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Plant traits and hydrological services of forest areas In Northern Portugal

Vânia Sofia Azevedo Santos

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Vânia Sofia Azevedo Santos

Dissertação de Mestrado em Ecologia, Ambiente e teritório
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Todas as correções determinadas pelo júri, e só essas, foram efetuadas.

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Plant traits and hydrological services of forest areas in Northern Portugal

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Mestrado em Ecologia, Ambiente e Território
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Abstract

Ecosystems provide important services contributing for human well-being. The ones involving water are commonly called hydrological services, namely water supply, flood regulation and erosion prevention, and are strongly dependent of plants and their traits. Although climate and soil conditions have a major influence on hydrological services provision when compared to plant traits, the later should not be neglected because they characterize the type of forest and shrub cover. This is important because cover is the only variable that can be managed, at short term, for services improvement. In this context, the study proposes to identify the most informative traits related to hydrological services provision from the dominant woody species in Northern Portugal. Also, it is proposed to evaluate the potential contribution of those traits to the three above hydrological services based on a spatial analysis of their prevalence in five distinct landscape mosaics.

In order to establish this relationship, a complete survey of traits and respective trait states from the dominant woody species in Northern Portugal was created based in literature review. Forty-nine species were inventoried for traits and trait's states related to leaf, stem, canopy and plant height. Then, a comparison between native and exotic species was done. Finally, the three most informative traits (leaf strategy, leaf size and plant height) were reclassified and mapped according to their contribution for provision of hydrological services. The rationale for this exercise was based on literature review.

In Northern Portugal, the majority of woody plants have small height with rounded canopy and evergreen leaves. In general, native plants have small plant height, whereas exotic have medium size as prevalent trait state. Other major differences are related to leaf size, which distinguishes native species with small leaf size, and exotics with large leaf size.

Regarding the spatial analysis of trait contribution for provision of hydrological services in the five landscape mosaics, Alturas do Barroso has high trait contribution to the provision of water supply service. Morais has high trait contribution to the provision of the flood regulation and erosion prevention services. Ousilhão has medium trait contribution to the provision of each service. Vitorino has high trait contribution for the provision of flood regulation service. Maps of potential provision of ecosystem services can be useful to support management decisions to improve hydrological services provision, such as forestation plans. It was concluded that plant traits can be used as a proxy indicator to evaluate the contribution of different woody species for hydrological services provision.

Key words: functional traits, flood regulation, erosion prevention, water supply.

Resumo

Os ecossistemas fornecem serviços importantes que contribuem para o bem-estar humano. Os que estão relacionados com a água são habitualmente denominados de serviços hidrológicos, como o fornecimento de água, regulação de cheias e prevenção da erosão, que estão fortemente dependentes das plantas e das suas caraterísticas. Embora o clima e as condições do solo tenham uma grande influência sobre a prestação de serviços hidrológico quando comparado com as caraterísticas das plantas, estas não devem ser negligenciadas, pois caraterizam o tipo de floresta e o coberto arbustivo. Isto é importante porque, o coberto vegetal é a única variável que pode ser gerida, a curto prazo, para uma melhor prestação de serviços. Neste contexto, este estudo propõe identificar as caraterísticas mais informativas relacionadas com a prestação de serviços hidrológicos das espécies lenhosas dominantes no Norte de Portugal. Além disso, propõe-se avaliar a contribuição dos caracteres funcionais para os três serviços hidrológicos mencionados, com base numa análise espacial aplicada em cinco mosaicos de paisagem distintos.

Para estabelecer esta relação, um levantamento completo das caraterísticas e respetivo estado de caractere das espécies arbóreas dominantes no Norte de Portugal foi elaborado com base na revisão bibliográfica. Quarenta e nove espécies foram inventariadas para caractere e estado de caractere relacionados com a folha, o caule, a copa e a altura da planta. Em seguida, uma comparação entre espécies nativas e exóticas foi realizada. Por último, as três caraterísticas mais importantes (forma de vida, o tamanho das folhas e a altura da planta) foram reclassificadas e espacializadas de acordo com a sua contribuição para a prestação de serviços hidrológicos.

No Norte de Portugal, a maioria das plantas lenhosas têm altura pequena, com copa arredondada e folhas perenes. Em geral, as plantas nativas são de altura pequena, enquanto as espécies exóticas têm altura média como característica predominante. Outras principais diferenças predem-se com tamanho da folha, que distingue as espécies nativas com folha pequena das exóticas com folha grande.

Em relação à análise espacial da contribuição dos caracteres para a prestação de serviços hidrológicos nas cinco mosaicos de paisagem, Alturas do Barroso apresenta maior contribuição dos caracteres para a prestação de serviço de fornecimento de água. Morais apresenta maior contribuição dos caracteres para a prestação do serviço de regulação de cheias e para prevenção da erosão. Ousilhão tem igual contribuição dos caracteres para a provisão dos três serviços. Os mapas do potencial de provisão dos serviços ecossitémicos podem ser úteis para apoiar as decisões de gestão de forma a melhorar a prestação de serviços hidrológicos, como por exemplo, os planos de ordenamento florestal. Conclui-se que as caraterísticas das plantas podem ser utilizadas como um indicador para avaliar a contribuição de diferentes espécies lenhosas para a prestação de serviços hidrológicos.

Palavras-chave: caracteres funcionais, fornecimentos de água (quantidade), regulação de cheias e prevenção da erosão.

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Abbreviations

MA - Millennium Ecosystem Assessment

FAO - Food and Agriculture Organization

CBD - The Convention on Biological Diversity

1. Introduction

1.1. Biodiversity and ecosystem services

Biodiversity, the variety of life on our planet, is defined by The Convention of Biological Diversity (CBD) "as the variety of species and all the genetic differences within each species. It encompasses the variety of ecosystems such as forests, drylands, wetlands, mountains, lakes, rivers, agricultural lands and islands". It includes diversity between species and ecosystems and within species itself (Pereira *et al*. 2009).

Around the world there are regions that have more diversity than others in matters of species. On the other hand, there are regions with less diversity of species but are nonetheless important, as they might support a large number of endemic species (i.e. species that only occur on that area/region). These areas are designated as "hotspots" (Fig. 1) and in the last decades, the 25 "hotspots" on Earth have lost over 70% of the original vegetation, making them priority areas for conservation (Myers *et al.* 2000).

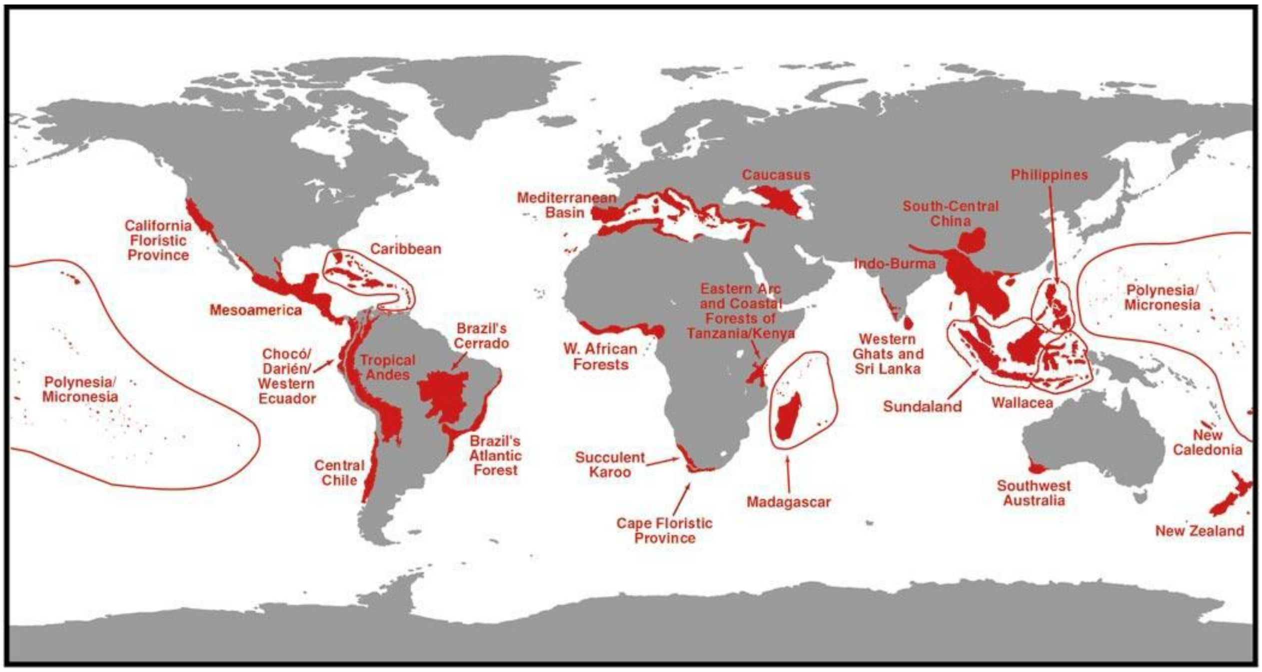


Fig. 1 – The twenty-five "hotspots" on Earth (Myers N. et al. (2000).

An ecosystem is a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (CBD). There are a diverse range of ecosystems that goes from open oceans to coral reefs, estuaries, floodplains, lakes, rivers, tropical forest to temperate forest, deserts and so on (TEEB, 2010).

"Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history". These changes on the ecosystems are entirely connected with increasing demands for food, water and fuel. In order to fulfill this demands, ecosystems and each component of biodiversity, such as species richness are threaten, as well as the services they provide (MA, 2005).

Ecosystem services are the benefits people obtain from ecosystems. These services include (Fig. 2) provisioning services such as food and water; regulating services such as floods, pollination and water quality; supporting services such as soil formation and photosynthesis; cultural services such as recreational and spiritual benefits (MA, 2005).

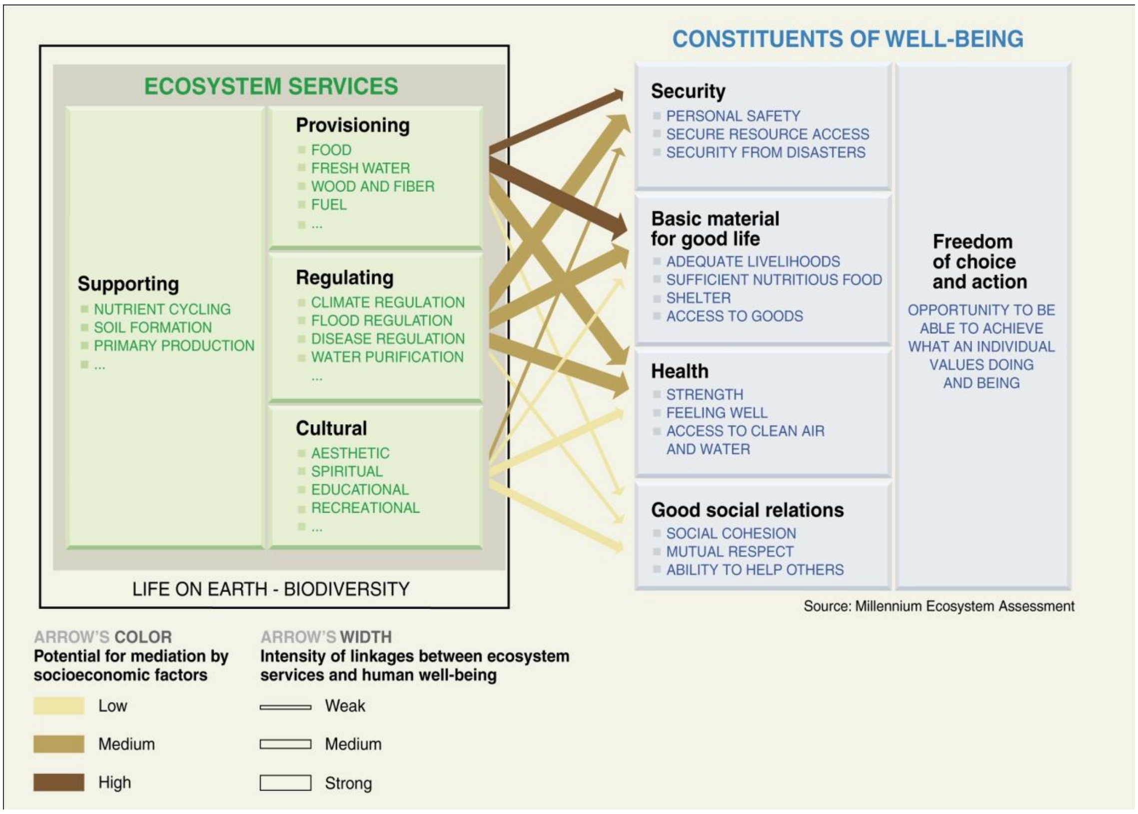


Fig. 2 – Linkages between ecosystem services and human well being. (Millennium Ecosystem Assessment, 2005).

The Millennium Ecosystem Assessment (MA) documented the importance of ecosystem services to human well-being and assessed the consequences of ecosystem change and defines strategies to enhance the conservation and sustainable use of the ecosystems (Guo *et al.*, 2010; MA, 2005).

It is essential to understand that humans are the beneficiaries of the ecosystems and therefore is extremely important to protect them and the services they provide

(Brauman *et al*., 2007). There can only be an ecosystem service if there's a human use for it.

1.1. Hydrological regulation and hydrological services

"Access to clean water is one of the most fundamental human rights". Although is not evenly distributed around the world and one in six people still don't have access to safe drinking water (FAO, 2013).

Hydrological services are one of many services provided by ecosystems. They involve the benefits to people produced by terrestrial ecosystems effects on freshwater. There are five categories of hydrological services: improvement of extractive water supply, improvement of in-stream water supply, water damage mitigation, provision of water-related cultural services and water-associated supporting services. Forests are one of the most prominent ecosystems for the provision of hydrological services (Brauman *et al*. 2007; Calder *et al*., 2001).

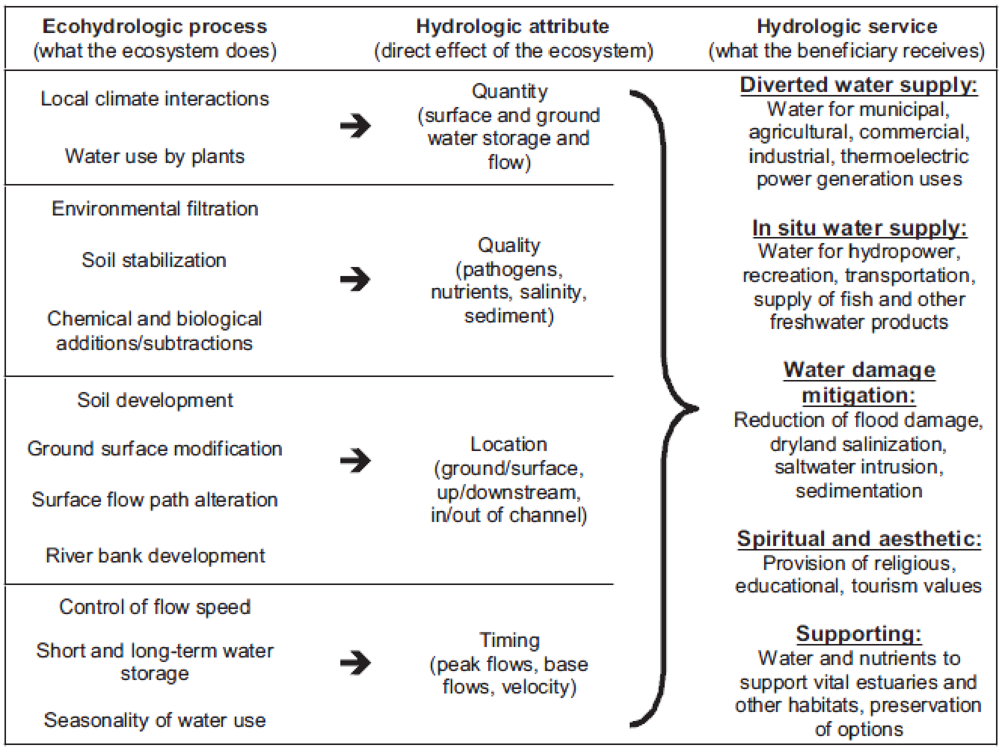


Fig. 3 - Relationship of A number of ecosystem processes affect each attribute (Brauman *et al*., 2007).

In forest ecosystems, after a rainfall event onto the forest canopy, the rain water can flow in different paths. It can be intercepted by the canopy and be re-evaporated before it reaches the soil – intercepted water (IW), it can also run through the gaps on the canopy or run off the canopy and reach the soil - throughfall (TF). It can run down the trunk into the soil - stemflow (SF). As it's illustrated in Fig. 3 water supply is one of many hydrological services with great importance for agriculture and industrial supply. Water supply function also depends on the role of ecosystems in hydrologic cycles focusing primarily on the storage capacity rather than the flow of water through the system. But others such as food regulation and erosion prevention are as much important as water supply. Forests mitigates water-related hazards as the canopy provides interception storage and breaks the impact of rain water reducing the risk of detaching soil particle and therefore initiate erosion (Barbier *et al*., 2009; Bredemeier, 2011; Breshears *et al.*, 2008; de Groot *et al.,* 2002).

1.2. Effects of vegetation and plant traits on hydrological cycle

It is common knowledge that forests and water have a long term relationship. Forests influence the hydrological cycle and they have an effect on water resources both quantitatively and qualitatively. It's a two-way relationship. Forests are extremely important to water ecosystems such as rivers, while water is essential for the sustainability of forests ecosystems. The benefits of forests for the supply of water are multiple. It is by maintaining high water quality that natural and managed forests make their most significant contribution (Calder *et al*., 2007; FAO, 2013).

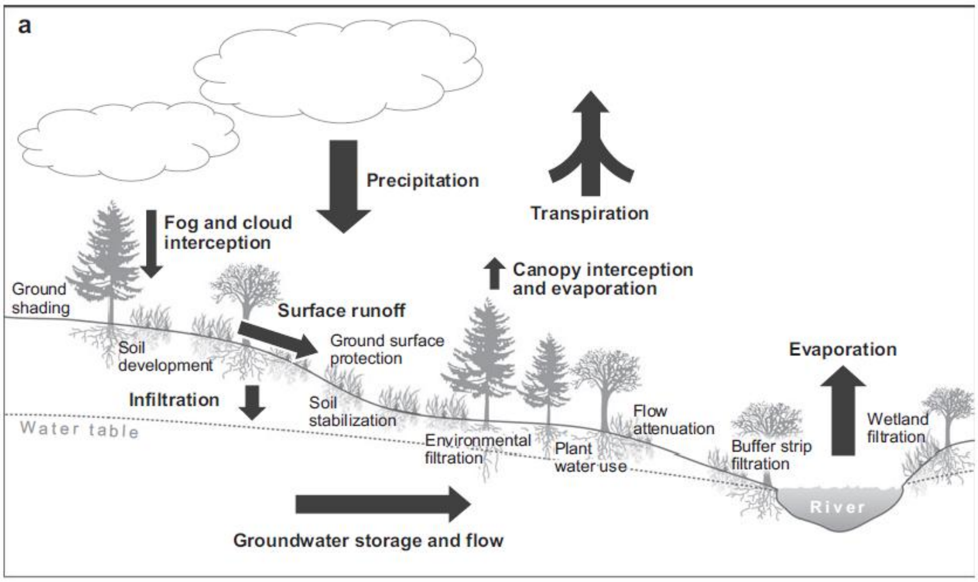


Fig. 4 (a) - Water cycle - ecosystem interactions. At the watershed scale, ecosystems affect water through local climate interactions, water use by plants, ground surface modification, and water quality modification (Brauman *et al*., 2007).

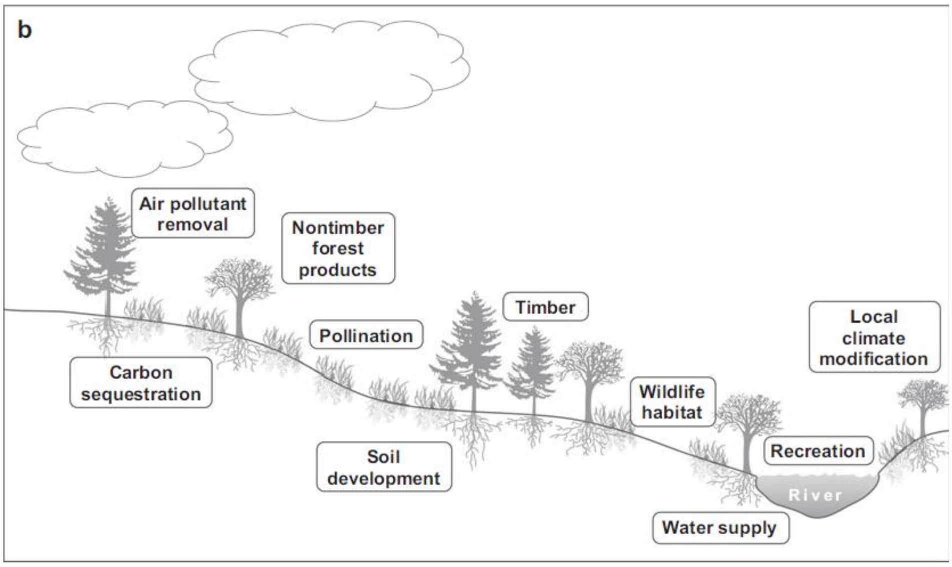


Fig. 4 (b) - Water cycle - ecosystem interactions. In addition to hydrologic services, a watershed produces a variety of other services; examples of these are shown in the figure (Brauman *et al*., 2007).

A large portion of the water used for agricultural, industrial and domestic needs is supplied by forested catchments. However, forests return less water to the soil as a large amount of water is intercepted by the canopy and is given back to the atmosphere through evapotranspiration. On the other hand, forest soils have dense and deep root system that enhances the infiltration and groundwater recharge and minimizes surface runoff. The availability and especially the quality of water are strongly influenced by forests and thus depended of proper forest management (Calder *et al.,* 2007; FAO, 2013).

Water use by forests is influenced by the seasons, climate, topography, soil, forest composition (age and tree species) and forest management practices. Therefore plant traits might influence the provision of hydrological services. Barbier et al (2009) reviewed studies that compared stand characteristics such as age or basal area, which are important factors of forest structure and canopy cover liable to affect water flows. From this they conclude that different traits state (e.g. deciduous/evergreen) influences the processes and the water flows (Barbier *et al*., 2009).

The study of traits and their influence on the hydrological processes has been approached in literature with several studies in catchments. However, the traits state varies according to the environmental conditions of each region. Therefore, it is important to analyse plant traits related to the water cycle in Northern Portugal, a region with environmental heterogeneity between the Atlantic West and the Mediterranean East (Barbier *et al*., 2009).

The relationship between hydrological services such as evapotranspiration, surface runoff with plant traits is represented in the following table.

Table 1 - Rational between hydrological processes and traits (Amado *et al.,* 2013).

Traits		Hydrological Processes	Rational
Canopy		Evapotranspiration Infiltration Surface runoff	Influence water storage area and subsequent rainfall interception. Prevents direct "splash" of raindrops into the soil.
Plant Height		Evapotranspiration	Defines the water use by the plant and the quantity transpired. Plant size implies larger surface exposed to increasing aerodynamic on the evaporation process.
Stem	Direction of growth	Evapotranspiration	Influence canopy form and therefore evapotranspiration
Stem	Texture	Stemflow	Hinders the raindrops arrival to the ground.
Leaf	Leaf strategy	Evapotranspiration Infiltration Surface runoff	Influences on transpiration, but mostly on water interception after the rainfall event, on seasonal terms. Absence of leaves on trees promotes surface runoff. Evergreen trees increase infiltration.
Leaf	Orientation	Evapotranspiration	Influence radiation interception and subsequent biomass increase. The exposed surface of the leaf influences transpiration. Interacts with the storage capacity and subsequent evaporation of water.
Leaf	Leaf Size (length and width)	Evapotranspiration Throughfall	Important for leaf cover definition, which influences the evapotranspiration.
Leaf	Form and texture	Evapotranspiration	Sets the exposed surface for transpiration.
Leaf	Pubescence, rolling, margin and cuticle	Evapotranspiration Throughfall	Influencing the exposed surface to transpiration, as well as how water droplets reach the ground after a rainfall event.

1.3. Objectives

This dissertation has the following objectives:

i. Identify the functional traits of dominant woody plants that most influence the provision of hydrological regulation services by forest and shrub vegetation;
ii. Collect information on those traits for dominant woody plants in the North of Portugal;
iii. Analyse the distribution of traits over the landscape in five sites with contrasting landscape mosaics in the North of Portugal;
iv. Discuss the potential provision of hydrological services by woody vegetation in the five landscapes mosaics.

2. Methods

2.1. Distribution of focal traits across woody species in the regional pool

2.1.1. Diversity of forest and shrub vegetation in Northern Portugal

Portugal is part of the Iberian Peninsula, situated in the Southwest Europe. It stands in a transition zone between two biogeographically regions, Eurosiberian Region and Mediterranean Region (Costa *et al.,* 1998). Throughout these regions, factors such as climate, soil conditions, topography, and altitude influence at a regional and local scale and, at different time scales, enabling an extraordinary diversity of forests. Regional and local variations of these factors allow distinguishing of forests with particular importance for biodiversity conservation, ecological processes regulation and provision of ecosystem services (Honrado *et al.*, 2011).

In general, forests can be natural, semi natural and anthropogenic. Natural forests are dominated by deciduous, evergreen and marcescent species. From Douro to Trás-os-Montes, with less rainy winters, cork oak forests (*Quercus suber*) and holmoak forests (*Quercus rotundifolia*) abound, frequently associated with prickly juniper (*Juniperus oxycedrus*). In rainy winter areas (Entre Douro and Minho) deciduous forests of *Quercus robur* and *Betula celtiberica* dominate. In transition areas (Mediterranean rainy areas) marcescent species such as *Quercus pyrenaica* and *Quercus faginea* occur. Other species can also occur, including *Alnus glutinosa*, *Salix atrocinerea*, *Fraxinus angustifolia*, *Laurus nobilis* and *Prunus lusitanica* (Honrado *et al.*, 2011).

Anthropogenic forests are dominated by exotic species. These forests usually have the sole purpose of providing production services such as timber and paper pulp. Therefore, species as *Eucalyptus globulus* and *Pinus pinaster* abound in these ecosystems. Other exotic species, *Pseudotsuga menziesii*, *Pinus sylvestris* and *Pinus nigra* can also occur. Species as *Quercus suber*, *Castanea sativa* and *Cupressus lusitanica* were also cultivated with production purposes (Honrado *et al.*, 2011).

Semi natural forests are, somehow, between natural and anthropogenic forests and might be formed by four distinct ways: (i) settlement by forests with native and exotics species; (ii) abandonment, absence or inadequate management of an anthropogenic forest leading to spontaneous regeneration of native species (e.g. abandon pine and eucalyptus forests); (iii) simplification of a preexistence native forest by management intensification; and (iv) invasion of a natural or anthropogenic forest by other invasive species (e.g. *Acacia dealbata*) (Honrado *et al.*, 2011).

Regarding the climate, the northwest of Portugal has a temperate climate, with rainy winters and dry and mild summers, influenced by the Atlantic Ocean, dominated by trees such as oaks (*Quercus* spp.), beeches (*Fagus* spp.), birches (*Betula* spp.), ashes (*Fraxinus* spp.) and shrubs such as furzes and heathers (*Ulex europaeus*, *U. minor*, *Erica ciliaris*, *E. cinerea* and *Daboecia cantabrica*) and others including *Adenocarpus complicatus* subsp. *lainzii*. On the other hand, the northeast has rainy winters and dry and hot summers influence by the Mediterranean, characterized by species such as pyrenean oak (*Quercus pyrenaica*), cork oak (*Qercus suber*) and brooms (*Genista obtusiramea*, *Vaccinium myrtillus*, *Carex asturica*, *Erica arborea*, *Juniperus alpine*, *Cytisus scoparius*, *Calluna vulgaris*) (Costa *et al.*, 1988; Honrado *et al.*, 2011). Therefore it is possible to distinguish three types of forests; mountain forests, temperate and sub-mediterranean forests and mediterranean forests.

In mountain territories, with cold and wet climate, forests dominated by *Betula celtiberica*, *Quercus pyrenaica*, *Vaccinium myrtillus* and *Quercus robur*. In areas as Entre Douro and Minho, typically sub-mediterranean forests abound including species as *Quercus suber*, *Arbutus unedo*, *Ruscus aculeatus*, *Laurus nobilis and Prunus lusitanica*. Mediterranean forests are dominated by evergreen species including *Quercus suber* or *Quercus rotundifolia* with junipers (*Juniperus oxicedrus*) and acebuche (*Olea sylvestris*) (Honrado *et al.*, 2011).

Soil conditions and topography are the factors that influence the most the type of vegetation in landscapes. Natural forests, related with moist soils of valleys are dominated by species such as *Alnus glutinosa*, *Salix atrocinerea*, *Fraxinus spp.* But also other species, *Celtis australis*, *Ulmus minor*, *Corylus avellana* and *Populus nigra*. Riparian forests are dominated by *Alnus glutinosa*, *Salix atrocinerea*, *Laurus nobilis* and *Fraxinus angustifolia* (Honrado *et al.*, 2011).

2.1.2. Selection of focal species

This selection was based on species that are represented in the North of Portugal, registered in the Checklist da Flora de Portugal. A set of criteria was established to select the focus species in Northern Portugal. It was selected the species that fulfilled the following criteria; (i) dominant tree and shrubs species; (ii) woody invasive species with strong expression; and (iii) non-native forest species with actual expression or with potential for production or protection services.

After applying these criteria, a list with forthy-nine species was created, which can be seen in the following table.

Table 2 - List of focal species.

	Native	Exotic
Shrubs	*Adenocarpus lainzii* *Calluna vulgaris* *Cistus ladanifer* *Cytisus multiflorus* *Cytisus striatus* *Erica arborea* *Erica australis* *Erica cinérea* *Erica umbellata* *Halimium lasianthum* *Genista florida* *Genista triacanthus* *Pterospartum tridentatum* *Rubus ulmifolius* *Ulex europeus sp. latebracteatus* *Ulex micranthus* *Ulex minor*	*Acacia longifolia* *Arundo donax* *Cortaderia selloana* *Hakea sericea*
Trees	*Alnus glutinosa* *Arbutus unedo* *Betula alba* *Fraxinus angustifolia* *Pinus pinaster* *Pinus sylvestris* *Prunus avium* *Quercus pyrenaica* *Quercus robur* Quercus rotundifolia *Quercus suber* *Salix atrocinerea*	*Acacia dealbata* *Acacia melanoxylon* *Ailanthus altissima* *Castanea sativa* *Cedrus atlantica* *Chamaecyparis lawsoniana* *Cupressus lusitanica* *Eucalyptus globulus* *Fagus sylvatica* *Juglans nigra* *Pinus nigra* *Platanus x hispanica* *Populus nigra* *Pseudotsuga menziesii* *Populus x canadensis* *Quercus rubra*

2.1.3. Selection of focal traits

The focal traits were selected based on literature and expert knowledge. As referred in 1.2 on the introduction section (Table 1) there is a relationship between traits and hydrological processes. Based on this relationship, the following traits were selected (Table 3).

Table 3 - Focal traits with hydrological importance.

Leaf Traits			**Stem Traits**	**Canopy Traits**	**Plant**
Leaf strategy	Form	Pubescence	Direction of growth	Form	Height
Orientation	Petiole	Margin	Rythidome	Diameter	
Consistency	Size	Rolling	Pubescence		
Arrangement	Cuticle		Bloom		

2.1.4. Matrix of species vs. traits

Before the construction of the matrix, a criterion for its filling was established. Each species has a code for its scientific name with the first three words of the genus and the first three words of the species (e.g. *Acacia dealbata* - ACADEA). The same criterion was applied with the trait name and trait state, but with a modification, instead of use the three words of the name, it was used the first three words of the trait and the first three words of the plant part where the trait is located or related to (e.g. Leaf strategy – Lea_Str; trait state: Deciduos - Lea_Dec). Some traits state is presence or absence, 1 stands for presence and 0 for absence.

Other considerations were made, namely referencing to the leaf strategy trait where marscecent species were consider deciduous because marscecent species have wilted leaves and, according to the altitude some species are deciduous but in the plateau they are marscecent. Peduncular leaves were considered vertical (orientation). The leaf form absence refers to spines, ephemeral leaves and absence of leaves. Although they are not the same characteristic, they have the same function on the hydrological processes.

Table 4- Traits and correspondent trait state.

Leaf

Trait	Leaf strategy	Orientation	Consistency	Form (Architecture)	Petiole
State	Deciduous	Horizontal	Leathery	Plane	Absence
	Evergreen	Vertical	Herbaceous	Acicular	Presence
			Succulent	Absence	

Leaf

Trait	Size	Cuticle	Pubescence	Margin	Rolling
State	Small	Absence	Absence	Entire	Absence
	Medium	Presence	Poorly developed	Deeply divided	Presence
	Large		Well developed	Shallowly divided	

Stem

Trait	Direction of growth	Rhytidome	Pubescence	Bloom
State	Erect	Rough	Absence	Absence
	Suberect	Smooth	Presence	Presence
	Prostrate			
	Subprostrate			

	Canopy		**Plant**
Trait	Form	Diameter	Height
State	Conic		Small
	Irregular		Medium
	Rounded		High

Regarding to the pubescence trait, bloom and other coating trait are accounting within this trait. This trait has three states: 0 that stands for no pubescence or other coating, 1, for poorly developed pubescence or other coating and 2 for well developed pubescence. The size of the leaves was estimated by its length and width. The margin of the leaves is entire if the leaf has no snip. Deeply divided if the leaf is compound or deeply sniped (e.g. lobate, palmatisect leaves) and shallowly divide if the leaves are simple and sniped (e.g. undulate, serrate leaves).

The data collection was based on the following literature; (i) López Gonzalez (2006); (ii) Castroviejo, (1990;1996); (iii) Amaral Franco (1984).

2.2. Spatial distribution of traits and potential provision of hydrological services

2.2.1. The five landscape mosaics

The Portugal areas of the EBONE project were used as the study areas. This project has focused on the development of an effective system of biodiversity data collection at regional, national and European levels. The reason these areas were chosen is based on the data information that is available at a species detail.

In Portugal, five areas were selected for data collection and floristic inventory; Alturas do Barroso, Medrões, Morais, Ousilhão and Vitorino. As it’s shown on Fig. 4 and Fig. 5, Ousilhão has a mountain climate, where *Quercus pyrenaica* dominate, Morais with a more Mediterranean climate dominated by Quercus rotundifolia and *Cistus ladanifer*. Alturas do Barroso is also influence by mountain climate, exhibiting its typical species including *Quercus pyrenaica*, *Betula alba*, *Cytisus striatus* and *Cytisus multiflorus*, whereas Medrões has sub-mediterranean climate with *Pinus pinaster* and *Eucalyptus globulus*. Vitorino has the influence of the Atlantic Ocean characteristic of *Quercus robur* and *Adenocarpus lainzii*.

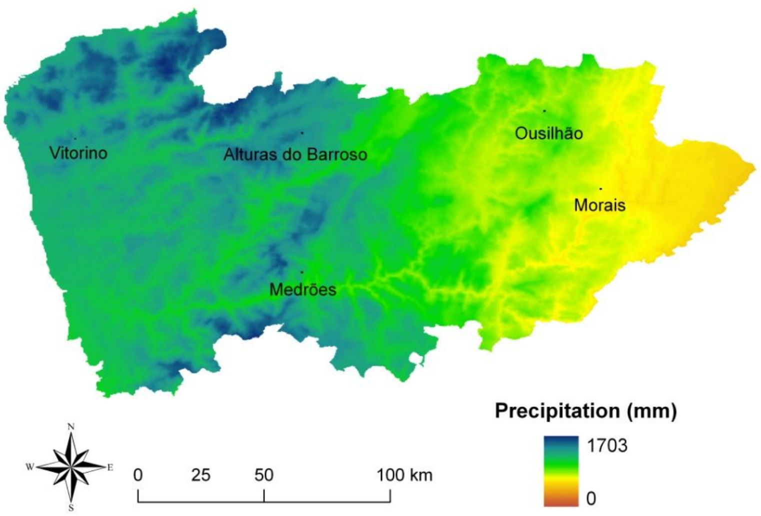


Fig. 5 – The five landscapes mosaics distribution on the North of Portugal. Mean annual precipitation (mm/yr, 250 m^2 pixel resolution) from Worldclim database, 1950-2000 (Worldclim, 2010).

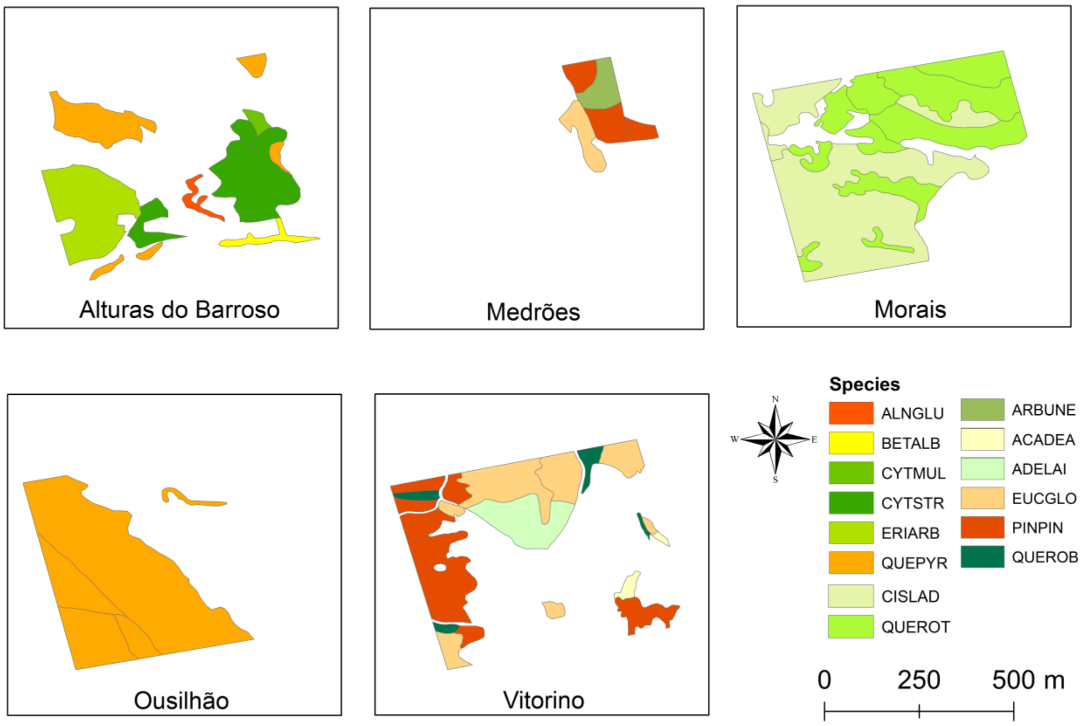


Fig. 6 – Distribution of species in the landscape mosaic. ACADEA (*Acacia dealbata*), ADELAI (*Adenocarpus lainzii*), ALNGLU (*Alnus glutinosa*), ARBUNE (*Arbutus unedo*), BETALB (*Betula alba*), CISLAD (*Cistus ladanifer*), CYTMUL (*Cytisus multiflorus*), CYTSTR (*Cytisus striatus*), EUCGLO (*Eucalyptus globulus*), ERIARB (*Erica arborea*), PINPIN (*Pinus pinaster*), QUEPYR (*Quercus pyrenaica*), QUEROB (*Quercus robur*) and QUEROT (*Quercus rotundifolia*).

It is possible to verify that Vitorino and Alturas do Barroso have exotics species, namely *Pinus pinaster* and *Eucalyptus globulus.* Vitorino also has *Acacia dealbata*, an invasive alien species.

2.2.2. Spatial analysis

The trait state was reclassified based on the contribution of the trait to the hydrological service, 1 (low contribution), 2 (medium contribution) and 3 (high contribution). The leaf strategy trait has only 1 and 3, because there are two trait states instead of three, deciduous or evergreen, according to Table 7 in the results section.

The spatial analysis was done on ArcGIS®. 9.3 version software from ESRI.

3. Results and discussion

3.1. Distribution of focal traits across woody species in the region pool

3.1.1. Distribution of trait state for the pool species

In a primary analysis of the matrix, the frequencies of the traits states were calculated (Table 5).

Table 5 - Trait state frequencies in the pool species.

Traits		(n=49 species) Trait state	(%)
Plant height		Small	51
		Medium	31
		High	18
Canopy form		Rounded	64
		Irregular	20
		Conic	16
Stem	Direction of growth	Erect	96
		Sub-prostrate	4
	Texture	Rough	57
		Smooth	43
	Pubescence	Absence	65
		Presence	35
	Bloom	Absence	94
		Presence	6
Leaf	Leaf strategy	Evergreen	57
		Deciduous	43
	Orientation	Vertical	65
		Horizontal	35
	Consistency	Leathery	51
		Herbaceous	49
	Architecture	Flat	76
		Acicular	16
		Absence	8
	Arrangement	Alternate	61
		Opposite	31
		Absence	8
	Size	Medium	41
		Small	35
		Large	24
	Cuticle	Absence	61
		Presence	39
	Pubescence	Absence	71
		Poorly developed	41
		Well developed	8
	Petiole	Absence	39
		Small	29
		Medium	22
		Large	10
	Margin	Entire	41
		Deeply divided	31
		Shallowly divided	28
	Rolling	Absence	88
		Presence	12

In terms of plant height, the trait state most frequent is small. For the canopy form, rounded is the more frequent trait state. Although stem direction of growth has five trait states, only two of them are represented, where erect is the dominant trait state. Stem texture dominant trait state is rough and most species have no stem pubescence or bloom.

Leaf strategy is mainly evergreen. For the leaf orientation the most frequent trait state is vertical. In terms of consistency, the frequent trait state is coriaceous. Leaf architecture is mainly flat and the arrangement of the leaves is mostly alternate. Medium size leaf dominates and, regarding to cuticle and pubescence, most species have no cuticle or pubescence. The petiole is mostly absence. In terms of leaf margin, the most frequent trait state is entire and most leaves have no rolling.

3.1.2. Frequencies of trait state for natives and exotics species

In this sub-chapter the frequencies of the trait state between native and exotics species were compared.

Table 6 - Frequencies of traits among native and exotic species.

Traits		Natives (n=29)		Exotics (n=20)	
		Trait state	(%)	Trait state	(%)
Plant height		Small	59	Medium	50
Canopy form		Rounded	76	Rounded	45
Stem	Direction of growth	Erect	93	Erect	100
	Texture	Rough	59	Rough	55
	Pubescence	Presence	52	Absence	90
	Bloom	Absence	93	Absence	95
Leaf	Leaf strategy	Evergreen	55	Evergreen	60
	Orientation	Vertical	62	Vertical	60
	Consistency	Leathery	55	Herbaceous	55
	Architecture	Flat	79	Flat	80
	Arrangement	Alternate	52	Alternate	75
	Size	Small	48	Large	50
	Cuticle	Absence	58	Absence	65
	Pubescence	Poorly developed	55	Absence	80
	Petiole	Absence	31	Absence	50
	Margin	Entire	38	Entire	45
	Rolling	Absence	79	Absence	100

It was expected that the majority of native species were deciduous. However, results show that 55% of native species are evergreen. This can be explained by the number of native shrubs. Eighteen out of twenty-nine native species are shrubs and, most of them are evergreen, resulting on a higher percentage of evergreen species than deciduous. However, most native species are deciduous and during the winter they are leafless. This characteristic promotes surface runoff. Exotic species, mostly evergreen, could contribute to water infiltration rates during all year.

In exotics species, most leaves are large, with vertical orientation, herbaceous consistency, flat architecture and alternate leaf arrangement. Leaves have no cuticle, pubescence and petiole, exhibiting an entire margin and absent rolling. Stem is mostly rough, with no pubescence and bloom, and the canopy is mostly rounded. Most native species have small leaves, with vertical orientation, leathery consistency, flat architecture and alternate leaf arrangement. Leaves have no cuticle and petiole, exhibiting poorly developed pubescence and no leaf rolling. Stem is rough with pubescence, and the canopy is mostly rounded. Exotic species with large leaves have higher foliage cover than natives.

Regarding terms of plant height, native species have small height contrasting exotic species that are mostly medium height. In native species this traits promotes a less efficiency on water catchment. On the other side, having less exposed area resulting in less evapotranspiration. Some exotic species, namely *Acacia dealbata*, have rapid growth. Alongside with others, this trait confers an advantage in eco-hydrological performance comparing to native species and exotics with slow growth.

3.2. Spatial distribution of traits potential provision of hydrological services

3.2.1. Selection of most informative traits

Traits and respective contribution to the provision of hydrological services (water supply, flood regulation and erosion prevention) were selected based on literature. The traits that influence the most are; leaf strategy, leaf size and plant height.

For the provision of water supply (quantity) service, deciduous species have high contribution to this service because during the winter they are leafless, promoting water infiltration from rainfall, whereas evergreen species have low contribution because they have leaves all year and evapotranspire the water back to the atmosphere. Small leaves intercept less rainfall water than large leaves, having high contribution to the service provision. The higher the plant, the lower the contribution it provides, because, high plants have higher evapotranspiration (Barbier *et al.*, 2009; Neary *et al.*, 2009).

For the provision of flood regulation services, evergreen species intercept water all year and evapotranspirate more water having higher contribution than deciduous species because, the later do not have leaves during winter when it rains the most. Large leaves also intercepted more water from the rainfall than small leaves. Regarding to plant height, high plants intercept more rainfall that return the rain water back to the atmosphere (Calder *et al.*, 2006).

For the provision of erosion prevention services, what matters is to have cover that protects soil from rainfall erosivity. Having forest or shrub cover is always better than to have agriculture, which mobilizes the soil contributing to soil erosion (Calder *et al.*, 2001). According to the C factor of MUSLE (Modified Universal Soil Loss Equation), which describes the influence of land cover on soil erosion, small height plants like shrubs have the higher contribution for soil erosion control, followed by trees (Pimenta *et al.*, 1998). This was qualified by Pimenta et al. 1998 for all the Corine land cover map classes in Portugal. However, to be deciduous is not so good, because during winter when it rains the most in Portugal, leaves or needles work as interception barrier. Regarding plant height, the higher the tree the lower the contribution because it may increase water drop, increasing water splash and detaching soil.

Table 7 – List of traits with potential contribution to hydrological services provision

	Hydrological service		
Traits contribution	Water supply (quantity)	Flood regulation	Erosion prevention
Leaf strategy			
Evergreen	Low	High	High
Deciduous	High	Low	Low
Leaf Size			
Small	High	Low	Low
Medium	Medium	Medium	Medium
Large	Low	High	High
Plant Height			
Small	High	Low	High
Medium	Medium	Medium	Medium
High	Low	High	Low

3.2.2. Spatial distribution of traits in selective landscape mosaics

After defining the most informative traits and establishing its contribution to each hydrological service potential provision, trait distribution in the landscape mosaics was mapped.

Fig. 7 shows the distribution of leaf strategy trait. Ousilhao has only *Quercus pyrenaica* as woody species, therefore is only deciduous as trait state. Morais is dominated by evergreen species (*Cistos ladanifer* and *Quercus rotundifolia*). Although Medrões is a mixed of woody species, all species are evergreen (*Pinus pinaster*, *Eucalyptus globulus* and *Arbutus unedo*). Alturas do Barroso and Vitorino are both mixed of deciduous and evergreen species.

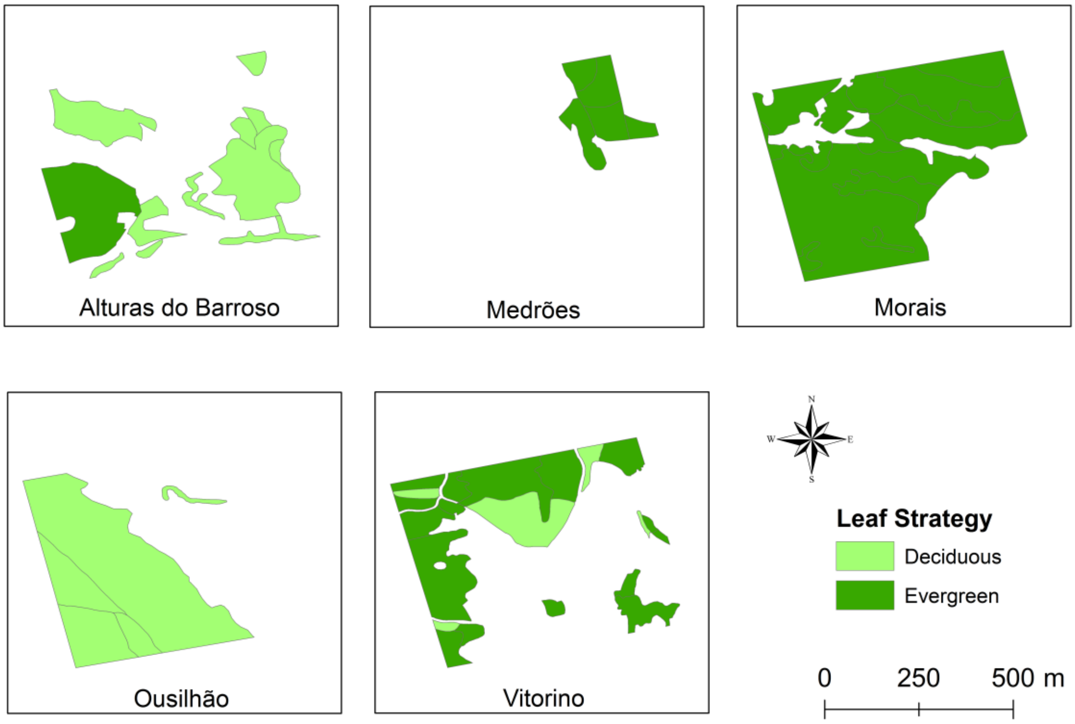


Fig. 7 - Leaf strategy trait distribution among species on the five landscapes mosaics.

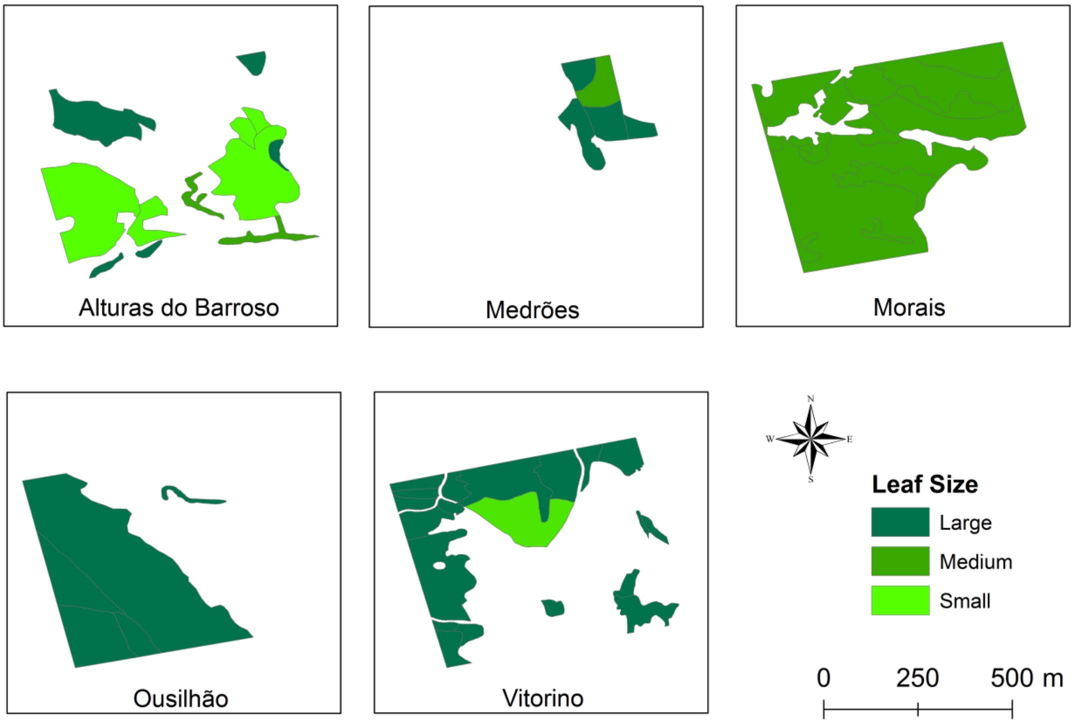


Fig. 8 – Distribution of the trait Leaf Size among species on the five landscapes mosaics.

Attending to the trait "leaf size" (Fig. 8), small leaves size corresponds to shrubs, with exception of *Cistus ladanifer* (Morais) that has medium size leaves. There is a clear dominance of medium and large leaves trees in the areas, aside from Alturas do Barroso that is dominated by shrubs such as *Erica arbora*, *Cytisus striatus* and *Cytisus multiflorus.*

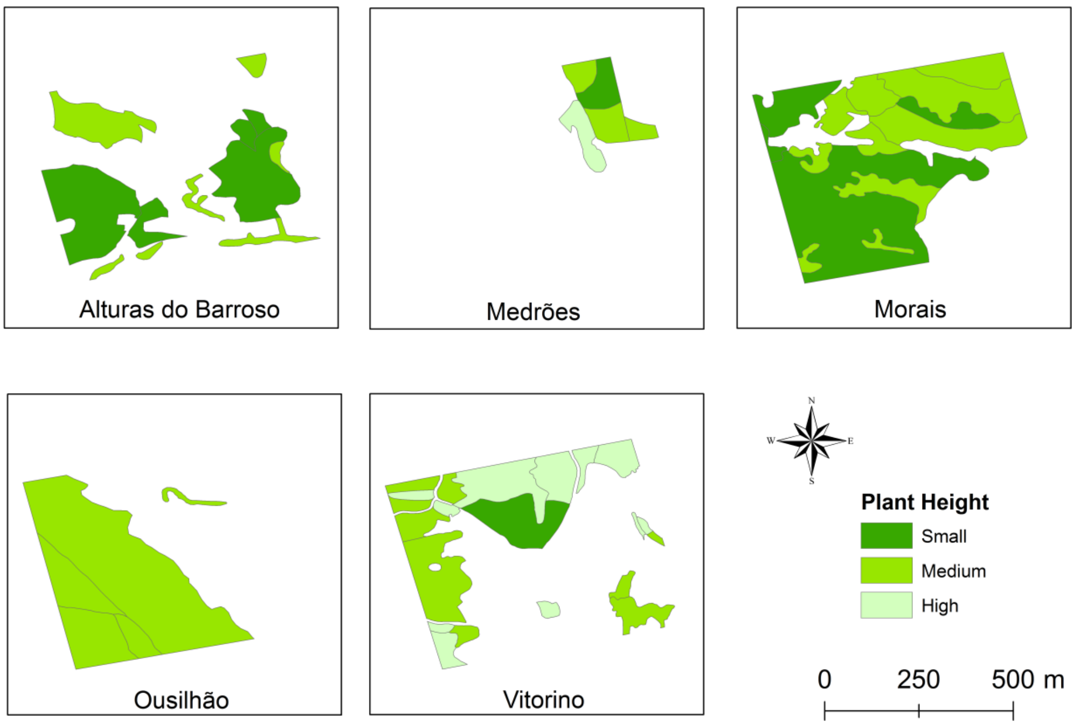


Fig. 9 – Plant height trait distribution on the five landscapes mosaics.

Small height plants correspond to shrubs represented in the five mosaics. Medium and high plants are trees. All oaks represented (*Quercus robur, Quercus pyrenaica and Quercus rotundifolia*) have medium height. *Eucalyptus globulus* is the only high tree represented in these areas.

3.2.3. Potential provision of hydrological services across landscape mosaics

In the following maps the contribution of all three traits previously selected for each hydrological service is represented.

Alturas do Barroso has the highest potential for the provision of water supply service (Fig.10), meaning that it has high trait contribution to the service. In this mosaic, the major land cover is shrubs and shrubs have high contribution to water supply, due to their small leaves and small plant height (Table 7) that promotes less rainfall interception (more water enters into the system).

On the other hand, Medrões has the lowest potential for the provision of the service, but is less spatially representative due to their small percentage of woody area. This lower potential is related to high plant height and evergreeness characteristic (Table 7), which promotes more rainfall intercepted back to the atmosphere.

In spite of Morais having only low to medium contribution to water supply, is the most spatially representative for the provision of this service in terms of woody area.

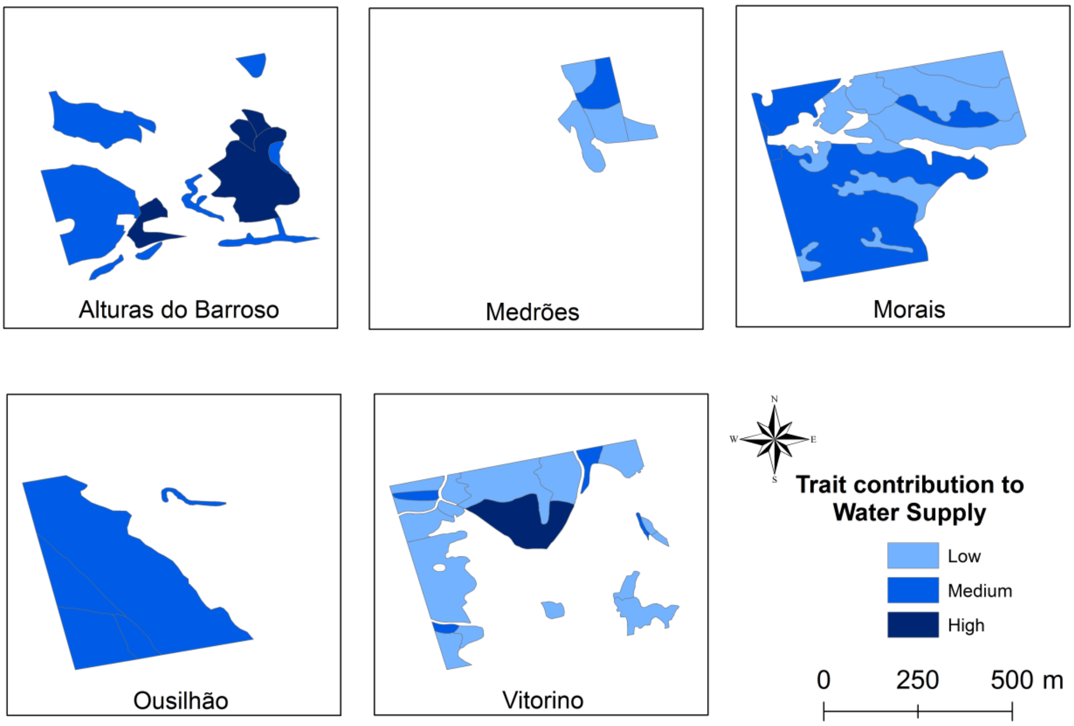


Fig. 10 – Trait contribution to water supply service in the five landscape mosaics.

Regarding to the provision of flood regulation service (Fig.11), Medrões, Morais and Vitorino show high trait contribution. Morais is highlighted because it has the major woody coverage, when compared to the other two locations. Large and evergreen trees influence flood regulation by intercepting rainfall, therefore reducing or mitigating floods. These effects would be expected to be most significant for small storms but the same might not be applied to largest storms (Calder *et al.*, 2006).

On the other hand, Alturas do Barroso has lowest trait contribution related to deciduous shrubs promoting less rainfall interception. It should be bear in mind that flood regulation service is mainly influenced by soil depth. In general, soils under forests are deeper and porous than soils under low shrubs (Calder *et al.,* 2002).

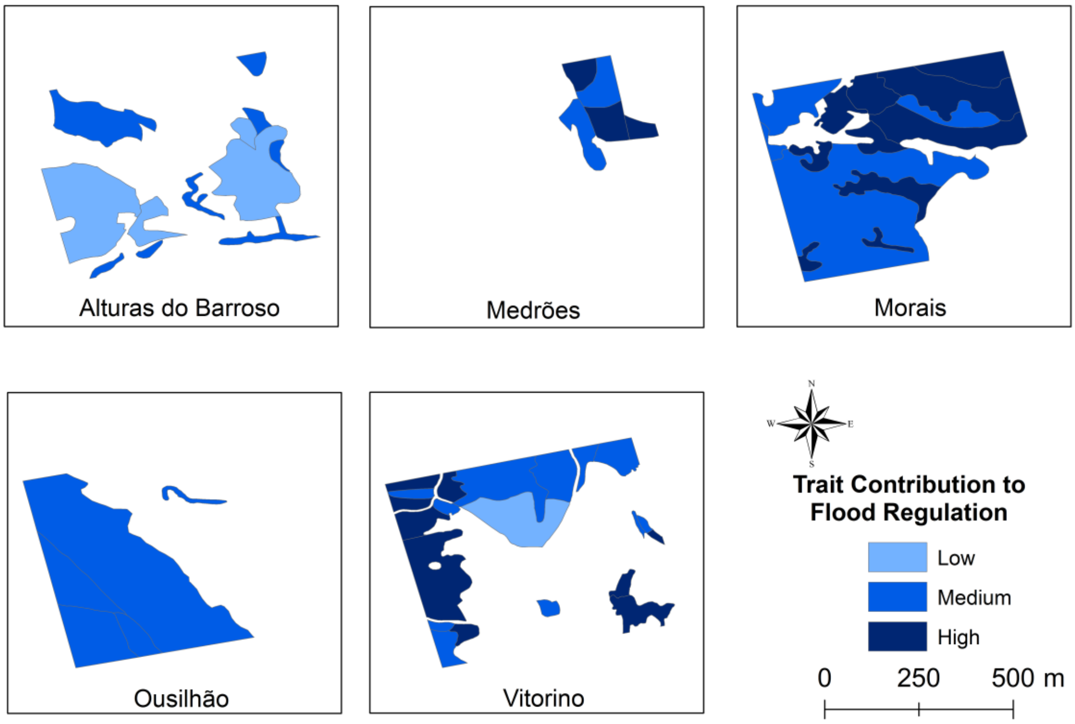


Fig. 11 – Trait contribution to flood regulation service. in the five landscape mosaics.

In terms of trait contribution to erosion prevention (Fig.12), Medrões, Morais and Vitorino show the highest trait contribution, due to their evergreen trees and shrubs characteristic (Table 7). On the contrary, Alturas do Barroso and Ousilhão have medium trait contribution to the service related to deciduous trait. There is no low contribution to soil erosion service because the low degree is related to agricultural practices more prone to erosion. To have forest and shrub cover is a good strategy to decrease soil erosion. However, forest and shrubs are prone to fire that increases the soil erosion (Moreira *et al.,* 2001). In addition, plantation forests promote soils erosion because of soil mobilization and management (Figueiredo *et al.,* 2011).

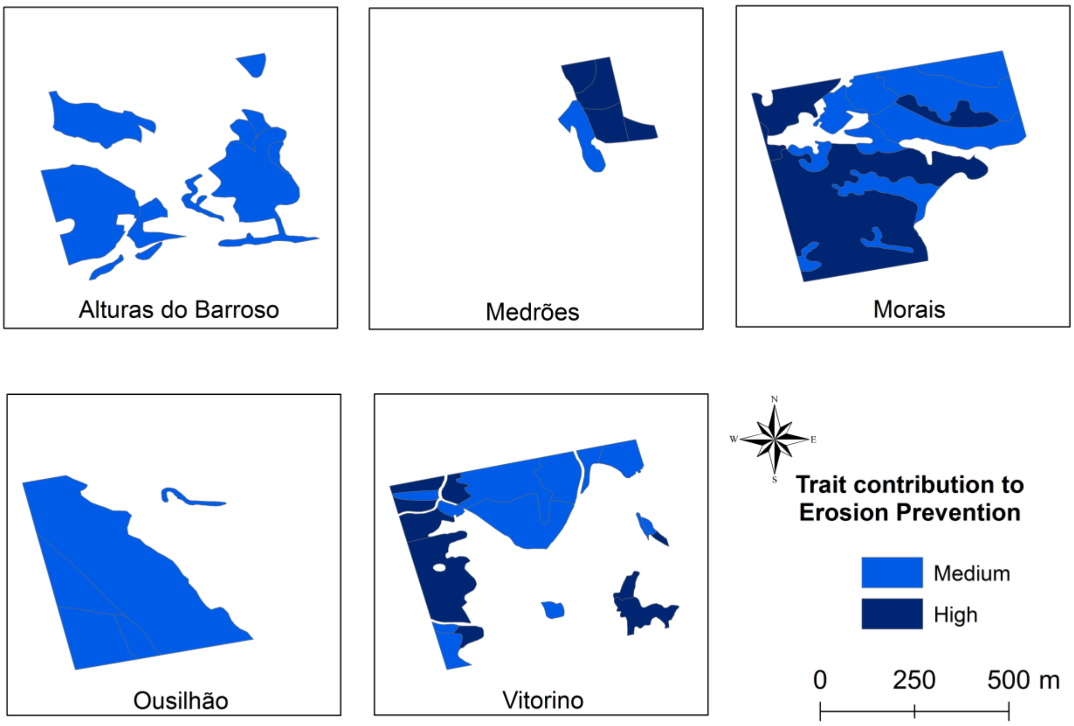
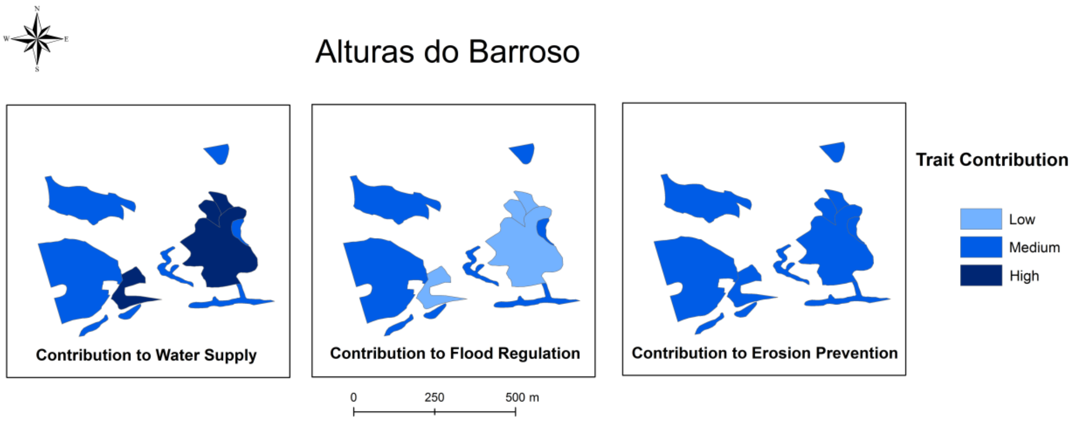
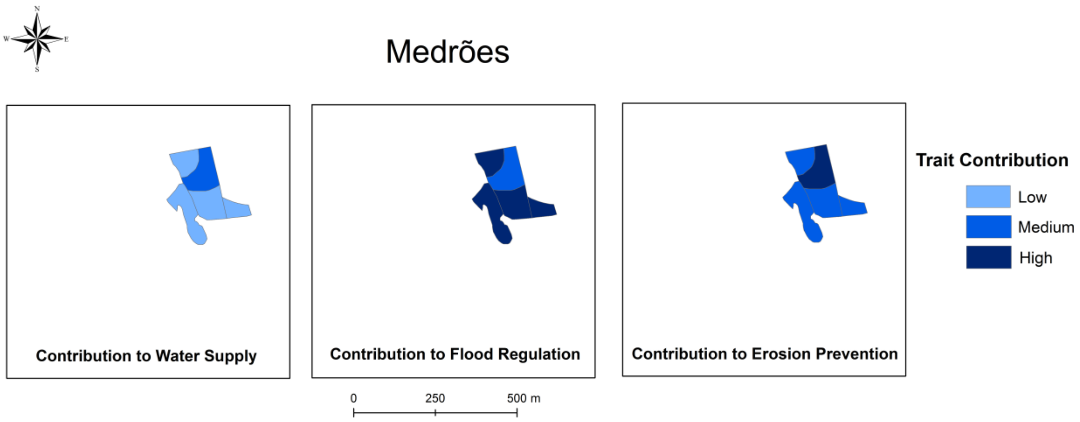


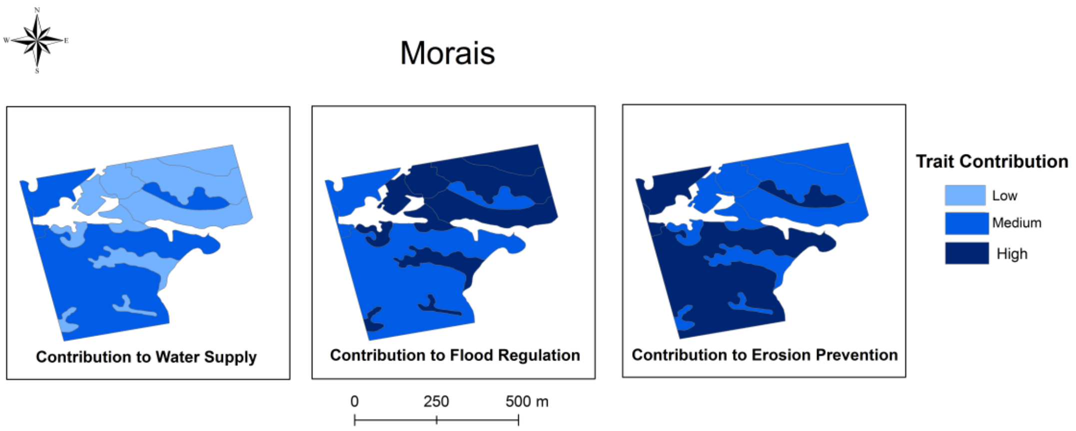
Fig. 12 - Trait contribution to erosion prevention service in the five landscape mosaics.

3.2.4. Potential provision of hydrological services in the individual mosaics

In this section the spatial distribution within the same mosaic to each hydrological service was analyzed.







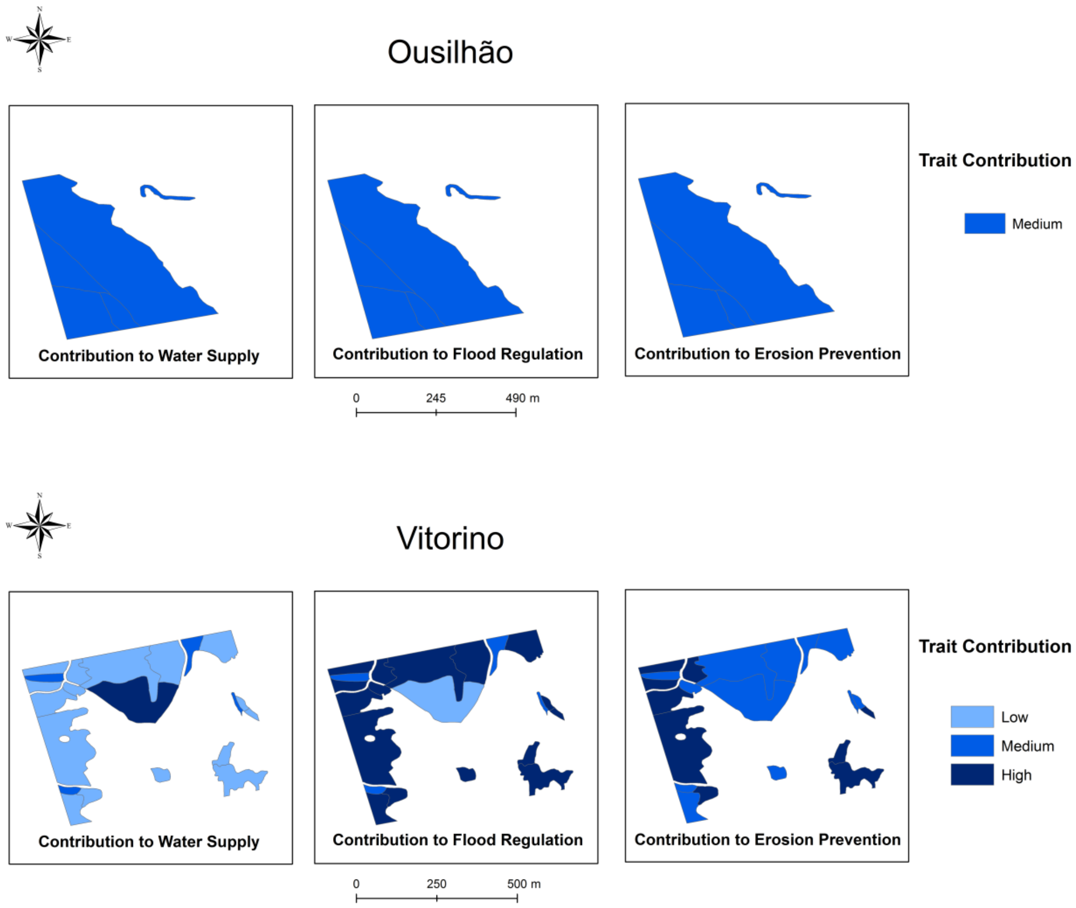


Fig. 13 – Trait contribution to the three hydrological services in the individual mosaics.

According to Fig. 13, Alturas do Barroso has higher potential for the provision of water supply service than for flood regulation and erosion prevention services. As seen in Fig.5 this area is located in a very rainy region and occupied mainly with deciduous species. Among others, these factors improve the contribution of this mosaic for the provision of water supply service.

Regarding Medrões, it has higher potential for the provision of flood regulation service and low contribution to water supply. The percentage of woody species area compared to the total area is small, and therefore the contribution of the mosaic cannot be judged for a small piece represented. To suggest management options to improve the provision of the services, all the mosaic should be taken into account.

Morais contribution to the provision of flood regulation and erosion prevention services is high, although the high contribution area is bigger in erosion prevention that corresponds to a shrub (*Cistus ladanifer*). Shrubs have high contribution to erosion prevention due to their small height (Table 7). Morais is located in the Mediterranean area, where soil erosion is problematic; therefore this species is suitable to this area.

In Ousilhão, the trait contribution is equal to the three hydrological services. This area has a mountain climate with medium annual precipitation (Fig.5) that is favorable to flood regulation service but not so favorable for water supply service although both services have medium contribution.

Vitorino has higher potential to the provision of flood regulation. This area is located in the coastal Atlantic climate with high annual precipitation. This annual precipitation is favorable to water supply service, but the species present in Vitorino have low influence to water supply service (evergreen characteristic).

In terms of further investigation linked to forest management, it’s interesting to understand the possibility of managing the mosaics to increase its potential provision of each service.

4. Conclusions

Plant traits are important characteristics to evaluate plant functional ecology. Specifically, some traits have a strong influence on the water cycle, which together with soil properties and climate conditions may influence the provision of hydrological services.

In this study, 18 plant traits (trees and shrubs) with respective state trait were recorded for 49 species in Northern Portugal. The majority of plants have small height with rounded canopy and evergreen characteristic as leaf strategy. Regarding steam traits, the direction of growth is erect in almost all plants studied. In addition, rough texture and absence of pubescence characterize almost two thirds of plants studied. Finally, considering leaf traits, plants are mainly with vertical orientation, leathery consistency, flat architecture, alternate arrangement, medium size, entire margin and cuticle, petiole and pubescence absent.

Subsequently, the state of traits was analyzed according to native or exotic differentiation. In general, native plants have small size, whereas exotic have medium size as prevalent trait. Both have mainly rounded canopy and evergreen as leaf strategy. However, there are many native plants as deciduous leaf strategy. The major differences are in leaf size, which distinguishes native species with small leaf size, and exotics with large. In addition, petiole is absent in both native and exotic. Pubescence is poorly developed in native species and absent in exotic.

Finally, three key traits for the provision of hydrological services were selected according to its influence in the water functioning (plant height, leaf strategy and leaf size). The hydrological services chosen were: water supply, flood regulation and soil erosion prevention. The rational and scores attributed to each trait were based in the literature. Those traits were then mapped for five landscapes mosaics distributed along different environmental regions in Northern Portugal. The specific advantage is that high-resolution land cover maps were used, allowing the spatialization by each specific species.

1) First, the trait was mapped:
    - Leaf strategy evergreen, medium leaf size and small height prevails in Morais, whereas deciduous, large leaf size and medium plant height characterize Ousilhao. In spite of both are located in the Mediterranean type of forests, Ousilhão represents the highlands and Morais the lowlands,

consequently these three traits shape the plant strategies to deal with environmental conditions of each region;

- In Medrões prevails evergreen, large leaf size and medium plant height. However, in Medrões, woody cover is not representative of all mosaics;
- Alturas do Barroso and Vitorino have a fairly distribution of trait state: in both half area is deciduous, half evergreen; half area has large leaf size, other half medium. For plant height small to medium prevails in Alturas do Barroso, whereas high to medium in Vitorino

2) Potential provision of hydrological services across landscape
   - Alturas do Barroso shows the highest potential for the provision of water supply service opposed to Medrões that shows lowest potential for the provision of the service.
   - Morais shows the highest potential for the provision of flood regulation service. Vitorino also has high potential but with a smaller woody area. Alturas do Barroso shows the lowest potential to the provision of this service.
   - Morais also shows highest potential for the provision of erosion prevention service opposed to Alturas do Barroso and Ousilhão that shows lowest potential to the provision of the service.

3) Potential provision of hydrological services in individual mosaics
   - Alturas do Barroso is more suitable for the provision of water supply service opposed to the provision of flood regulation service. Its climate improves the potential contribution of water supply service.
   - Medrões is more suitable for the provision of flood regulation service opposed to water supply service. The low woody area makes this mosaic less representative from all mosaics.
   - Morais is more suitable for the provision of erosion prevention having a bigger high contribution area. However, it is also suitable for the provision of flood regulation service. The climate is favorable to the provision of the flood regulation service.
   - Ousilhão. is the mosaic that shows medium contribution to each service. With further investigation of the other covers, not

accounted in this analysis, the potential provision of each service could be enhanced.

- Vitorino is more suitable to the provision of flood regulation service opposed to the provision of water supply.

It can be concluded that plant traits influence the potential provision of hydrological services, in this case, water supply (quantity), flood regulation and erosion prevention. However, plant traits are only a piece in the puzzle that supports the provision of services by ecosystems. A whole set of factors needs to be accounted regarding to forests and forest management.

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Appendices

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Lea_Siz - Leaf size

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Lea_Wid - Leaf width

Lea_ Cut - Leaf cuticle

Lea_Pub - Leaf pubescence

Lea_Mar - Leaf margin

Lea_Rol - Leaf rolling

Appendix 2 - Complete survey of species traits (stem, canopy and plant height)

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Ste_Pub - Stem pubescence

Ste_Bloom - Stem bloom

Can_For- Canopy form

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Pla_Hei - Plant height

Pla_Siz - Plant Size

Appendix 3 – Trait contribution to water supply service

Appendix 4 – Trait contribution to flood regulation service

Appendix 5 – Trait contribution to erosion prevention service

Appendix 1 - Complete survey of species traits (leaf)

CODE	Species	Leaves												
		Lea_Str	**Lea_Ori**	**Lea_Con**	**Lea_Arc**	**Lea_Arr**	**Lea_Pec**	**Lea_Siz**	**Lea_Len**	**Lea_Wid**	**Lea_Cut**	**Lea_Pub**	**Lea_Mar**	**Lea_Rol**
1	ACADEA	Lea_Per	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Alt	12,63	Lea_Lar	127,07	45,67	0	1	Lea_Dee	0
2	ACALON	Lea_Per	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Alt	0	Lea_Med	100	14	0	0	Lea_Ent	0
3	ACAMEL	Lea_Per	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	0	Lea_Med	95	17,25	0	0	Lea_Ent	0
4	ADELAI	Lea_Dec	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Opp	4,5	Lea_Sma	15	4,5	0	1	Lea_Dee	0
5	AILALT	Lea_Dec	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Alt	6	Lea_Med	105	47,5	0	0	Lea_Dee	0
6	ALNGLU	Lea_Dec	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	12,5	Lea_Med	70	50,67	0	1	Lea_Sha	0
7	ARBUNE	Lea_Per	Lea_Hor	Lea_Lea	Lea_ Fla	Lea_Alt	6,12	Lea_Med	75	19,27	1	0	Lea_Sha	0
8	ARUDON	Lea_Per	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Alt	0	Lea_Lar	500	60	1	0	Lea_Ent	0
9	BETALB	Lea_Dec	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	22,45	Lea_Med	50	40	0	0	Lea_Sha	0
10	CALVUL	Lea_Per	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Opp	0	Lea_Sma	2,5	1	1	0	Lea_Ent	1
11	CASSAT	Lea_Dec	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	20	Lea_Lar	175	50	1	0	Lea_Sha	0
12	CEDATL	Lea_Per	Lea_Ver	Lea_Lea	Lea_Aci	Lea_Opp	0	Lea_Sma	17,13	1,92	1	0	Lea_Dee	0
13	CHALAW	Lea_Per	Lea_Ver	Lea_Lea	Lea_Aci	Lea_Opp	0	Lea_Sma	1,27	1,05	1	0	Lea_Ent	0
14	CISLAD	Lea_Per	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Opp	0	Lea_Med	60	13,5	0	1	Lea_Ent	0
15	CORSEL	Lea_Per	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Alt	0	Lea_Lar	914,4	15	0	0	Lea_Sha	0
16	CUPLUS	Lea_Per	Lea_Ver	Lea_Lea	Lea_Aci	Lea_Opp	0	Lea_Sma	1,75	0,83	0	0	Lea_Ent	0
17	CYTMUL	Lea_Dec	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Alt	0,9	Lea_Sma	4,5	4	0	2	Lea_Dee	0
18	CYTSTR	Lea_Dec	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Alt	5	Lea_Sma	15	3,5	0	1	Lea_Dee	0
19	ERIARB	Lea_Per	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Opp	0,5	Lea_Sma	4	2,5	0	1	Lea_Ent	1
20	ERIAUS	Lea_Per	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Opp	0,5	Lea_Sma	5	0,5	1	1	Lea_Sha	1
21	ERICIN	Lea_Per	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Opp	0,5	Lea_Sma	4,5	0,34	0	1	Lea_Sha	1
22	ERIUMB	Lea_Per	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Opp	0,5	Lea_Sma	3,5	0,7	0	1	Lea_Sha	1
23	EUCGLO	Lea_Per	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Alt	22,5	Lea_Lar	215	27,5	1	0	Lea_Ent	0

24	FAGSYL	Lea_Dec	Lea_Ver	Lea_Her	Lea_Fla	Lea_Alt	9,32	Lea_Med	60,98	40,28	0	1	Lea_Sha	0
25	FRAANG	Lea_Dec	Lea_Ver	Lea_Her	Lea_Fla	Lea_Alt	51,44	Lea_Med	80	29	0	0	Lea_Dee	0
26	GENFLO	Lea_Dec	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Alt	1,5	Lea_Sma	15	3,5	0	1	Lea_Ent	0
27	GENTRI	Lea_Dec	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	0	Lea_Sma	5,5	1,5	0	1	Lea_Dee	0
28	HAKSER	Lea_Per	Lea_Hor	Lea_Lea	Lea_Aci	Lea_Alt	0	Lea_Med	55	1	0	0	Lea_Ent	0
29	HALLAS	Lea_Per	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Opp	2,5	Lea_Med	35	5,13	0	1	Lea_Ent	0
30	JUGNIG	Lea_Dec	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Alt	75	Lea_Lar	291	200	0	1	Lea_Dee	0
31	PINNIG	Lea_Per	Lea_Ver	Lea_Lea	Lea_Aci	Lea_Opp	0	Lea_Lar	155	1,75	1	0	Lea_Ent	0
32	PINPIN	Lea_Per	Lea_Ver	Lea_Lea	Lea_Aci	Lea_Opp	0	Lea_Lar	125	2,5	1	0	Lea_Dee	0
33	PINSYL	Lea_Per	Lea_Ver	Lea_Lea	Lea_Aci	Lea_Opp	0	Lea_Med	50	1,25	1	0	Lea_Dee	0
34	PLAHIS	Lea_Dec	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	15	Lea_Lar	170	210	0	0	Lea_Sha	0
35	POPCAN	Lea_Dec	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	16,55	Lea_Med	45,9	24,92	0	1	Lea_Sha	0
36	POPNIG	Lea_Dec	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	40	Lea_Med	75	6	0	0	Lea_Sha	0
37	PRUAVI	Lea_Dec	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	35	Lea_Med	105	55	0	1	Lea_Sha	0
38	PSEMEN	Lea_Per	Lea_Ver	Lea_Lea	Lea_Aci	Lea_Opp	0	Lea_Med	29,3	1,27	1	0	Lea_Ent	0
39	PTETRI	Lea_Per	Lea_Ver	Lea_Lea	Lea_Abs		0	Lea_Sma	4,16	5,47	1	1	Lea_Sha	1
40	QUEPYR	Lea_Dec	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Alt	25	Lea_Lar	130	87,5	1	2	Lea_Dee	0
41	QUEROB	Lea_Dec	Lea_Ver	Lea_Her	Lea_ Fla	Lea_Alt	4,5	Lea_Lar	120	61	0	0	Lea_Dee	0
42	QUEROT	Lea_Per	Lea_Hor	Lea_Lea	Lea_ Fla	Lea_Alt	6,6	Lea_Med	60	12	1	1	Lea_Ent	0
43	QUERUB	Lea_Dec	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Alt	19,53	Lea_Lar	175	135	0	0	Lea_Dee	0
44	QUESUB	Lea_Per	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Alt	5,64	Lea_Med	38,99	25,35	1	2	Lea_Ent	0
45	RUBULM	Lea_Dec	Lea_Hor	Lea_Her	Lea_ Fla	Lea_Alt	34,52	Lea_Med	85,17	78,6	0	1	Lea_Dee	0
46	SALATR	Lea_Dec	Lea_Ver	Lea_Lea	Lea_ Fla	Lea_Alt	10	Lea_Med	60	15	0	2	Lea_Ent	0
47	ULEEUR	Lea_Per	Lea_Hor	Lea_Lea	Lea_Abs		0	Lea_Sma	8,5	1,23	1	1	Lea_Ent	0
48	ULEMIC	Lea_Per	Lea_Hor	Lea_Lea	Lea_Abs		0	Lea_Sma	4	1	1	0	Lea_Ent	0
49	ULEMIN	Lea_Per	Lea_Hor	Lea_Lea	Lea_Abs		0	Lea_Sma	5	0,78	1	0	Lea_Ent	0

Appendix 2 - Complete survey of species traits (stem, canopy and plant height)

CODE	Species	Stems				Canopy		Plant	
		Ste_Dir	**Ste_Tex**	**Ste_Pub**	**Ste_Blo**	**Can_For**	**Can_Dia**	**Pla_Hei**	**Pla_Siz**
1	ACADEA	Ste_Ere	Ste_Smo	1	1	Can_Rou		15	Pla_Med
2	ACALON	Ste_Ere	Ste_Rou	0	0	Can_Rou		8	Pla_Sma
3	ACAMEL	Ste_Ere	Ste_Rou	0	0	Can_Rou		15	Pla_Med
4	ADELAI	Ste_Ere	Ste_Rou	1	1	Can_Rou		2	Pla_Sma
5	AILALT	Ste_Ere	Ste_Smo	0	0	Can_Irr		30	Pla_Med
6	ALNGLU	Ste_Ere	Ste_Rou	0	0	Can_Con	10 m	25	Pla_Med
7	ARBUNE	Ste_Ere	Ste_Rou	0	0	Can_Rou		5	Pla_Sma
8	ARUDON	Ste_Ere	Ste_Smo	0	0	Can_Irr		6	Pla_Sma
9	BETALB	Ste_Ere	Ste_Smo	0	0	Can_Con		20	Pla_Med
10	CALVUL	Ste_Ere	Ste_Smo	1	0	Can_Irr		0,6	Pla_Sma
11	CASSAT	Ste_Ere	Ste_Rou	0	0	Can_Rou		30	Pla_Med
12	CEDATL	Ste_Ere	Ste_Rou	0	0	Can_Con		45	Pla_Hig
13	CHALAW	Ste_Ere	Ste_Rou	0	0	Can_Con		40	Pla_Hig
14	CISLAD	Ste_Ere	Ste_Smo	1	0	Can_Rou		2	Pla_Sma
15	CORSEL	Ste_Ere	Ste_Smo	0	0	Can_Irr	76,03 cm	3	Pla_Sma
16	CUPLUS	Ste_Ere	Ste_Rou	0	0	Can_Con		30	Pla_Med
17	CYTMUL	Ste_Ere	Ste_Rou	1	0	Can_Rou		1,5	Pla_Sma
18	CYTSTR	Ste_Ere	Ste_Rou	1	0	Can_Rou		2	Pla_Sma
19	ERIARB	Ste_Ere	Ste_Smo	1	0	Can_Rou	40 cm	2,5	Pla_Sma
20	ERIAUS	Ste_Ere	Ste_Rou	1	0	Can_Rou		1,5	Pla_Sma
21	ERICIN	Ste_Ere	Ste_Rou	1	0	Can_Rou		0,75	Pla_Hig
22	ERIUMB	Ste_Ere	Ste_Smo	1	0	Can_Con		0,3	Pla_Sma
23	EUCGLO	Ste_Ere	Ste_Smo	0	0	Can_Rou		45	Pla_Hig

24	FAGSYL	Ste_Ere	Ste_Smo	0	0	Can_Rou		35	Pla_Hig
25	FRAANG	Ste_Ere	Ste_Sub	0	0	Can_Irr		15	Pla_Med
26	GENFLO	Ste_Ere	Ste_Rou	1	0	Can_Rou		2	Pla_Sma
27	GENTRI	Ste_Ere	Ste_Rou	0	0	Can_Rou		1	Pla_Sma
28	HAKSER	Ste_Ere	Ste_Rou	1	0	Can_Irr		4	Pla_Sma
29	HALLAS	Ste_Ere	Ste_Smo	1	0	Can_Rou		1,75	Pla_Sma
30	JUGNIG	Ste_Ere	Ste_Rou	0	0	Can_Rou		50	Pla_Hig
31	PINNIG	Ste_Ere	Ste_Rou	0	0	Can_Con		30	Pla_Med
32	PINPIN	Ste_Ere	Ste_Smo	0	0	Can_Rou		25	Pla_Med
33	PINSYL	Ste_Ere	Ste_Rou	0	0	Can_Rou		30	Pla_Med
34	PLAHIS	Ste_Ere	Ste_Smo	0	0	Can_Rou		35	Plan_Hig
35	POPCAN	Ste_Ere	Ste_Smo	0	0	Can_Irr		30	Pla_Med
36	POPNIG	Ste_Ere	Ste_Rou	0	0	Can_Irr		25	Pla_Med
37	PRUAVI	Ste_Ere	Ste_Smo	0	0	Can_Rou		20	Pla_Med
38	PSEMEN	Ste_Ere	Ste_Smo	0	0	Can_Con		100	Pla_Hig
39	PTETRI	Ste_SPr	Ste_Rou	0	0	Can_Irr		0,6	Pla_Sma
40	QUEPYR	Ste_Ere	Ste_Rou	0	0	Can_Rou		25	Pla_Med
41	QUEROB	Ste_Ere	Ste_Rou	0	0	Can_Rou		30	Pla_Hig
42	QUEROT	Ste_Ere	Ste_Rou	0	0	Can_Rou		15	Pla_Hig
43	QUERUB	Ste_Ere	Ste_Rou	0	0	Can_Rou		25	Pla_Hig
44	QUESUB	Ste_Ere	Ste_Sub	1	0	Can_Rou		15	Pla_Med
45	RUBULM	Ste_SPr	Ste_Rou	0	1	Can_Irr		2,5	Pla_Sma
46	SALATR	Ste_Ere	Ste_Smo	1	0	Can_Rou		12	Pla_Med
47	ULEEUR	Ste_Ere	Ste_Smo	1	0	Can_Rou		1	Pla_Sma
48	ULEMIC	Ste_Ere	Ste_Rou	0	0	Can_Rou		0,65	Pla_Sma
49	ULEMIN	Ste_Ere	Ste_Rou	1	0	Can_Rou		2	Pla_Sma

Appendix 3 – Trait contribution to water supply service

CODE	Sp.	Water Supply									
		Lea_Str	**Lea_Siz**	**Pla_Siz**	Value	Contribution	Alturas do Barroso	Medrões	Morais	Ousilhão	Vitorino
1	ACADEA	1	1	2	1,333333	Low					x
2	ACALON	1	2	3	2	Medium					
3	ACAMEL	1	2	2	1,666667	Medium					
4	ADELAI	3	3	3	3	High					x
5	AILALT	3	2	2	2,333333	Medium					
6	ALNGLU	3	2	2	2,333333	Medium	x				
7	ARBUNE	1	2	3	2	Medium		X			
8	ARUDON	1	1	3	1,666667	Medium					
9	BETALB	3	2	2	2,333333	Medium	x				
10	CALVUL	1	3	3	2,333333	Medium					
11	CASSAT	3	1	2	2	Medium					
12	CEDATL	1	3	1	1,666667	Medium					
13	CHALAW	1	3	1	1,666667	Medium					
14	CISLAD	1	2	3	2	Medium			x		
15	CORSEL	1	1	3	1,666667	Medium					
16	CUPLUS	1	3	2	2	Medium					
17	CYTMUL	3	3	3	3	High	x				
18	CYTSTR	3	3	3	3	High	x				
19	ERIARB	1	3	3	2,333333	Medium	x				
20	ERIAUS	1	3	3	2,333333	Medium					
21	ERICIN	1	3	1	1,666667	Medium					
22	ERIUMB	1	3	3	2,333333	Medium					
23	EUCGLO	1	1	1	1	Low		X			x

24	FAGSYL	3	2	1	2	Medium					
25	FRAANG	3	2	2	2,333333	Medium					
26	GENFLO	3	3	3	3	High					
27	GENTRI	3	3	3	3	High					
28	HAKSER	1	2	3	2	Medium					
29	HALLAS	1	2	3	2	Medium					
30	JUGNIG	3	1	1	1,666667	Medium					
31	PINNIG	1	1	2	1,333333	Low					x
32	PINPIN	1	1	2	1,333333	Low		x			
33	PINSYL	1	2	2	1,666667	Medium					
34	PLAHIS	3	1	1	1,666667	Medium					
35	POPCAN	3	2	2	2,333333	Medium					
36	POPNIG	3	2	2	2,333333	Medium					
37	PRUAVI	3	2	2	2,333333	Medium					
38	PSEMEN	1	2	1	1,333333	Low					
39	PTETRI	1	3	3	2,333333	Medium					
40	QUEPYR	3	1	2	2	Medium	x			x	
41	QUEROB	3	1	1	1,666667	Medium					x
42	QUEROT	1	2	1	1,333333	Low			x		
43	QUERUB	3	1	1	1,666667	Medium					
44	QUESUB	1	2	2	1,666667	Medium					
45	RUBULM	3	2	3	2,666667	High					
46	SALATR	3	2	2	2,333333	Medium					
47	ULEEUR	1	3	3	2,333333	Medium					
48	ULEMIC	1	3	3	2,333333	Medium					
49	ULEMIN	1	3	3	2,333333	Medium					

Appendix 4 - Trait contribution to flood regulation service.

CODE	Sp.	Flood Protection									
		Lea_Str	**Lea_Siz**	**Pla_Siz**	Value	Contribution	Alturas do Barroso	Medrões	Morais	Ousilhão	Vitorino
1	ACADEA	3	3	2	2,666667	High					x
2	ACALON	3	2	1	2	Medium					
3	ACAMEL	3	2	2	2,333333	Medium					
4	ADELAI	1	1	1	1	Low					x
5	AILALT	1	2	2	1,666667	Medium					
6	ALNGLU	1	2	2	1,666667	Medium	x				
7	ARBUNE	3	2	1	2	Medium		x			
8	ARUDON	3	3	1	2,333333	Medium					
9	BETALB	1	2	2	1,666667	Medium	x				
10	CALVUL	3	1	1	1,666667	Medium					
11	CASSAT	1	3	2	2	Medium					
12	CEDATL	3	1	3	2,333333	Medium					
13	CHALAW	3	1	3	2,333333	Medium					
14	CISLAD	3	2	1	2	Medium			x		
15	CORSEL	3	3	1	2,333333	Medium					
16	CUPLUS	3	1	2	2	Medium					
17	CYTMUL	1	1	1	1	Low	x				
18	CYTSTR	1	1	1	1	Low	x				
19	ERIARB	3	1	1	1,666667	Medium	x				
20	ERIAUS	3	1	1	1,666667	Medium					
21	ERICIN	3	1	3	2,333333	Medium					
22	ERIUMB	3	1	1	1,666667	Medium					
23	EUCGLO	3	3	3	3	High		x			x

24	FAGSYL	1	2	3	2	Medium					
25	FRAANG	1	2	1	1,333333	Low					
26	GENFLO	1	1	1	1	Low					
27	GENTRI	1	1	1	1	Low					
28	HAKSER	3	2	1	2	Medium					
29	HALLAS	3	2	1	2	Medium					
30	JUGNIG	1	3	3	2,333333	Medium					
31	PINNIG	3	3	2	2,666667	High					x
32	PINPIN	3	3	2	2,666667	High		x			
33	PINSYL	3	2	2	2,333333	Medium					
34	PLAHIS	1	3	3	2,333333	Medium					
35	POPCAN	1	2	2	1,666667	Medium					
36	POPNIG	1	2	2	1,666667	Medium					
37	PRUAVI	1	2	2	1,666667	Medium					
38	PSEMEN	3	2	3	2,666667	High					
39	PTETRI	3	1	1	1,666667	Medium					
40	QUEPYR	1	3	2	2	Medium	x			x	
41	QUEROB	1	3	3	2,333333	Medium					x
42	QUEROT	3	2	3	2,666667	High			x		
43	QUERUB	1	3	3	2,333333	Medium					
44	QUESUB	3	2	2	2,333333	Medium					
45	RUBULM	1	2	1	1,333333	Low					
46	SALATR	1	2	2	1,666667	Medium					
47	ULEEUR	3	1	1	1,666667	Medium					
48	ULEMIC	3	1	1	1,666667	Medium					
49	ULEMIN	3	1	1	1,666667	Medium					

Appendix 5 – Trait contribution to erosion prevention service.

CODE	Sp.	Erosion Prevention									
		Lea_Lif	**Lea_Siz**	**Pla_Siz**	Value	Contribution	Alturas do Barroso	Medrões	Morais	Ousilhão	Vitorino
1	ACADEA	3	3	2	2,666667	High					x
2	ACALON	3	2	3	2,666667	High					
3	ACAMEL	3	2	2	2,333333	Medium					
4	ADELAI	1	1	3	1,666667	Medium					x
5	AILALT	1	2	2	1,666667	Medium					
6	ALNGLU	1	2	2	1,666667	Medium	x				
7	ARBUNE	3	2	3	2,666667	High		x			
8	ARUDON	3	3	3	3	High					
9	BETALB	1	2	2	1,666667	Medium	x				
10	CALVUL	3	1	3	2,333333	Medium					
11	CASSAT	1	3	2	2	Medium					
12	CEDATL	3	1	1	1,666667	Medium					
13	CHALAW	3	1	1	1,666667	Medium					
14	CISLAD	3	2	3	2,666667	High			x		
15	CORSEL	3	3	3	3	High					
16	CUPLUS	3	1	2	2	Medium					
17	CYTMUL	1	1	3	1,666667	Medium	x				
18	CYTSTR	1	1	3	1,666667	Medium	x				
19	ERIARB	3	1	3	2,333333	Medium	x				
20	ERIAUS	3	1	3	2,333333	Medium					
21	ERICIN	3	1	1	1,666667	Medium					
22	ERIUMB	3	1	3	2,333333	Medium					
23	EUCGLO	3	3	1	2,333333	Medium		x			x

24	FAGSYL	1	2	1	1,333333	Low					
25	FRAANG	1	2	2	1,666667	Medium					
26	GENFLO	1	1	3	1,666667	Medium					
27	GENTRI	1	1	3	1,666667	Medium					
28	HAKSER	3	2	3	2,666667	High					
29	HALLAS	3	2	3	2,666667	High					
30	JUGNIG	1	3	1	1,666667	Medium					
31	PINNIG	3	3	2	2,666667	Medium					x
32	PINPIN	3	3	2	2,666667	High		x			
33	PINSYL	3	2	2	2,333333	Medium					
34	PLAHIS	1	3	1	1,666667	Medium					
35	POPCAN	1	2	2	1,666667	Medium					
36	POPNIG	1	2	2	1,666667	Medium					
37	PRUAVI	1	2	2	1,666667	Medium					
38	PSEMEN	3	2	1	2	Medium					
39	PTETRI	3	1	3	2,333333	Medium					
40	QUEPYR	1	3	2	2	Medium	x			x	
41	QUEROB	1	3	2	2	Medium					x
42	QUEROT	3	2	2	2,333333	Medium			x		
43	QUERUB	1	3	1	1,666667	Medium					
44	QUESUB	3	2	2	2,333333	Medium					
45	RUBULM	1	2	3	2	Medium					
46	SALATR	1	2	1	1,333333	Medium					
47	ULEEUR	3	1	3	2,333333	Medium					
48	ULEMIC	3	1	3	2,333333	Medium					
49	ULEMIN	3	1	3	2,333333	Medium					