (third level).
33	**Forest/ Non-forest vegetation mosaic**	Areas with forest intermingled with scrubland and grassland (third level).
34	**Degraded vegetation**	Areas where vegetation was affected by a visible, clear and recent disturbance (third level)
Third Level (Code_3)		
311	Forest vegetation-**Unidentified trees**	Areas with plants reaching the size of a tree without peculiar features to enable *taxa* identification, seen in the background of old photographs. No distinction was made within this class. From this to sixth level the codes were as following: 3111; 31111; 311111.
312	Forest vegetation-**Native trees**	Plant communities clearly dominated by tree species belonging to natural flora of Madeira (fourth level).
313	Forest vegetation-**Exotic trees**	Plant communities clearly dominated by trees of foreign origin fully naturalised or acclimatised (fourth level).
314	Forest vegetation-**Mixture of native and exotic trees**	Native woodlands invaded by exotic trees, or exotic forest stands with native tree species regeneration without clear dominance. No distinction was made within this class. From this to sixth level the codes were as following: 3141; 31411; 314111.
321	Non-forest vegetation**- Unidentified none-forest vegetation**	Thickets and grasslands without peculiar features to enable *taxa* identification seen in the background of old photographs. No distinction was made within this class. From this to sixth level the codes were as following: 3211; 32111; 321111.
322	Non-forest vegetation**- Native non-forest vegetation**	Native shrubs, climbers and herbs, for which was possible to identify the *taxa* or the community (fourth level).
323	Non-forest vegetation**- Exotic non-forest vegetation**	Exotic shrubs, climbers and herbs, for which was possible to identify the *taxa* (fourth level).
324	Non-forest vegetation**- Mixture of native and exotic non-arboreal plants**	Scrublands/grasslands with native and exotic species without clear dominance. No distinction was made within this class. From this to sixth level the codes were as following: 3241; 32411; 324111.
331	Forest/ Non-forest vegetation mosaic **– Mosaic of climax community and substitution stages**	Vegetation patches sampled all together when it was not possible to separate the different communities intermingled in a complex mosaic. Included both well-developed mature communities with high degree of connectivity, and disconnected areas (fourth level).
332	Forest/ Non-forest vegetation mosaic **– Mixture of native trees and exotic non-arboreal plants**	Native woodlands invaded by exotic shrubs, climbers and herbs (fourth level).
333	Forest/ Non-forest vegetation mosaic **- Mixture of exotic trees and native non-arboreal plants**	Exotic forest stands with native shrubs, climbers and herbs. (table fourth level).
334	Forest/ Non-forest vegetation mosaic **- Mixture of exotic trees and exotic non-arboreal plants**	Exotic forest stands with exotic shrubs, climbers and herbs (table fourth level).
335	Forest/ Non-forest vegetation mosaic **- Mixture of trees and non-arboreal plants (exotic and native)**	Gardens, parks, and other urban green spaces. No distinction was made within this class. From this to sixth level the codes were as following: 3351; 33511; 335111.
341	Degraded vegetation **– Burnt vegetation**	Vegetation damaged by fire. No distinction was made within this class. From this to sixth level the codes were as following: 3411; 34111; 341111.
342	Degraded vegetation **- Landslide**	Vegetation damaged by landslides. No distinction was made within this class. From this to sixth level the codes were as following: 3421; 34211; 342111.
343	Degraded vegetation **– Uncovered soil**	Bare soil or covered by low vegetation growing sparsely (fourth level).
Fourth Level (Code_4)		
3121	Forest vegetation-Native trees **– Climatophylous communities**	Plant communities clearly dominated by tree species belonging to the forest stage of climatophylous series that can occur in the area accordingly to Capelo *et al* (2004) (fifth level)
3122	Forest vegetation-Native trees **– Edaphohigrophylous communities**	Plant communities clearly dominated by tree species belonging to the hygrophillic forests that can occur in the area accordingly to Capelo *et al* (2004) (fifth level)
3131	Forest vegetation-Exotic trees **- Hardwood forests**	Forest stands clearly dominated by broadleaf trees (fifth level)

3132	**Forest vegetation-Exotic trees – Softwood forests**	Forest stands clearly dominated by conifers (fifth level)
3133	**Forest vegetation-Exotic trees – Mixture of hardwood and softwood trees**	Mixed forest stands of conifers and broadleaf trees without a clear dominance. No distinction was made within this class. From this to sixth level the codes were as following: 31331; 313311.
3221	**Non-forest vegetation- Native non-forest vegetation – Native scrubland**	Plant communities clearly dominated by shrub species belonging to the seral stages of climatophylous series that can occur in the area accordingly to Capelo *et al* (2004) (fifth level).
3222	**Non-forest vegetation- Native non-forest vegetation – Native grassland**	Plant communities clearly dominated by herbaceous species belonging to the seral stages of climatophylous series that can occur in the area accordingly to Capelo *et al* (2004) (fifth level)
3223	**Non-forest vegetation- Native non-forest vegetation – Mixture of native shrubs and *Rubus* spp.**	Vegetation patches sampled all together when it was not possible to separate the shrubs communities of seral stages intermingled in a complex mosaic with climbing shrubs (*Rubus* spp.). No distinction was made within this class. From this to sixth level the codes were as following: 32231; 322311.
3224	**Non-forest vegetation- Mosaic of native scrubland and grassland**	Vegetation patches sampled all together when it was not possible to separate the shrub communities of seral stages intermingled in a complex mosaic with forbs and grasses (table fifth level).
3225	**Non-forest vegetation- Native non-forest vegetation – Rupicolous vegetation**	Communities found on rocky cliffs and scarps (fifth level)
3226	**Non-forest vegetation - Native non-forest vegetation - Hygrophilic vegetation**	Herbaceous plants located along riparian environments (fifth level).
3227	**Non-forest vegetation - Native non-forest vegetation - Coastal vegetation**	Communities found on coastline rocks and soils. No distinction was made within this class. From this to sixth level the codes were as following: 32271; 322711.
3231	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs**	Exotic shrubs and climbers, for which was possible to identify the *taxa* (fifth level).
3233	**Non-forest vegetation - Exotic non-forest vegetation – Exotic herbs**	Exotic herbs, for which was possible to identify the *taxa* (fifth level).
3234	**Non-forest vegetation - Exotic non-forest vegetation – Mixture of exotic shrubs and herbs**	Mixture of exotic shrubs and exotic herbs (fifth level).
3235	**Non-forest vegetation - Exotic non-forest vegetation – Hygrophilic exotic vegetation (*Arundo donax*)**	Plant assemblages dominated by *Arundo donax*. No distinction was made within this class. From this to sixth level the codes were as following: 32351; 323511.
3311	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – Mosaic of natural vegetation assemblages (Unidentified communities)**	Vegetation patches with pattern of natural vegetation assemblages but without peculiar features to enable *taxa* identification; seen in the background of old photographs. No distinction was made within this class. From this to sixth level the codes were as following: 33111; 333111.
3312	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Oleetum* and seral stages**	Vegetation patches sampled all together when it was not possible to separate the forest community from seral stages intermingled in a complex mosaic (fifth level).
3313	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Apollonietum* and seral stages**	Vegetation patches sampled all together when it was not possible to separate the forest community from seral stages intermingled in a complex mosaic (fifth level).
3314	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ocoteetum* and seral stages**	Vegetation patches sampled all together when it was not possible to separate the forest community from seral stages intermingled in a complex mosaic (fifth level).
3315	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ericetum* and seral stages**	Vegetation patches sampled all together when it was not possible to separate the forest community from seral stages intermingled in a complex mosaic (fifth level).
3321	**Forest/ Non-forest vegetation mosaic – Mixture of native trees and exotic non-arboreal plants – Native trees and exotic shrubs**	Native woodlands invaded by exotic shrubs and climbers (fifth level).
3322	**Forest/ Non-forest vegetation mosaic – Mixture of native trees and exotic non-arboreal plants - Native trees and unidentified exotic herbs**	Native woodlands invaded by unidentified exotic herbs. No distinction was made within this class. From this to sixth level the codes were as following: 33221; 332211.
3331	**Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-**	Exotic forest stands with native shrubs, climbers and herbs (fifth level).

	arboreal plants **– Exotic trees and native shrubs**	
3332	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants **– Exotic trees and native herbs**	Exotic forest stands with native shrubs, climbers and herbs (fifth level).
3341	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-arboreal plants **– Exotic trees and exotic shrubs**	Exotic forest stands with exotic shrubs and climbers (fifth level).
3342	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-arboreal plants **– Exotic trees and exotic herbs**	Exotic forest stands with exotic herbs (fifth level).
3431	Degraded vegetation – Uncovered soil **– Bare soil**	Bare soil in trails or due cattle treading. No distinction was made within this class. From this to sixth level the codes were as following: 34311; 343111.
3432	Degraded vegetation – Uncovered soil **– Soil with very sparse vegetation**	Soil covered by low vegetation growing sparsely. No distinction was made within this class. From this to sixth level the codes were as following: 34321; 343211.
Fifth Level (Code_5)		
31211	Forest vegetation-Native trees – Climatophylous communities **– *Mayteno umbellatae-Oleetum maderensis***	Plant community clearly dominated by *Olea maderensis* occurring in the potential area accordingly to Capelo *et al* (2004). No distinction was made within this class. From this to sixth level the codes were as following: 312111.
31212	Forest vegetation-Native trees – Climatophylous communities **- *Helichryso melaleuci-Siderxyletum marmulanae***	Plant community clearly dominated by *Siderxylon mirmulans* occurring in the potential area accordingly to Capelo *et al* (2004). No distinction was made within this class. From this to sixth level the codes were as following: 312121.
31213	Forest vegetation-Native trees – Climatophylous communities **- *Semele androgynae-Apollonietum barbujanae***	Plant community clearly dominated by *Apollonias barbujana* subsp. *barbujana* occurring in the potential area accordingly to Capelo *et al* (2004). No distinction was made within this class. From this to sixth level the codes were as following: 312131.
31214	Forest vegetation-Native trees – Climatophylous communities **- *Clethro arboreae-Ocoteetum foetentis***	Plant community clearly dominated *Ocotea foetens* occurring in the potential area accordingly to Capelo *et al* (2004). No distinction was made within this class. From this to sixth level the codes were as following: 312141.
31215	Forest vegetation-Native trees – Climatophylous communities **- *Polysticho falcinelli-Ericetum arboreae***	Plant community clearly dominated by *Erica arborea* occurring in the potential area accordingly to Capelo *et al* (2004). No distinction was made within this class. From this to sixth level the codes were as following: 312141.
31221	Forest vegetation-Native trees – Edaphohigrophylous communities **- *Rhamno glandulosi-Sambucetum lanceolati***	Plant community clearly dominated by *Sambucus lanceolata* occurring in upper course of permanent streams accordingly to Capelo et *al* (2004). No distinction was made within this class. From this to sixth level the codes were as following: 312211.
31222	Forest vegetation-Native trees – Edaphohigrophylous communities **- *Diplazio caudati-Perseetum indicae***	Plant community clearly dominated by *Persea indica* occurring in middle stretches of permanent streams accordingly to Capelo *et al* (2004). No distinction was made within this class. From this to sixth level the codes were as following: 312221.
31223	Forest vegetation-Native trees – Edaphohigrophylous communities **- *Scrophulario hirtae-Salicetum canariensis***	Plant community clearly dominated *Salix canariensis* occurring in lower parts of permanent streams accordingly to Capelo *et al* (2004). No distinction was made within this class. From this to sixth level the codes were as following: 312231.
31311	Forest vegetation-Exotic trees - Hardwood forests **– *Acacia* spp.**	Stands clearly dominated by trees of genus *Acacia* (sixth level).
31312	Forest vegetation-Exotic trees - Hardwood forests **– *Eucalyptus globulus***	Stands clearly dominated by *Eucalyptus globulus*. No distinction was made within this class. From this to sixth level the codes were as following: 313121.
31313	Forest vegetation-Exotic trees - Hardwood forests **– Pittosporum *undulatum***	Stands clearly dominated by *Pittosporum undulatum*. No distinction was made within this class. From this to sixth level the codes were as following: 313131.
31314	Forest vegetation-Exotic trees - Hardwood forests **– *Castanea sativa***	Stands clearly dominated by *Castanea sativa*. No distinction was made within this class. From this to sixth level the codes were as following: 313141.
31315	Forest vegetation-Exotic trees - Hardwood forests **– *Quercus* spp.**	Stands clearly dominated by trees of genus *Quercus* (sixth level).

31317	Forest vegetation-Exotic trees - Hardwood forests **– *Salix babilonica***	Stands clearly dominated by *Salix babilonica* No distinction was made within this class. From this to sixth level the codes were as following: 313171
31318	Forest vegetation-Exotic trees - Hardwood forests **– *Phoenix canariensis***	Stands clearly dominated by *Phoenix canariensis*. No distinction was made within this class. From this to sixth level the codes were as following: 313181
31319	Forest vegetation-Exotic trees - Hardwood forests **– Mixture of hardwood trees**	Stands with different broadleaf trees without clear dominance. No distinction was made within this class. From this to sixth level the codes were as following: 313191.
31321	Forest vegetation-Exotic trees **– Softwood forests- *Pinus* spp.**	Stands clearly dominated by trees of genus *Pinus* (sixth level).)
32211	Non-forest vegetation**-** Native non-forest vegetation – Native scrubland **– Scrubland seral stage**	Plant communities clearly dominated by high–scrub and low-scrub species belonging to natural hedges and substitution stages of climatophylous series that can occur in the area accordingly to Capelo *et al* (2004) (sixth level).
32212	Non-forest vegetation**-** Native non-forest vegetation – Native scrubland – **topographical climax**	High–scrub and low-scrub as permanent community in very steep cliffs (sixth level)
32221	Non-forest vegetation**-** Native non-forest vegetation – Native grassland **– Perennial grassland seral stage**	Plant communities clearly dominated by perennial forbs and grasses belonging to seral stages of climatophylous series that can occur in the area accordingly to Capelo *et al* (2004) (sixth level).
32222	Non-forest vegetation**-** Native non-forest vegetation – Native grassland **– Non-seral herbaceous perennial plants (*Pteridium aquilinum*)**	Single species stands of *Pteridium aquilinum*. No distinction was made within this class. From this to sixth level the codes were as following: 322221.
32223	Non-forest vegetation**-** Native non-forest vegetation – Native grassland **– Annual grassland seral stage**	Plant communities clearly dominated by annual forbs and grasses belonging to seral stages of climatophylous series that can occur in the area accordingly to Capelo *et al* (2004) (sixth level).
32224	Non-forest vegetation**-** Native non-forest vegetation – Native grassland**- Assemblage of non-seral herbaceous annual plants**	Temporarily assemblage of herbaceous plants occurring in alluvial deposits. No distinction was made within this class. From this to sixth level the codes were as following: 322241.
32241	Non-forest vegetation- Mosaic of native scrubland and grassland **- Mosaic of native scrubland and grassland (Unidentified communities)**	Vegetation patches with pattern of natural vegetation assemblages but without peculiar features to enable *taxa* identification; seen in the background of old photographs. No distinction was made within this class. From this to sixth level the codes were as following: 322411
32242	Non-forest vegetation- Mosaic of native scrubland and grassland **- Mosaic of scrubland and perennial grassland seral stages**	Vegetation patches sampled all together when it was not possible to separate the shrub communities of seral stages intermingled in a complex mosaic with perennial forbs and grasses (sixth level).
32243	Non-forest vegetation- Mosaic of native scrubland and grassland **- Mosaic of scrubland and annual grassland seral stages**	Vegetation patches sampled all together when it was not possible to separate the shrub communities of seral stages intermingled in a complex mosaic with annual forbs and grasses (sixth level).
32251	Non-forest vegetation- Native non-forest vegetation – Rupicolous vegetation **- Unidentified rupicolous vegetation**	Communities found on rocky cliffs and scarps with pattern of natural vegetation assemblages but without peculiar features to enable *taxa* identification; seen in old photographs. No distinction was made within this class. From this to sixth level the codes were as following: 322511
32252	Non-forest vegetation- Native non-forest vegetation – Rupicolous vegetation- ***Sedo nudi-Aeonietum glutinosi***	Communities found on rocky cliffs and scarps found in mosaic with potential and seral stages. No distinction was made within this class. From this to sixth level the codes were as following: 322521
32253	Non-forest vegetation - Native non-forest vegetation - Hygrophilic vegetation **– *Sinapidendro gymnocalicis-Sedetum brissemoreti***	Communities found on rocky cliffs and scarps found in mosaic with potential and seral stages. No distinction was made within this class. From this to sixth level the codes were as following: 322531
32254	Non-forest vegetation - Native non-forest vegetation - Hygrophilic vegetation **– *Musschietum aureae***	Communities found on rocky cliffs and scarps found in mosaic with potencial and seral stages. No distinction was made within this class. From this to sixth level the codes were as following: 322541
32261	Non-forest vegetation - Native non-forest vegetation - Hygrophilic vegetation **– Unidentified hygrophilic vegetation**	Herbaceous plants located along riparian environments with pattern of natural vegetation assemblages but without peculiar features to enable *taxa* identification; seen in old photographs. No distinction was made within this class. From this to sixth level the codes were as following: 322611
32262	Non-forest vegetation - Native non-forest vegetation - Hygrophilic vegetation **– Community with *Phragmites australis***	Community with *Phragmites australis* located along riparian environments. No distinction was made within this class. From this to sixth level the codes were as following: 322621
32263	Non-forest vegetation - Native non-forest vegetation - Hygrophilic vegetation **– Community with *Juncus acutus***	Community with *Juncus acutus* located along riparian environments. No distinction was made within this class. From this to sixth level the codes were as following: 322631

32264	Non-forest vegetation - Native non-forest vegetation - Hygrophilic vegetation – ***Deschampsietum argenteae***	Community dominated by *Deschampsia argentea* located along waterfalls. No distinction was made within this class. From this to sixth level the codes were as following: 322641
32311	Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs **– High and low exotic bushes**	Exotic shrubs for which was possible to identify the *taxa* (sixth level).
32312	Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs **– Exotic climber-scrubs**	Exotic woody climbers for which was possible to identify the *taxa* (sixth level).
32331	Non-forest vegetation - Exotic non-forest vegetation – Exotic herbs **– Exotic Perennial herbs**	Exotic perennial herbs for which was possible to identify the *taxa* (sixth level).
32332	Non-forest vegetation - Exotic non-forest vegetation – Exotic herbs **– Exotic annual herbs**	Exotic annual herbs for which was possible to identify the *taxa* (sixth level).
32341	Non-forest vegetation - Exotic non-forest vegetation **– Mixture of exotic shrubs**	Mixture of exotic shrubs (High, low scrub and woody climbers) without a clear dominance. No distinction was made within this class. From this to sixth level the codes were as following: 323411
32342	Non-forest vegetation - Exotic non-forest vegetation **– Mixture of exotic shrubs and herbs**	Mixture of exotic shrubs and exotic herbs without a clear dominance. No distinction was made within this class. From this to sixth level the codes were as following: 323421
33121	Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Oleetum* and seral stages **– *Oleetum* and scrub community**	Vegetation patches sampled all together when it was not possible to separate the oleaster tree community from scrub seral stages intermingled in a complex mosaic (sixth level).
33122	Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Oleetum* and seral stages **– *Oleetum* and grassland community**	Vegetation patches sampled all together when it was not possible to separate the oleaster tree community from grassland seral stages intermingled in a complex mosaic (sixth level).
33131	Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Apollonietum* and seral stages **– *Apollonietum* and scrub community**	Vegetation patches sampled all together when it was not possible to separate the barbusano-tree community from scrub seral stages intermingled in a complex mosaic (sixth level).
33132	Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Apollonietum* and seral stages **– *Apollonietum* and grassland community**	Vegetation patches sampled all together when it was not possible to separate the barbusano-tree community from grassland seral stages intermingled in a complex mosaic (sixth level).
33141	Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ocoteetum* and seral stages **– *Ocoteetum* and scrub community**	Vegetation patches sampled all together when it was not possible to separate the stink-laurel tree community from scrub seral stages intermingled in a complex mosaic (sixth level).
33142	Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ocoteetum* and seral stages **– *Ocoteetum* and grassland community**	Vegetation patches sampled all together when it was not possible to separate the stink-laurel community from grassland seral stages intermingled in a complex mosaic (sixth level).
33151	Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ericetum* and seral stages **– *Ericetum* and scrub community**	Vegetation patches sampled all together when it was not possible to separate the tree-heath community from scrub seral stages intermingled in a complex mosaic (sixth level).
33152	Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ericetum* and seral stages **– *Ericetum* and grassland community**	Vegetation patches sampled all together when it was not possible to separate the forest community from grassland seral stages intermingled in a complex mosaic (sixth level).
33211	Forest/ Non-forest vegetation mosaic – Mixture of native trees and exotic non-arboreal plants **– Native trees and high and low exotic bushes**	Native woodlands invaded by exotic shrubs. No distinction was made within this class. From this to sixth level the codes were as following: 332111.
33212	Forest/ Non-forest vegetation mosaic – Mixture of native trees and exotic non-arboreal plants **– Native trees and exotic climber-scrubs**	Native woodlands invaded by exotic woody climbers. No distinction was made within this class. From this to sixth level the codes were as following: 332121.

33311	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants **– Exotic trees and native shrubs**	Exotic forest stands with native shrubs (sixth level).
33312	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants **– Exotic trees and native woody climbers (*Rubus* spp.)**	Exotic forest stands with native woody climbers (*Rubus* spp.) (sixth level).
33321	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants **– Exotic trees and native perennial herbs**	Exotic forest stands with native shrubs, climbers and herbs (sixth level).
33322	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants **– Exotic trees and native annual herbs**	Exotic forest stands with native shrubs, climbers and herbs (sixth level).
33411	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-arboreal plants **– Exotic trees and exotic shrubs**	Exotic forest stands with exotic shrubs (sixth level).
33412	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-arboreal plants **– Exotic trees and exotic climber scrubs**	Exotic forest stands with exotic climbers (sixth level).
33421	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-arboreal plants **– Exotic trees and exotic perennial herbs**	Exotic forest stands with exotic perennial herbs (sixth level).
33422	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-arboreal plants **– Exotic trees and exotic annual herbs**	Exotic forest stands with exotic annual herbs (sixth level).
	Sixth Level (Code_6)	
313111	Forest vegetation-Exotic trees - Hardwood forests – *Acacia* spp. **- *Acacia* mearnsii**	Stands clearly dominated by *Acacia mearnsii*
313112	Forest vegetation-Exotic trees - Hardwood forests – *Acacia* spp - **Acacia sp.**	Stands clearly dominated by trees species of genus *Acacia* other than *Acacia mearnsii.*
313151	Forest vegetation-Exotic trees - Hardwood forests – *Quercus* spp.**– *Quercus robur***	Stands clearly dominated by *Quercus robur*.
313152	Forest vegetation-Exotic trees - Hardwood forests – *Quercus* spp.**– *Quercus ilex***	Stands clearly dominated by *Quercus ilex.*
313211	Forest vegetation-Exotic trees – Softwood forests- *Pinus* spp. **– *Pinus pinaster***	Stands clearly dominated by *Pinus pinaster*
313212	Forest vegetation-Exotic trees – Softwood forests- *Pinus* spp. **- *Pinus* sp.**	Stands clearly dominated by trees species of genus *Pinus* other than *Pinus pinaster.*
322111	Non-forest vegetation- Native non-forest vegetation – Native scrubland – Scrubland seral stage **– *Euphorbietum piscatoriae***	Plant community clearly dominated by *Euphorbia piscatoria.*
322112	Non-forest vegetation- Native non-forest vegetation – Native scrubland – Scrubland seral stage **- *Artemisio argenteae-Genistetum tenerae***	Plant community clearly dominated by *Genista tenera and Artemisia argentea*.
322113	Non-forest vegetation- Native non-forest vegetation – Native scrubland - Scrubland seral stage **– *Myrtus communis–Hypericetum canariensis***	Plant community clearly dominated by *Hypericum canariense and Myrtus communis.*
322114	Non-forest vegetation- Native non-forest vegetation – Native scrubland – Scrubland seral stage **- *Globulario salicinae-Ericetum arboreae***	Plant community clearly dominated by *Erica arborea and Globularia salicina*.
322115	Non-forest vegetation- Native non-forest vegetation – Native scrubland – Scrubland seral stage **- *Vaccinio padifoli-Ericetum maderincolae***	Plant community clearly dominated by *Erica platycodon* subsp. *maderincola* and *Vaccinium padifolium.*
322116	Non-forest vegetation- Native non-forest vegetation – Native scrubland – Scrubland seral stage **- *Bystropogono puntacti-Telinetum maderensis***	Plant community clearly dominated by *Teline maderensis* and *Bystropogon punctatus.*

322117	Non-forest vegetation- Native non-forest vegetation – Native scrubland – Scrubland seral stage **– Community of *Erica maderincola***	Plant community clearly dominated by *Erica platycodon* subsp. *maderincola*
322118	Non-forest vegetation- Native non-forest vegetation – Native scrubland – Scrubland seral stage **– *Argyranthemo montanae-Ericetum maderensis***	Plant communities clearly dominated by *Erica maderensis and Argyranthemum pinnatifidum* subsp. *montanum*.
322121	Non-forest vegetation- Native non-forest vegetation – Native scrubland – topographical climax **– Community of *Euphorbia piscatoria***	Permanent community in steep cliffs dominated by *Euphorbia piscatoria*
322122	Non-forest vegetation- Native non-forest vegetation – Native scrubland – topographical climax **– *Vaccinio padifoli-Ericetum maderincolae***	Permanent community in steep cliffs dominated by *Erica platycodon* subsp. *maderincola* and *Vaccinium padifolium.*
322211	Non-forest vegetation- Native non-forest vegetation – Native grassland – Perennial grassland seral stage **- *Cenchro ciliaris-Hyparrhenietum sinaicae***	Plant community clearly dominated by *Hyparrhenia sinaica and Cenchrus ciliaris.*
322212	Non-forest vegetation- Native non-forest vegetation – Native grassland – Perennial grassland seral stage **- *Dactylo hylodes-Hyparrhenietum sinaicae***	Plant community clearly dominated by *Hyparrhenia sinaica and Dactylis hylodes.*
322213	Non-forest vegetation- Native non-forest vegetation – Native grassland – Perennial grassland seral stage **- *Pericaulido auritae-Geranietum palmatae***	Plant community clearly dominated by *Geranium palmatum* and *Pericallis aurita.*
322215	Non-forest vegetation- Native non-forest vegetation – Native grassland – Perennial grassland seral stage - ***Vicio capreolatae-Odontietum hollianae***	Plant community clearly dominated by *Odontites holliana and Vicia capreolata.*
322214	Non-forest vegetation- Native non-forest vegetation – Native grassland – Perennial grassland seral stage **- *Teucrio francoi-Origanetum virentis***	*Plant community clearly dominated by Origanum virens and Teucrium francoi.*
322231	Non-forest vegetation- Native non-forest vegetation – Native grassland – Annual grassland seral stage **- *Galactito tomentosae-Brachypodietum distachyae***	*Plant community clearly dominated by Brachypodium distachyon and Galactites tomentosa.*
322232	Non-forest vegetation- Native non-forest vegetation – Native grassland – Annual grassland seral stage **- *Campanulo erini-Wahlenbergietum lobelioidis***	*Plant community clearly dominated by Wahlenbergia lobelioides and Campanula erinus.*
322233	Non-forest vegetation- Native non-forest vegetation – Native grassland – Annual grassland seral stage **- *Leontodo longirostris-Ornithopetum perpusilli***	*Plant community clearly dominated by Ornithopus perpusillus and Leontodo longirostris.*
322421	Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and perennial grassland seral stages **– *Euphorbietum/Hyparrhenietum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Euphorbia piscatoria* intermingled in a complex mosaic with community of *Hyparrhenia sinaica*.
322422	Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and perennial grassland seral stages **– *Hypericetum/Hyparrhenietum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Hypericum canariense* intermingled in a complex mosaic with community of *Hyparrhenia sinaica*.
322423	Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and perennial grassland seral stages **– *Ericetum/Hyparrhenietum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Erica arborea* intermingled in a complex mosaic with community of *Hyparrhenia sinaica*.
322424	Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and perennial grassland seral stages **– *Ericetum/Geranietum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Erica platycodon* subsp. *maderincola* intermingled in a complex mosaic with community of *Geranium palmatum.*
322425	Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and perennial grassland seral stages **– *Ericetum/Odontietum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Erica platycodon* subsp *maderincola* intermingled in a complex mosaic with community of *Odontites holliana*

322426	**Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and perennial grassland seral stages – *Ericetum/Origanetum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Erica platycodon* subsp *maderincola* intermingled in a complex mosaic with community of *Origanum virens*
322431	**Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and annual grassland seral stages – *Euphorbietum/Brachypodietum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Euphorbia piscatoria* intermingled in a complex mosaic with community of *Brachypodium distachyon.*
322432	**Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and annual grassland seral stages – *Euphorbietum/Wahlenbergietum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Euphorbia piscatoria* intermingled in a complex mosaic with community of *Wahlenbergia lobelioides.*
322433	**Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and annual grassland seral stages - *Hypericetum/Wahlenbergietum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Hypericum canariense* intermingled in a complex mosaic with community of *Wahlenbergia lobelioides*
322434	**Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and annual grassland seral stages - *Ericetum/Wahlenbergietum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Erica arborea* intermingled in a complex mosaic with community of *Wahlenbergia lobelioides*
322435	**Non-forest vegetation- Mosaic of native scrubland and grassland - Mosaic of scrubland and annual grassland seral stages - *Ericetum/Ornithopetum***	Vegetation patches sampled all together when it was not possible to separate the shrub community of *Erica platycodon* subsp *maderincola* intermingled in a complex mosaic with community of *Ornithopus perpusillus*
323111	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – High and low exotic bushes – *Cytisus* spp.**	Plant assemblage clearly dominated by *Cytisus scoparius and/or Cytisus striatus*
323112	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – High and low exotic bushes – *Ulex* spp.**	Plant assemblage clearly dominated by *Ulex europaeus subsp. latebracteatus and/or Ulex minor.*
323113	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – High and low exotic bushes – *Opuntia tuna***	Plant assemblage clearly dominated by *Opuntia tuna.*
323114	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – High and low exotic bushes – *Solanum mauritianum***	Plant assemblage clearly dominated by *Solanum mauritianum.*
323115	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – High and low exotic bushes – *Tamarix gallica***	Plant assemblage clearly dominated by *Tamarix gallica.*
323116	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – High and low exotic bushes – *Agave americana***	Plant community clearly dominated by *Agave americana*
323117	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – High and low exotic bushes – *Nicotiana glauca***	Plant assemblage clearly dominated by *Nicotiana glauca*
323118	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – High and low exotic bushes – *Hedychium gardnerianum***	Plant assemblage clearly dominated by *Hedychium gardnerianum.*
323119	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – High and low exotic bushes – *Ageratina adenophora***	Plant assemblage clearly dominated by *Ageratina adenophora.*
323121	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – Exotic climber-scrubs- *Cardiospermum grandiflorum***	Plant assemblage clearly dominated by *Cardiospermum grandiflorum.*
323122	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – Exotic climber-scrubs – *Podranea ricasoliana***	Plant assemblage clearly dominated by *Podranea ricasoliana.*
323123	**Non-forest vegetation - Exotic non-forest vegetation – Exotic shrubs – Exotic climber-scrubs – *Passiflora molissima***	Plant assemblage clearly dominated by *Passiflora molissima.*
323311	**Non-forest vegetation - Exotic non-forest vegetation – Exotic herbs – Exotic Perennial herbs – *Brachiaria mutica***	Plant assemblage clearly dominated by *Brachiaria mutica.*
323312	**Non-forest vegetation - Exotic non-forest vegetation – Exotic herbs – Exotic Perennial herbs – *Pennisetum purpureum***	Plant assemblage clearly dominated by *Pennisetum purpureum*

323313	**Non-forest vegetation - Exotic non-forest vegetation – Exotic herbs – Exotic Perennial herbs – *Oxalis pes-caprae***	Plant assemblage clearly dominated by *Oxalis pes-caprae.*
323314	**Non-forest vegetation - Exotic non-forest vegetation – Exotic herbs – Exotic Perennial herbs – *Agapanthus praecox***	Plant assemblage clearly dominated by *Agapanthus praecox.*
323321	**Non-forest vegetation - Exotic non-forest vegetation – Exotic herbs – Exotic annual herbs – *Tropaeoleum majus***	Plant assemblage clearly dominated by *Tropaeoleum majus.*
331211	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Oleetum* and seral stages – *Oleetum* and scrub community – Oleetum/*Euphorbietum***	Vegetation patches sampled all together when it was not possible to separate the community of *Olea maderensis* intermingled in a complex mosaic with a community dominated by *Euphorbia piscatoria.*
331212	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Oleetum* and seral stages – *Oleetum* and scrub community - Oleetum/*Genistetum***	Vegetation patches sampled all together when it was not possible to separate the community of *Olea maderensis* intermingled in a complex mosaic with a community dominated by *Genista tenera.*
331221	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Oleetum* and seral stages – *Oleetum* and grassland community – Oleetum/ *Hyparrhenietum***	Vegetation patches sampled all together when it was not possible to separate the community of *Olea maderensis* intermingled in a complex mosaic with a community dominated by *Hyparrhenia sinaica*
331222	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Oleetum* and seral stages – *Oleetum* and grassland community – Oleetum/ *Brachypodietum***	Vegetation patches sampled all together when it was not possible to separate the community of *Olea maderensis* intermingled in a complex mosaic with a community dominated by *Brachypodium distachyon.*
331311	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Apollonietum* and seral stages – *Apollonietum* and scrub community – *Apollonietum/Ericetum***	Vegetation patches sampled all together when it was not possible to separate the community of *Apollonias barbujana* intermingled in a complex mosaic with a community dominated by *Erica arborea.*
331312	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Apollonietum* and seral stages – *Apollonietum* and scrub community – *Apollonietum/Hypericetum***	Vegetation patches sampled all together when it was not possible to separate the community of *Apollonias barbujana* intermingled in a complex mosaic with a community dominated by *Hypericum canariense.*
331321	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Apollonietum* and seral stages – *Apollonietum* and grassland community - *Apollonietum/Hyparrhenietum***	Vegetation patches sampled all together when it was not possible to separate the community of *Apollonias barbujana* intermingled in a complex mosaic with a community dominated by *Hyparrhenia sinaica*
331322	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Apollonietum* and seral stages – *Apollonietum* and grassland community - *Apollonietum/Wahlenbergietum***	Vegetation patches sampled all together when it was not possible to separate the community of *Apollonias barbujana* intermingled in a complex mosaic with a community dominated by *Wahlenbergia lobelioides.*
331411	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ocoteetum* and seral stages – *Ocoteetum* and scrub community – *Ocoteetum/Ericetum***	Vegetation patches sampled all together when it was not possible to separate the community of *Ocotea foetens* intermingled in a complex mosaic with a community dominated by *Erica platycodon* subsp. *maderincola.*
331412	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ocoteetum* and seral stages – *Ocoteetum* and scrub community – *Ocoteetum/Telinetum***	Vegetation patches sampled all together when it was not possible to separate the community of *Ocotea foetens* intermingled in a complex mosaic with a community dominated by *Teline maderensis.*
331421	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ocoteetum* and seral stages – *Ocoteetum* and grassland community – *Ocoteetum/Geranietum***	Vegetation patches sampled all together when it was not possible to separate the community of *Ocotea foetens* intermingled in a complex mosaic with a community dominated by *Geranium palmatum.*
331421	**Forest/ Non-forest vegetation mosaic – Mosaic of potential community and substitution stages – *Ocoteetum* and seral**	Vegetation patches sampled all together when it was not possible to separate the community of *Ocotea foetens* intermingled in a complex mosaic with a community dominated by *Ornithopus perpusillus.*

	stages – *Ocoteetum* and grassland community **– *Ocoteetum/Ornithopetum***	
331511	Forest/ Non-forest vegetation mosaic **–** Mosaic of potential community and substitution stages – *Ericetum* and seral stages – *Ericetum* and scrub community – ***Ericetum/*Community of Erica maderincola**	Vegetation patches sampled all together when it was not possible to separate the community of *Erica arborea* intermingled in a complex mosaic with a community of *Erica platycodon* subsp. *maderincola*..
331512	Forest/ Non-forest vegetation mosaic **–** Mosaic of potential community and substitution stages – *Ericetum* and seral stages – *Ericetum* and scrub community – ***Ericetum/Ericetum***	Vegetation patches sampled all together when it was not possible to separate the community of *Erica arborea* intermingled in a complex mosaic with a community of *Erica maderensis.*
331521	Forest/ Non-forest vegetation mosaic **–** Mosaic of potential community and substitution stages – *Ericetum* and seral stages – *Ericetum* and grassland community **– *Ericetum/Odontietum***	Vegetation patches sampled all together when it was not possible to separate the community of *Erica arborea* intermingled in a complex mosaic with a community of *Odontites holliana.*
331522	Forest/ Non-forest vegetation mosaic **–** Mosaic of potential community and substitution stages – *Ericetum* and seral stages – *Ericetum* and grassland community **– *Ericetum/Origanetum***	Vegetation patches sampled all together when it was not possible to separate the community of *Erica arborea* intermingled in a complex mosaic with a community of *Origanum virens.*
331523	Forest/ Non-forest vegetation mosaic **–** Mosaic of potential community and substitution stages – *Ericetum* and seral stages **– *Ericetum* and grassland community – *Ericetum/Ornithopetum***	Vegetation patches sampled all together when it was not possible to separate the community of *Erica arborea* intermingled in a complex mosaic with a community of *Ornithopus perpusillus.*
333111	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants **– Exotic trees and native shrubs - Hardwood trees/native shrubs**	Forest stands of broadleaf trees with native shrubs.
333112	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants **– Exotic trees and native shrubs - Softwood trees/ native shrubs**	Exotic forest stands of conifers with native shrubs.
33312	Forest/ Non-forest vegetation mosaic **-** Mixture of exotic trees and native non-arboreal plants – Exotic trees and native woody climbers (*Rubus* spp.) **- Hardwood trees/ native woody climbers (*Rubus* spp.)**	Exotic forest stands of broadleaf trees with native woody climbers (*Rubus* spp.).
33312	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants – Exotic trees and native woody climbers (*Rubus* spp.) **- Softwood trees/ native woody climbers (*Rubus* spp.)**	Exotic forest stands of conifers with native woody climbers (*Rubus* spp.).
333211	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants – Exotic trees and native perennial herbs **- Hardwood trees/ native perennial herbs**	Exotic forest stands of broadleaf trees with native perennial herbs.
333212	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants – Exotic trees and native perennial herbs **- Softwood trees/ native perennial herbs**	Exotic forest stands of conifers with native perennial herbs.
333221	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants – Exotic trees and native annual herbs **- Hardwood trees/ native annual herbs**	Exotic forest stands of broadleaf trees with native annual herbs.
333222	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and native non-arboreal plants – Exotic trees and native annual herbs **- Softwood trees/ native annual herbs**	Exotic forest stands of conifers with native annual herbs.
334111	Forest/ Non-forest vegetation mosaic **-** Mixture of exotic trees and exotic non-arboreal plants – Exotic trees and exotic shrubs **- Hardwood trees/exotic shrubs**	Exotic forest stands of broadleaf trees with exotic shrubs.
334112	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-	Exotic forest stands of conifers with exotic shrubs.

	arboreal plants – Exotic trees and exotic shrubs **- Softwood trees/exotic shrubs**	
334121	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-arboreal plants – Exotic trees and exotic woody climbers **- Hardwood trees/exotic climber scrubs**	Exotic forest stands of broadleaf trees with exotic climber scrubs
334122	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-arboreal plants – Exotic trees and exotic woody climbers **- Softwood trees/exotic climber scrubs**	Exotic forest stands of conifers with exotic climber scrubs.
334211	Forest/ Non-forest vegetation mosaic - Mixture of exotic trees and exotic non-arboreal plants **– Exotic trees and exotic herbs - Hardwood trees/exotic herbs**	Exotic forest stands of broadleaf trees with exotic herbs.
334222	Forest/ Non-forest vegetation mosaic **-** Mixture of exotic trees and exotic non-arboreal plants **– Exotic trees and exotic herbs - Softwood trees/exotic herbs**	Exotic forest stands of conifers with exotic herbs.

1.4. Level 2 and level 3 of Bare ground classes

Bare ground Classes

Code	Designation	Description
Second Level (Code_2)		
41	**Bare rocks**	Exposed bedrock surfaces (third level)
42	**Slag heaps**	Debris from demolished buildings, excavations. No distinction was made within this class. From this to sixth level the codes were as following: 421; 4211; 42111; 421111.
43	**Superficial deposits of non-cohesive natural materials**	Superficial deposits of unconsolidated sediments forming water stream banks and beaches (third level).
Third Level (Code_3)		
411	Bare rocks **– Bedrock in escarpments and cliffs.**	Vertical, or near vertical, rock exposures on escarpments and cliffs. No distinction was made within this class. From this to sixth level the codes were as following: 4111; 41111; 411111.
412	Bare rocks **– Bedrock in banks and bed of water streams**	Banks and dry stream bottom of rivulets and creeks. No distinction was made within this class. From this to sixth level the codes were as following: 4121; 41211; 412111.
413	Bare rocks **– Bedrock in rock outcrops**	Exposed bedrock surfaces appearing above the surrounding land. No distinction was made within this class. From this to sixth level the codes were as following: 4131; 41311; 413111.
431	Superficial deposits of non-cohesive natural materials **– Coarse-grained sediments**	Deposits of stones and pebbles on water stream bed and banks, and on beaches. No distinction was made within this class. From this to sixth level the codes were as following: 4311; 43111; 431111.
432	Superficial deposits of non-cohesive natural materials **– Finely-grained sediments**	Deposits of sand on water stream bed and banks, and on beaches. No distinction was made within this class. From this to sixth level the codes were as following: 4321; 43211; 432111.

1.5. Level 2 of Water Classes

Water Classes

Code	Designation	Description
Second Level (Code_2)		
51	**Ice**	Snow and hail accumulations in the higher elevations. No distinction was made within this class. From this to sixth level the codes were as following: 511; 5111; 51111; 511111.
52	**Water body surfaces**	Water streams and lagoons. No distinction was made within this class. From this to sixth level the codes were as following: 521; 5211; 52111; 521111.

8.3 Appendix 3: Photographs from tourist activity: a source to assess vegetation change using repeat landscape photography – Paper published in *Journal of Tourism and Sustainability* in 2011

Original Article

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Photographs from tourist activity: a source to assess vegetation change using repeat landscape photography

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Keywords
Landscape change
Vegetation dynamics
Repeated photography
Madeira Island

Abstract
This paper provides an overview of the application of Repeat Landscape Photography Technique (RLPT) as a useful method to quantify change and vegetation dynamics in areas without other sources of historical vegetation data. The historical profile of the landscape provides helpful information to predict future changes, being essential to design strategies for conservation and restoration policies. Although the aim is to recognize tourism activity as an abundant supply of photographs to perform vegetation ecology studies, the information achieved by scientific research can assist a careful management and contribute to sustainable tourism, especially nature-based tourism.

Palavras-chave
Alteração de paisagem
Dinâmica de vegetação
Fotografia repetida
Ilha da Madeira

Resumo
Este artigo aborda sumariamente a utilização da Técnica de Refotografia de Paisagem (TRP) como método útil para avaliar quantitativamente a alteração e dinâmica da vegetação, particularmente em áreas sem registos documentais. O facto de providenciar informação sobre as alterações do passado ajuda a prever as alterações futuras e contribui para delinear estratégias de conservação e recuperação da paisagem. Embora o objectivo seja o de mostrar a contribuição da actividade turística para estudos de Ecologia da Vegetação, o facto destes fornecerem informação para gestão da paisagem natural contribuem para a sustentatibilidade do turismo, particularmente do turismo ligado à natureza.

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Repeating old photographs to assess vegetation change

Landscape change can be very dramatic in regions under intense anthropological activity, but also where human influence diminuished due to rural depopulation (Debussche et al., 1999). Therefore, the relationship between vegetation cover and human activity is not easy to analyse, especially in situations where documented records are scarce. Landscape photographs can be used to detect, analyse and interpret land cover change, because they are a record of landscape composition within a certain time (Pickard, 2002).

Repeating landscape photographs in order to study landscape changes has been used for more than 100 years, especially in geology (Malde, 1973). In vegetation ecology, Hastings and Turner used it for the first time in Arizona in 1965 (Pickard, 2002). Since then it has often been applied to assess the effects of fire, grazing and human impact, to evaluate trends in vegetation cover over time, and to obtain information on vegetation dynamics (Debussche et al., 1999; Butler and DeChano, 2001; Hall, 2001; Pickard, 2002; Start and Handasyde, 2002; Clark and Hardegree, 2005; Turner, 2005; Roush et al., 2007). Landscape change can be appraised at a most basic level by comparing the original to the repeated photograph (Fig.1) acquired from the same point in space and with the same orientation of the original. Detecting significant differences within the juxtaposed pairs can be a rather efficient method of gathering information for educational purposes or to accomplish coarse vegetation changes. However, the approach is entirely subjective and quantitative analysis is more adequate for assessing vegetation change and dynamics (Debussche et al., 1999; Butler and DeChano, 2001; Clark and Hardegree, 2005; Hendrick and Copenheaver, 2009).

Usually the quantitative assessment of the vegetation change is conducted by the digital analysis of aerial photography and remotely sensed images, but ground-based photographs can also be used to quantitatively evaluate the landscape change and vegetation dynamics. Although landscape photography does not allow for ground surface coverage assessment, due to limitations related to an oblique angle of view, it brings some advantages by revealing features not visible on vertical projection (Malde, 1973); by evaluating long-term vegetation dynamics because they are an older record than the first aerial photography (Debussche et al., 1999; Clark and Hardegree, 2005); and needless to say by being less expensive.

Figure 1 - Old photograph of Ribeira de São Jorge valley (North coast, Madeira) over 100 years old (left) (Vicentes Gomes da Silva, courtesy of AHConceição) and replica of the same view (right) (by MMS and APC, 2007).

Using Repeat Landscape Photography Technique in Madeira Island

The method's effectiveness was stated by the authors of the present article in a research to assess vegetation change and dynamics in Madeira Island over the last hundred years using RLPT (Repeat Landscape Photography Technique). The quantitative approach combined old and completely new methods (Pupo-Correia, 2007), by using image-processing software (IDRISI32) to prepare images and to quantify the variation pixel by pixel.

Analysis performed clearly showed pristine vegetation destruction at the end of the 19th and the beginning of the 20th centuries. The measures to prevent deforestation during five centuries of human occupancy were unsuccessful, and the reforestation led to a massive cover with exotic plants. Although the results revealed recovery according to the successional model proposed by Capelo et al., (2004), attesting also the model itself, the actual native vegetation occurred where it already existed or in areas without intense human pressure, showing a very low regeneration from humanised or invaded areas. The evidence of the ecosystem fragility and the exotic species invasion of recent and moderately disturbed gaps forecasts that resilience might not be enough to avoid invasion success, pointing to the need for additional careful management. Therefore, vegetation dynamics information achieved by this procedure, being more objective than the one attained with visual comparison, can provide an adequate estimation of the overall trends and be helpful in guiding the conservation and restoration policies.

Figure 3 - Ribeira do Inferno valley (North coast, Madeira) in late 19th (unknown photographer, courtesy of ARM)

Figure 2 - Levada of Rabaçal, Ribeira da Janela valley (High inland, Madeira) in late 19th century (unknown photographer, Dr. Almada collection, property of APC)

Figure 4 - Levada dos Piornais, Ribeira dos Socorridos valley (South coast, Madeira) in early 1930's (Figueira photographers, property of APC)

Figure 5 - Old postcard showing rural landscape (Camacha, Madeira) in early 20th century (unknown photographer, property of APC)

However, landscape change assessment by RLPT when using very old photographs can be affected by several limitations, such as lack of information (e.g. date, location); difficulty in obtaining the replicas due to profound alteration of landscape; and losses in image quality that can influence image analysis. Besides, for old images that do not allow species identification, it is utterly impossible to identify vegetation cover types, if they are absent from the current landscape. Another limitation of using historic photographs for vegetation studies is the fact that images with natural views are rare as opposed to an overabundance of humanised landscape, not only due to photographers own interest but also because upper elevations were hard to reach in those times.

Despite the possibility and advantages of repeating more recent landscape photography (Start and Handasyde, 2002) it does not evaluate long-term dynamics. On the contrary, historical landscape photographs taken in the late 1800's and early 20th century offers the possibility of spanning much longer time intervals. Furthermore, they are a useful source of information over a period that begins with agriculture and forest over-exploitation high point, when a great number of exotic plants were introduced, and covers a period of land abandonment (Menezes de Sequeira et al., 2007). This is particularly relevant where the present vegetation is a mix of native and non-native species, and the future depends on species interaction, the environment and management actions (Pickard, 2002). RLPT with historical photos can provide a pre-invasion baseline, time-lag information, forecast the ecosystem resilience and thus guide the management decisions that should be applied in each area.

The existence of a significant amount of historical images in Madeira Island is a result of the fast development of photography related to the activity carried out by the local photographers since 1856. Also, because photography had become popular worldwide, photos were often purchased on family outings, by tourists (Fig.2), during scientific or photographic expeditions and survey activities (Fig.3). But, more than that, the early tourism industry, due to Madeira's mild climate provided plentiful collections of photographs (Fig.4) and postcards (Fig.5) bought as souvenirs by an unusual number of visitors.

Current tourism activity and particularly the one related with natural resources can be an abundant source of images. Despite the evidence of an activity being carried out on a massive scale that can endanger fragile areas in the environments visited (Ruschmann, 1998), the panoply of natural landscape images available all over the web and particularly those shown by Google Earth attests that the tourism industry is a copious source of material to study landscape change through RLPT.

On the other hand, strategies for conservation and restoration designed with information provided through repeat photography offers the possibility avoiding the depletion of the economic value of the natural landscape as required for sustainable tourism.

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References

Butler D.R., DeChano L.M. (2001). Environmental change in Glacier National Park, Montana: an assessment through repeat photography from fire lookouts. Physical Geography. 22: 291-304.

Capelo J., Menezes de Sequeira M., Jardim R., Costa J.C. (2004). Guia da Excursão Geobotânica dos V Encontros ALFA 2004 à Ilha da Madeira in: A paisagem vegetal da ilha da Madeira. In: Capelo J. (Ed.), Quercetea, pp. 5-45.

Clark P., Hardegree S. (2005). Quantifying vegetation change by Point Sampling Landscape Photography Time Series. Rangeland Ecology & Management 58: 588-597.

Debussche M., Lepart J., Dervieux A. (1999). Mediterranean landscape changes: evidence from old postcards. Global Ecology and Biogeography 8: 3-15.

Hall F. (2001). Ground-based photographic monitoring, General Technical Report PNW-GTR-503. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland.

Hendrick L.E., Copenheaver C.A. (2009). Using Repeat Landscape Photography to Assess Vegetation Changes in Rural Communities of the Southern Appalachian Mountains in Virginia, USA. Mountain Research and Development 29(1): 21-29.

Malde H.E. (1973). Geologic bench marks by terrestrial photography. Journal of Research of the United Stated Geological Survey 1: 193-206.

Menezes de Sequeira M., Jardim R., Capelo J. (2007). A chegada dos portugueses às ilhas - o antes e o depois (Madeira) in: Açores e Madeira - A floresta das ilhas. In: Silva J.S. (Ed.), Árvores e Florestas de Portugal. Público, Comunicação Social SA e Fundação Luso-Americana para o Desenvolvimento, Lisboa, pp. 165-194.

Pickard J. (2002). Assessing vegetation change over a century using repeat photography. Australian Journal of Botany 50: 409-414.

Pupo-Correia A. (2007). História Recente da Paisagem Vegetal da Madeira. Utilização de recursos fotográficos antigos e recentes como elementos comparativos. Unpublished MSc Thesis, Universidade da Madeira, Funchal.

Roush W., Munroe J.S., Fagre D.B. (2007). Development of a Spatial Analysis Method Using Ground-Based Repeat Photography to Detect Changes in the Alpine Treeline Ecotone, Glacier National Park, Montana, USA. Arctic, Antarctic and Alpine Research 39(2): 297 – 308.

Ruschmann D.V.d.M. (1998). Ethics in Ecoturism Services. Turismo- Visão e Ação 1(1): 9-17.

Start A.N., Handasyde T. (2002). Using photographs to document environmental change: the effects of dams on the riparian environment of the lower Ord River. Australian Journal of Botany 50: 465-480.

Turner R.M. (2005). Vegetation in transition: The Southwest's dynamic past century. USDA Forest Service Proceedings 36: 223- 228.

8.4 Appendix 4. Landscape repeat photography: Solutions to improve efficiency of a useful tool for vegetation research- paper to be published in *Silva Lusitana*, nº Especial Ano XXII, Novembro 2014

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Landscape repeat photography: Solutions to improve efficiency of a useful tool for vegetation research

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Abstract. Landscape repeat photography is an effective tool to quantitatively assess vegetation change and dynamics. Ground photography has advantages over vertical imagery (e.g. time frame, landscape details, and costs) and is recognised as a useful way to get information for vegetation analysis. However several limitations are referred and this paper addresses solutions to overcome several issues (e.g. biased sampling, scale variability, view blockage and species and vegetation recognition), based on the undergoing project "Assessing Madeira vegetation change over more than one hundred years by comparing historical landscape photographs taken from the late 1800's to early 20th century and replicas obtained since 2006 until 2012".

Key words: landscape change, vegetation dynamics, historical landscape photography, re-photography, Madeira Island

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Fotografia repetida de paisagem: Soluções para melhorar a eficiência de uma ferramenta útil para o estudo da vegetação

Sumário. A fotografia repetida de paisagem pode ser uma ferramenta efectiva para a determinação quantitativa da alteração e de dinâmica da vegetação. A fotografia feita ao nível do solo tem vantagens sobre a detecção remota (e.g. custos, visualiação de detalhes e o intervalo de tempo abrangido) e é reconhecida como um método útil para análise da vegetação. No entanto várias limitações são reconhecidas e este artigo incide sobre as soluções para algumas destas questões (e.g. amostragem tendenciosa, variabilidade de escala, obstrução da vista da paisagem e a identificação de espécies e comunidades). Estes resultados baseiam-se no projecto em curso "Avaliação da alteração da vegetação em mais de 100 anos pela comparação de fotografias tiradas no final do século XIX e início do século XX e as réplicas obtidas entre 2006 e 2012".

Palavras-chave: alteração da paisagem, dinâmica da vegetação, fotografia histórica da paisagem, refotografia, ilha da Madeira

La photographie répétée du paysage: solutions pour améliorer l'efficience de un outil outile pour l'étude de la végétation.

Résumé. La photographie répétée du paysage est un outil effective pour évaluer quantitativement le changement et dynamique de la végétation. La photographie au terrain possède des avantages sur l'imagerie verticale (par exemple, le temps écoulé, les détails du paysage, et les coûts) et est reconnu comme un moyen utile pour analyser la végétation. Cependant, certaines limitations sont reconnues et cet article document aborde des solutions pour surmonter plusieurs problèmes (par exemple, l'échantillonnage biaisé, la variabilité d'échelle, obstruction de la vue et la reconnaissance des espèces e de la végétation), basé sur l'expérience du projet en cour: «Évaluation de le changement de la végétation sur plus de cent ans, par comparant des photographies historiques de paysage prises à partir de la fin des années 1800 au début du XXe siècle et des réplique exécutés entre 2006 et 2012".

Mots clés: changement de paysage, dynamique de la végétation, photographie historique de paysage, rephotographie, île de Madère

Introduction

The term "repeat photography" (RP) is applied normally to ground-based photography (terrestrial photography) that is taken over time. It has been used either to monitor short periods or to re-photograph historical photographs after decades or a century (HART and LAYCOCK, 1996; HALL, 2001; PICKARD, 2002; KULL, 2005). Two main types of ground-based photography are useful to document changes over the time: site-specific RP and landscape RP. The first is directed to a specific topic to be documented in detail (HALL, 2001; CRIMMINS and CRIMMINS, 2008). The second aims to document change in landscape-sized areas, and includes conventional landscape photography or the panoramic photography with a 360-degree view (HALL, 2001).

Common landscape photography is an effective tool for quantitative vegetation change and dynamics assessment, and has several advantages over vertical imagery which is used usually for this evaluation (e.g. time frame, landscape details, and costs). Most authors recognised it as a useful way to get information for vegetation analysis, although pointing several limitations. In this paper the solutions proposed in the literature are revised (i) and compared or completed with those resulting from the Madeira Island repeat photography project (ii).

Limitations and proposed solutions

Biased sample

A collection of historical photographs always represents a spatial biased sample (ZIER and BAKER, 2006), except when original historical collection aimed a systematic survey (RHEMTULLA *et al.*, 2002; HIGGS, 2003). The non-random choice of the original location (DEBUSSCHE *et al.*, 1999) or the reduced sampled area (TURNER *et al.*,1998; PICKARD, 2002; START and HANDASYDE, 2002) can lead to over or under-representation of specific vegetation communities. Historical photographs were often taken in easily accessible sites leading to an overestimation of anthropogenic cover (VALE, 2001; RHEMTULLA *et al.*, 2002; KULL, 2005; TURNER, 2005; HENDRICK and COPENHEAVER, 2009). In addition some views are generally over-represented (e.g. spectacular scenic landscape), giving an inadequate representation of the landscape (DEBUSSCHE *et al.*, 1999; KULL, 2005; ZIER and BAKER 2006).

i) A solution to minimise over-representation lies on selecting a set of photographs spread over the study area (RHEMTULLA *et al.*, 2002; ZIER and BAKER, 2006), and if an area is seen in more than one photograph choosing just one of the overlapped views (DEBUSSCHE *et al.*, 1999; RHEMTULLA *et al.*, 2002). During selection photographs must be visually analysed to check for systematic bias favouring any specific vegetation type (RHEMTULLA *et al.*, 2002). Further strategies include: (1) distributing photographs across vegetation types (ZIER and BAKER, 2006); (2) grouping results by sub-region or giving analytical weight in accordance with the number of photos of different sub-regions (KULL, 2005); (3) analysing the background, distant from the main interest of the original photographer (DEBUSSCHE *et al.*,1999); (4) dividing a view into multiple units or contrariwise gathering different views to represent a single unit (BULLOCK and TURNER, 2010); and transferring trends into a map, or maps representing different time intervals, to determine zones of similar trends or a regional trend (KULL, 2005).

ii) The historical collection of Madeira landscape was selected covering the entire study area, across elevation gradients and vegetation types removing overlapped photo sections from the sampling, and results grouped by sub-region. These measures were crucial because the majority of the photographs of the original collection where taken with a touristic purpose (see PUPO-CORREIA *et al.* 2011), and over-represented tourist points of interest.

Problems related with the oblique angle

Scale variability

Ground-based photographs, being taken at an oblique angle, have a variable scale throughout the image, preventing the use of the photogrammetric techniques to evaluate vegetation change (RHEMTULLA *et al.*, 2002; CLARK and HARDEGREE, 2005). Furthermore, scale variability within each photograph and among different photographs can favour landscape features located on closer plans (RHEMTULLA *et al.*, 2002).

i) In order to deal with scale variability DEBUSSCHE *et al.* (1999) divided the photograph into three parts (foreground, mid-distance, and background) and CLARK and HARDEGREE (2005) sampled randomly pixels distributed over an image line (assumed as having the same distance to the camera). According to RHEMTULLA *et al.*, (2002) if no obvious systematic bias benefits one vegetation type over another it is possible to get an accurate estimation of relative vegetation cover without the need of scale compensation.

ii) Madeira is dissected by deep ravines showing huge complexity, therefore, plans presenting an extreme difference in distance to the camera were considered as distinct units.

View obstruction

Areas hidden by landforms or high vegetation prevent the evaluation of the total area, and changes can obstruct or reveal landscape portions making non-equivalent parts unsuitable for comparison (DEBUSSCHE *et al.*, 1999; CLARK and HARDEGREE, 2005).

i) When views are obstructed MCCLARAN *et al.*, (2010) suggested combining ground photos with aerial photographs or oblique-ground photographs obtained in hill summits, and MOSELEY (2006) and ZIER and BAKER (2006) suggested making careful observations in the field to evaluate the hidden areas.

ii) In the Madeira project only areas depicted in the image were considered as suitable for analysis and merely parts seen in both images were appraised (DEBUSSCHE *et al.*, 1999).

Difficulties in obtaining the replica

Finding the landscape photographed and original photo point

For accurate analysis it is crucial to find the exact location. Documentation concerning the photograph locations is seldom found (RHEMTULLA *et al.*, 2002; HENDRICK and COPENHEAVER, 2009) and the time elapsed since the historical photograph was taken makes the task hard and time-consuming (MALDE, 1973, VEBLEN and LORENZ, 1991; MUNROE, 2003; KULL, 2005).

i) Old photographs were often taken in still popular sites (MUNROE, 2003; WEBB, 1996) and the knowledge of the territory can be helpful (MALDE, 1973, VEBLEN and LORENZ, 1991). Solutions suggested to deal with the relocation of the camera include: (1) prospecting the image for clues (HALL, 2001; HANKS *et al.*, 2010); (2) searching historical documents (HALL, 2001; KULL, 2005); (3) information from local residents (HALL, 2001; HENDRICK and COPENHEAVER, 2009; HANKS *et al.*, 2010); and (4) using Virtual RP (orthophotomaps, digital elevation models, and GIS software or Google Earth) to access to a virtual landscape (HANKS *et al.*, 2010).

ii) Due to touristic origin of most of photos of the Madeira collection the views represent popular sightseeing places. Therefore, it was easy to find a general location.

Relocating the camera: duplicating the original view

Sometimes it is easy to identify the exact location because old photographers did not stray far from roads and paths, but on other occasions the original position is not easily recognised, making the relocation a challenging process (VEBLEN and LORENZ, 1991; MUNROE, 2003; KULL, 2005; HENDRICK and COPENHEAVER, 2009; HANKS *et al.*, 2010).

i) Methods to relocate the camera involve, in general, the comparison of features in old photograph with present landscape (PICKARD, 2002). Precise systems, using mathematical calculations, can be used although they are very time-consuming (BOYER *et al.*, 2010). Most authors follow the simple procedure established by MALDE (1973) i.e. aligning near and distant features in the centre of the field of view, in conformity with the parallax principle , also used to replicate the azimuth of the camera axis (by moving along the central line until obtaining the alignment of features in the periphery). The height above ground of the original camera is also important for accuracy. The camera height varied greatly [cameras mounted on tripods, firstly fixed then adjustable, cameras used without support at breast height or eye level (BOYER *et al.*, 2010)] and can be determined by comparing objects in the foreground and the background.

ii) Locating the camera in the exact position and height was achieved as proposed by MALDE (1973), i.e. a coarse "cross-hair" grid was drawn on the printed copy to compare the view and to line up features in the foreground and background. However, image orientation was established by the intersection of the lines that cross the fiducial marks [a simplification of the aerial photography method to identify the principal point (LILLESAND and KIEFER, 1994)]. To obtain maximum stability a tripod was used but when impractical photos were taken hand-held.

Relocating the camera: verifying the correct position

i) When digital cameras were not available the correct position in the field was checked using Polaroid cameras. Nowadays the LCD screen of digital cameras have proved to be quick and accurate (BOYER *et al.*, 2010).

ii) Verifying the correct position in field was done by comparing features observed in the printed photograph and the digital image. Although difficult in bright sunlight (PICKARD, 2002) adjusting brightness levels of the LCD or adding a shade makes it easier.

Retaking the photograph: difficulties due to alteration

Sometimes landscape underwent remarkable transformations that prevent repeating the photo from the exact location. Either because it is impossible to recognise landforms (HALL, 2001), or the place for the retake is no longer accessible (e.g. erosion) or even the original view is obscured by new constructions or vegetation growth in the foreground (VEBLEN and LORENZ, 1991; WEBB, 1996; HALL, 2001; ZIER and BAKER, 2006; BOYER *et al.*, 2010).

i) Some authors excluded photos in these situations (HENDRICK and COPENHEAVER, 2009) while others considered that if an alternative photo-point is located up to 25 m away an useful replicate could be obtained (ZIER and BAKER, 2006).

ii) Whenever it was impossible to repeat the photograph from the exact location the photos were not considered for analysis, except when the original view was only partly hidden allowing a sectional analysis.

Retaking the photograph: difficulties due to environmental conditions

Time of day, season of the year, air quality, and lighting conditions affect image characteristics. Poor quality of historical photographs (due to the conditions described) led some authors to reject them (HALL, 2001). Retaking photographs in a different time of day, time of year and weather conditions originate different shadows and lead to misinterpretations (WEBB, 1996; KULL, 2005; LEWIS, 2010).

i) Usually there is no record of the original conditions, but time and season can be inferred based on shadows direction and length (BOYER *et al.*, 2010) or vegetation phenology (RHEMTULLA *et al.*, 2002). Sometimes, after locating the site, weather conditions (e.g. fog) prevent retaking the photograph, a problem solved by revisiting the site (HALL, 2001; HENDRICK and COPENHEAVER, 2009).

ii) Sometimes it was possible to infer time of day and season to replicate light and shadows.

Retaking the photograph: difficulties due to photographic equipment

The effect of changing the camera format, position and distance to objects was discussed by HALL (2001), supporting ROGERS *et al.* (1984 p. xxi) statement: "views made with cameras of different focal lengths from the same lens position will always match exactly, provided that both are printed and cropped to the same size". This is a very important conclusion since original cameras, especially before 1930, are no longer available (HALL, 2001).

i) Although the use the original equipment (or lens with the same focal length) is not necessary, attention should be paid to some old characteristics (BOYER *et al.*, 2010), such as wider format of the original photographs requiring the use of wide-angle lens (KULL, 2005).

ii) The new photographs were taken with wide-angle lens (AF-S Nikkor 18-70 mm) to cover a larger field of view to avoid losing information during trimming operations.

Retaking the photograph: obtaining an accurate matched photo pair

Even photographs taken from the exact position never match exactly, and if used for quantification they need landscape features to be located in the same image coordinates (MUNROE, 2003; CLARK and HARDEGREE, 2005; KULL, 2005; ZIER and BAKER, 2006).

i) Several authors used photo editing programs (MUNROE, 2003; KULL, 2005; ZIER and BAKER, 2006; HENDRICK and COPENHEAVER, 2009) to resize and crop the images to similar field of view while others used remote sensing programs to map one image onto another (MANIER and LAVEN, 2002; CLARK and HARDEGREE, 2005).

ii) A better match was obtained by spatially registering the new photograph to the historical image (root mean square error ≤ 0.5) using remote sensing and geographic information system technologies (IDRISI and ArcGIS).

Difficulties in image analysis

Undated photographs

Not knowing the exact age of the historical photographs is a problem, especially when the aim is to get a rate of change (VEBLEN and LORENZ, 1991; MUNROE, 2003).

i) However, historical research about the time when the photographer developed his activity, the date of the expedition, or details in historical landscape can help to estimate the date of undated photographs (*op. cit.*).

ii) For undated photographs some research on the subjects mentioned above gave indication of the age. Only photos with time assigned were used.

Irregular time span

Another point of concern is the lack of uniform date and time span of the photographs within a collection as for instance old photos taken over a time interval of 80 years and the new photos retaken over a period of 10 years (KULL, 2005).

i) Because historical photos span different time periods and landscape evolution is more complex than two single moments in time suggests KULL (*op. cit.*) proposed a graphic representation to show the state of the vegetation over time (for further details see author).

ii) Photos with time assigned were used and grouped in three sets of photographs spanning a different time interval (125-100; 100-75, 75-50). This procedure aimed both to get uniformity in the age of photographs within a group and to get information about the change that happened in shorter time spans in order to understand the long-term vegetation dynamics.

Image quality

Another issue is low resolution (MCCLAREN *et al.*, 2010) and degradation of the old photograph (WEBB, 1996). Poor photo quality can prevent accurate pairing in the field (BOYER *et al.*, 2010) or cause loss of important information (KULL, 2005).

i) Although image-processing software can be used to manipulate and amend decaying photographs those images cannot be compared (MUNROE, 2003).

ii) Only photographs with sufficient quality to identify vegetation and land use types where selected. Distant background plans were not considered if such aspects were not clear enough.

Species and vegetation identification

Limitations include: (1) evaluating composition and structure inside the forest stand (MOSELEY, 2006); (2) appraising density of the forest due to indistinct crown closure (RHEMTULLA *et al.*, 2002), (3) evaluating changes in communities of herbaceous species (KAY, 2003); (4) identifying plant species (START and HANDASYDE, 2002).

i) Although many authors mentioned these limitations few solutions were proposed. MOSELEY (2006) suggested intensive fieldwork to overcome failures but this is not possible for old photographs. Contrarily to aerial photography, which has developed plenty bibliography aiming species recognition (e.g. SAYN-WITTGENSTEIN, 1978), this was not a matter of concern of ground based photography: probably because the horizontal perspective, which facilitates landscape features recognition (MALDE, 1973; KULL, 2005), plants are seen with their characteristic appearance. SAYN-WITTGENSTEIN (*op. cit.*) suggested to eliminate improbable species and to use knowledge of species associations and ecological requirements to establish the communities that can occur in the area, and to observe other characteristics such as crown shape, branching habit and characteristics of the foliage to identify species. As the scale decreases those features became useless and identification has to be based on photographic tone, texture and patterns.

ii) Species recognition followed some suggestions made by aerial photo interpreters. Species identification in historical images was possible for several trees based on crown shapes and branching habits (e.g. *Pinus pinaster* Aiton). Smaller plants could also be identified in the foreground and mid-ground based on size, texture, foliage pattern and sometimes the shape of the leaves (e.g. *Arundo donax* L.). Identification of plant communities was based on visual similarity to the pattern of species association seen in new images. Species and communities recognition in the new photographs was facilitated by colour and supported by supplementary photographs taken with long focal length lens and field data (Floristic inventories and Phytosociologial relevés).

Data analysis

In spite of the usefulness of quantification, to get information from a large set of photographs (KULL, 2005), the majority of studies made a qualitative approach mainly due to scale variability that restrain the application of the existing photogrammetric techniques (CLARK and HARDEGREE, 2005).

i) Nevertheless, some authors addressed a quantitative assessment either by applying simple methods as (1) attributing categories (e.g. more trees/less trees), (2) counting presence or absence of particular items (e.g. vegetation species), or by using rather complex methods involving orthorectification, pixel classification, and polygons digitizing (KULL, 2005). Even so, ground-based photography cannot calculate absolute measures but instead relative or proportional measures (RHEMTULLA *et al.*, 2002). Using other techniques of historical ecology like: (1) local dendrochronology studies (ELLIOT and BAKER, 2004); (2) data about climate, species auto-ecology, soils, land use or other ancillary information about the past, which can support the interpretation, is possible to reduce the subjectivity in the assessment (PICKARD, 2002; TURNER *et al.*, 2003)

ii) To obtain a quantitative assessment of vegetation change and dynamics, digital images were imported into the image analysis software (ArcGis and IDRISI32) to enable both coregistration of images pairs and sampling process. To develop a logical explanation about nature, causes and direction of the change the analysis was combined with other data as: additional historical information, dendrochronology of main phanerophytes seen in the landscape and sometimes aerial photography.

Conclusions

Some of the problems of using historical photographs are related to the fact that time elapsed can difficult obtaining the replica. For issues like bad quality of the old photograph, huge transformations of the landscape, and undetermined age there is no solution and images have to be rejected. For other issues several methodological strategies can be applied in order to get a set of images forming a complete and unbiased sample of the landscape.

Repeat landscape photography makes possible to analyse relative vegetation cover and assess change and vegetation dynamics however it does not give the same type of quantitative data as other standard methods of evaluating change in the landscape. Despite being inept to replace aerial photography and satellite based imagery it can be very useful to complement data (GRUELL, 2010) and has several advantages over those methods. Being ground-based photography a low-technology tool it is less costly (KULL, 2005; GRUELL, 2010) and since photography became very popular in late 1800s, it is possible to go much further in time (RHEMTULLA *et al.*, 2002; KULL, 2005) and to analyse much larger intervals (KAY, 2003; CLARK and HARDEGREE, 2005; KULL, 2005, GRUELL, 2010).

Hence, as final remark "…Consider briefly the alternative of not using RP. We would face decades of uncertainty while we waited for results from long-term monitoring and long-term experiments,.." (PICKARD, 2002, p. 414).

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References

BOYER, D.E., WEBB, R.H., TURNER, R., 2010. Techniques of matching and archiving repeat photography used in the Desert Laboratory collection. In: Webb, R.H., Boyer, D.E., Turner, R.M. (eds.), *Repeat Photography Methods and Applications in the Natural Sciences,* Island Press, Washington, pp. 12-23.

BULLOCK, S.H., TURNER, R.M., 2010. Plant Populations Fluxes in the Sonoran Desert shown by Repeat Photography. In: Webb, R.H., Boyer, D.E., Turner, R.M. (eds.), *Repeat Photography Methods and Applications in the Natural Sciences*, Island Press, Washington, pp. 119-131.

CLARK, P., HARDEGREE, S., 2005. Quantifying vegetation change by Point Sampling Landscape Photography Time Series. *Rangeland Ecology & Management* **58**: 588-597.

CRIMMINS, M.A., CRIMMINS, T.M., 2008. Monitoring Plant Phenology Using Digital Repeat Photography. *Environmental Management* **41**: 949-958.

DEBUSSCHE, M., LEPART, J., DERVIEUX, A., 1999. Mediterranean landscape changes: evidence from old postcards. *Global Ecology and Biogeography* **8**: 3-15.

ELLIOT, G.P., BAKER, W.L., 2004. Quaking aspen (*Populus tremuloides* Michx) at treeline: a century of change in the Juan Mountains, Colorado, USA. *Journal of Biogeography* **31**: 733-745.

GRUELL G., 2010. Foreword. In: Webb, R.H., Boyer, D.E., Turner, R.M. (eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington, pp. xiii-xviii.

HALL, F., 2001. *Ground-based photographic monitoring, General Technical Report PNW-GTR-503*. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, pp. 340.

HANKS, T.C., J, L.B., WEBB, R., 2010. Virtual Repeat Photography. In: Webb, R.H., Boyer, D.E., Turner, R.M. (eds.), *Repeat Photography Methods and Applications in the Natural Sciences*, Island Press, Washington, pp. 24-31.

HART, R.H., LAYCOCK, W.A., 1996. Repeat photography on range and forest lands in the Western United States. *Journal of Range Management* **49**: 60-67.

HENDRICK, L.E., COPENHEAVER, C.A., 2009. Using Repeat Landscape Photography to Assess Vegetation Change in Rural Communities of the Southern Appalachian Mountains in Virginia, USA. *Mountain Research and Development* **29**(1): 21-29.

HIGGS, E., 2003. *Nature by design: people, natural process, and ecological design.* Massachusetts Institute of Technology, The MIT Press, Cambridge, Massachusetts, 341 pp.

KULL, C.A., 2005. Historical Landscape repeat photography as a tool for land use change research. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography* **59**: 253-268.

LEWIS, D., 2010. Catle, Repeat photography, and changing vegetation in the Victoria River District, Northern territory, Australia. In: Webb, R.H., Boyer, D.E., Turner, R.M. (eds.), *Repeat Photography Methods and Applications in the Natural Sciences*, Island Press, Washington, pp. 197-210.

LILLESAND, T.M., KIEFER, R.W., 1994. *Remote Sensing and Image Interpretation* (3rd Edition). John Wiley and Sons, New York, 750pp.

MALDE, H.E., 1973. Geologic bench marks by terrestrial photography. *Journal of Research of the United Stated Geological Survey* **1**: 193-206.

MANIER, D.J., LAVEN, R.D., 2002. Changes in landscape patterns associated with the persistence of aspen (*Populus tremuloides* Michx.) on the western slope of the Rocky Mountains, Colorado. *Forest Ecology and Management* **167**(1-3), 263-28.

MCCLARAN, M.P., BROWNING, D.M., HUANG, C.Y., 2010. Temporal Dynamics and Spatial Variability in Desert Grassland Vegetation, In: Webb, R.H., Boyer, D.E., Turner, R.M. (eds.), *Repeat Photography Methods and Aplications in the Natural Sciences*, Island Press, Washington pp. 145-166.

MOSELEY, R.K., 2006. Historical Landscape Change in Northwestern Yunnan, China: Using Repeat Photography to Assess the Perceptions and Realities of Biodiversity Loss. *Mountain Research and Development* **26**(3): 214-219.

MUNROE, J.S., 2003. Estimates of Litle Ice Age Climate Iferred Through Historical Rephotography, Northern Uinta Mountains, U.S.A. *Artic, Antartic, and Alpine Research* **35**(4): 489-498.

PICKARD, J., 2002. Assessing vegetation change over a century using repeat photography. *Australian Journal of Botany* **50**: 409-414.

PUPO-CORREIA, A., ARANHA, J., MENEZES DE SEQUEIRA, M., 2011. Photographs from tourist activity: a source to assess vegetation change using repeat landscape photography. *Journal of Tourism and Sustainability* **1**(1): 13-17.

RHEMTULLA, J.M., HALL, R. J., HIGGS, E., MACDONALD, E., 2002. Eight years of change: vegetation in the montane ecoregion of Jasper National Park, Alberta, Canada. *Canadian Journal of Forest Research* **32**: 2010-2021.

ROGERS, G.F., MALDE, H.E., TURNER, R.M., 1984. Bibliography for Repeat Photography for Evaluating Landscape Change. University of Utah Press, Salt Lake City, 179 pp.

SAYN-WITTGENSTEIN, L., 1978. *Recognition of trees on aerial photographs*. Canadian forest service, Ottawa, 97 pp.

START, A.N., HANDASYDE, T., 2002. Using photographs to document environmental change: the effects of dams on the riparian environment of the lower Ord River. *Australian Journal of Botany* **50**: 465-480.

TURNER, R.H., OCHUNG, H. A., TURNER, J.B., 1998. *Kenya's changing landscape.* The University Arizona Press, Tucson, 177 pp.

TURNER, M.G., 2005. Landscape Ecology: What is the state of Science? *Annual Review of Ecology and systematics* **36**: 319-344.

VALE, T., 2001. Landscape change, global change, and the wisdom of Roy Bedichek. *Physical Geography* **22**(4): 277-290.

VEBLEN, T.T., LORENZ, D.C., 1991. *The Colorado Front Range. A century of Ecological Change*. University of Utah Press, Salt Lake City, 186 pp.

WEBB, R.H., 1996. *Grand Canyon: A century of change. Rephotography of the 1889-1890 Stanton Expedition.* The University of Arizona Press, Tucson, 290 pp.

ZIER, J.L., BAKER, W.L., 2006. A century of vegetation change in the San Juan Mountains, Colorado: An analysis using repeat photography. *Forest Ecology and Management* **228**: 251-262.

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