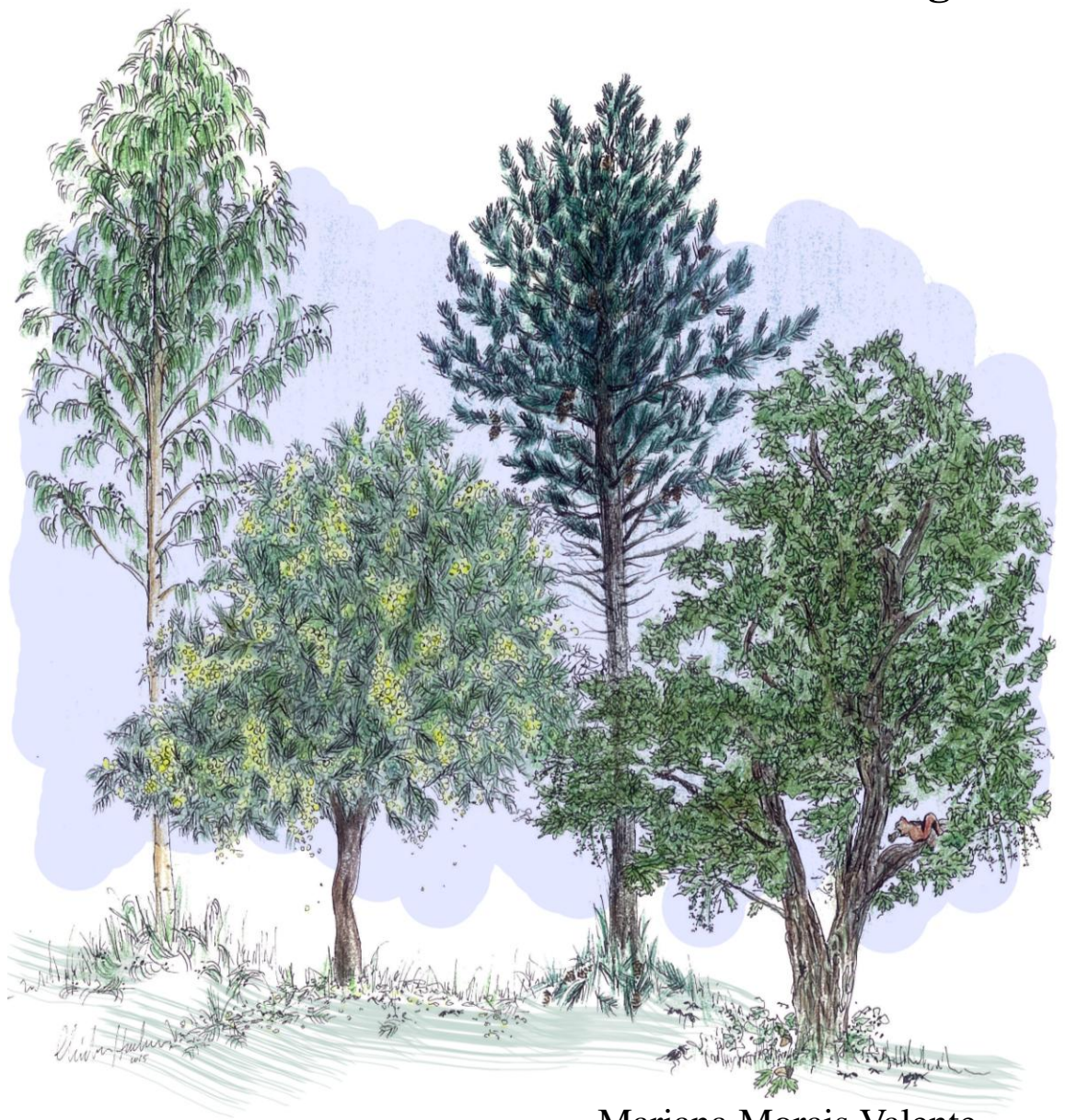




DEPARTAMENTO DE CIÊNCIAS DA VIDA

FACULDADE DE CIÊNCIAS E TECNOLOGIA  
UNIVERSIDADE DE COIMBRA

## Year round resource abundance in native and exotic woodlands in Central Portugal



Mariana Morais Valente

2015



# DEPARTAMENTO DE CIÊNCIAS DA VIDA

FACULDADE DE CIÊNCIAS E TECNOLOGIA  
UNIVERSIDADE DE COIMBRA

## **Year round resource abundance in native and exotic woodlands in Central Portugal**

Dissertação apresentada à Universidade de Coimbra para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia, realizada sob a orientação científica do Professor Doutor Jaime Ramos (Universidade de Coimbra) e do Doutor Rúben Heleno (Universidade de Coimbra)

Mariana Morais Valente

---

2015

## **Agradecimentos**

A realização desta tese não teria sido possível sem o auxílio e o apoio de várias pessoas, às quais quero expressar todos os meus agradecimentos:

Ao Professor Doutor Jaime Ramos, pela disponibilidade prestada desde o início deste trabalho, pela paciência, eficiência, transmissão de conhecimentos e por todas as contribuições e correções que foram imprescindíveis para a sua concretização.

Ao Doutor Ruben Heleno, por ter aceitado embarcar nesta aventura, mesmo sem me conhecer. Obrigada pelas ideias, pelo tempo despendido, pelas contribuições dadas, pelas correções, pelas chamadas e visitas ao laboratório, no momento certo e oportuno. Agradeço também as palavras amigas e o incentivo constante.

Ao Luís Silva, por me ter acompanhado nas primeiras saídas de campo, mesmo ao fim de semana (quer fizesse sol quer fizesse chuva, mesmo temendo pela minha vida com a sua condução) e por estar sempre pronto para ajudar-me. Obrigada também pela amizade, pela energia e confiança transmitida e pelo apoio imprescindível na fase de tratamento estatístico dos dados. Acho que já perdi a conta do número de vezes que te agradei, mas... nesta situação, um obrigado é muito pouco para o muito que já fizeste!

A todos os meus colegas do laboratório de Ecologia Funcional da Universidade de Coimbra pelo companheirismo, estímulo e boa disposição que tornaram mais agradável o tempo passado na triagem e classificação dos artrópodes. Um agradecimento especial ao Sérgio Timóteo pela ajuda na classificação das formigas e ao Alejandro pelo esclarecimento de dúvidas na classificação de alguns artrópodes.

A todos os meus professores que contribuíram para a minha formação pessoal e académica, agradeço a exigência, os ensinamentos e a dedicação. Ao meu Professor de Biologia, Rui Soares, por ter incutido em mim o gosto pelas saídas de campo e que um dia afirmou que ainda me iria ver “no meio das plantas”, hoje confirma-se que tinha toda a razão. Gostaria de destacar também o Professor Doutor António Xavier Pereira Coutinho, pela presença constante no laboratório, encorajando-me na

classificação dos artrópodes. Obrigada também pelo incentivo dado ao longo de todo o Mestrado.

Um especial sentido agradecimento ao meu querido Professor Toni. O início desta tese coincidiu com a triste notícia da sua partida, mas nem por isso deixou de ser a motivação para que eu possa ir mais além. Acreditou sempre em mim, mais do que eu própria, acompanhou-me na infância, na adolescência, na entrada na faculdade e com orgulho no final da Licenciatura. Saudade é a palavra certa para descrever a sua falta.

Às minhas companheiras de aventura, Ana Vaz e Ana Sofia, pelos momentos partilhados, por ouvirem os meus desabafos, por me compreenderem tão bem e sobretudo pela amizade.

A Coimbra... a cidade que aprendi a amar.

A todos os meus amigos por compreenderem (ou não) estes meus dias de ausência e sobretudo por entenderem o meu mau humor e a pouca disponibilidade para saídas. Obrigada Nídia, Celine, Mónica, Sofia, Mariana, Raquel, Bárbara, Rosário, Diogo, Marina, João, Nuno, Catarina, Sílvia, Bruna, Tiago... Obrigada à Cláudia pelo fantástico desenho da capa desta tese.

À minha família, porque sem ela isto não seria possível. Aos meus avós, pelos mimos, carinho e apoio incondicional. Ao meu pai Carlos, pela energia contagiante que transmite e pela força e encorajamento constantes. À minha mãe, Maria Emília, a minha grande Mestre, por ser o grande exemplo na minha vida, mulher, mãe e profissional, sem ela não seria o que sou hoje. Agradeço ainda à minha mãe pela companhia em algumas saídas de campo e, essencialmente, por me inculcar o gosto pela Biologia.

Por último quero agradecer mais uma vez aos meus pais pelo maior presente que me deram na vida, a minha irmã Manuela. O orgulho que sinto é grande e não poderia estar mais feliz por ter concentrado na mesma pessoa a melhor amiga e irmã.

## Resumo

As florestas são ecossistemas muito importantes, responsáveis por muitos serviços vitais para os seres humanos, e estão diretamente dependentes da biodiversidade. Porém, as ações humanas têm contribuído para a alteração rápida da composição, estrutura e função da maior parte dos ecossistemas, incluindo das florestas, levando a alterações nos serviços essenciais para a sobrevivência humana.

A destruição, alteração e homogeneização das florestas podem ser responsáveis pela perda de espécies e deterioração do funcionamento dos ecossistemas. A coexistência das diferentes espécies vai depender principalmente da disponibilidade de recursos tróficos. As florestas portuguesas dominadas originalmente por *Quercus* sp. têm vindo a sofrer alterações devido à implementação de agricultura intensiva, e mais recentemente ao abandono agrícola, e à introdução de espécies exóticas, como o *Eucalyptus globulus* e a *Acacia dealbata*. Além disso, as florestas passaram a ser geridas pelo Homem o que contribuiu para o aumento de plantações de monoculturas. Espera-se que estas mudanças afetem não só as comunidades vegetais, mas também podem ser altamente negativas para a diversidade e abundância de artrópodes e assim afetando os restantes níveis tróficos das cadeias alimentares.

Neste estudo pretendemos comparar a abundância, diversidade e disponibilidade de recursos primários (i.e. vegetais) e de artrópodes ao longo de um ano em bosques exóticos (plantações de eucaliptos *Eucalyptus globulus* e bosques de acácias *Acacia dealbata*) e bosques nativos e naturalizados (bosques dominados por *Quercus faginea* e plantações de pinheiro-bravo *Pinus pinaster*, respetivamente). Três tipos de recursos primários: flores, folhas e frutos, foram contabilizados entre janeiro e dezembro de 2014. Além disso, os artrópodes foram amostrados no verão de 2013 e no inverno e primavera de 2014.

Verificámos que nos bosques nativos, os recursos primários foram mais diversos, mais abundantes e mais homogeneamente distribuídos no tempo do que nas plantações e nos bosques de acácia. Relativamente aos artrópodes, apenas se registaram-se diferenças significativas na abundância, diversidade e biomassa de artrópodes entre as estações do ano. A biomassa média de artrópodes durante o verão foi bastante mais elevada na floresta nativa, mas a grande variabilidade dos dados

impediu que as diferenças fossem significativas. Possivelmente um maior número de estações de amostragem seria importante em estudos futuros, nomeadamente devido à elevada fragmentação dos habitats na área de estudo.

Os bosques de acácia e as plantações de eucaliptos produzem um grande número de folhas e flores, altamente concentrados nos meses de inverno. No entanto, tal pico na produção de recursos não foi acompanhado por um aumento na biomassa e riqueza específica de artrópodes. Tal poderá ser explicado pelas condições climatéricas desfavoráveis nesta altura do ano, o que indica que no centro de Portugal o valor em termos de recursos primários que estes bosques e plantações de espécies exóticas podem proporcionar para níveis tróficos superiores é relativamente reduzido.

**Palavras-chave:** ecossistemas florestais, biodiversidade, bosques nativos, bosques exóticos, plantações, *Quercus faginea*, *Pinus pinaster*, *Eucalyptus globulus*, *Acacia dealbata*, recursos primários, artrópodes.

## Abstract

Forests are very important ecosystems, responsible for many vital services to humans and are directly dependent on biodiversity. However, human actions have contributed to the rapid change in the composition, structure and function of most ecosystems, causing changes in essential services for human survival.

The destruction, alteration and homogenization are responsible for the loss of species, and deterioration of forest ecosystem. The coexistence of different species will depend chiefly on the availability of trophic resources. The Portuguese forests originally dominated by *Quercus* sp. have been suffering changes due to the implementation of intensive agriculture and the introduction of exotic species, such as *Eucalyptus globulus* and *Acacia dealbata*. Furthermore, forests started to be managed by Human that contributed to the increase of monoculture tree plantations. These changes can be particularly negative not only for vegetation, but also to the diversity and abundance of arthropods and thus also to other trophic levels of food webs.

In this study we will compare the abundance and diversity of primary resources available and arthropods over an entire year in exotic woods (eucalyptus plantations *Eucalyptus globulus* and acacia woods *Acacia dealbata*) and native and naturalized woods (woods dominated by *Quercus faginea* and *Pinus pinaster* plantations respectively). Three types of primary resources: flowers, leaves and fruits were recorded between January and December (2014) in the three habitats. Arthropods were sampled during summer (2013) and winter and spring (2014).

We found that in native woods, primary resources were more diverse, more abundant and more widely spaced in time than in plantations and acacia woodlands. While only season was identified to significantly affect the abundance, diversity and biomass of arthropods. The mean arthropods biomass, during the summer was much higher in native woods, but the large data variability prevented the identification of significant differences. It is possible that a great number of sampling stations would be important in future studies, particularly due to the high fragmentation of the habitats in the study area.

We also found that acacia and eucalyptus stands provide a large number of flowers and leaves, largely concentrated on few winter months. However such strong increase in resources was not matched by an increase in the biomass and richness of arthropods, because environmental conditions are much less favorable to arthropods at this time of the year. This suggests that although stands with exotic plant species provide many resources at specific periods of the year in the center of Portugal, these should be little used by higher trophic levels.

**Keywords:** forest ecosystems, biodiversity, native forests, exotic woods, plantations, *Quercus faginea*, *Pinus pinaster* and *Eucalyptus globulus*, *Acacia dealbata*, primary resources, arthropods.



## Index

<b>List of Figures</b> .....	IX
<b>List of Tables</b> .....	XI
<b>Chapter 1. Introduction</b> .....	1
1.1 Forest Ecosystem Services .....	2
1.2 Natural Forests vs Plantation Forests (exotic or non-exotic) .....	3
1.3 The evolution of Portuguese Forests .....	5
1.4 Biodiversity in natural forests, forestry plantations and exotic forests.....	6
1.5 Effects of forest modification in the arthropods communities.....	8
<b>Chapter 2. Material and Methods</b> .....	11
2.1. Study sites and experimental design.....	12
2.2 Leave, flower and fruit sampling.....	13
2.3 Arthropods sampling.....	15
2.4 Data analysis.....	17
<b>Chapter 3. Results</b> .....	19
3.1 Abundance and diversity of leaves, flowers and fruits.....	20
Flowers.....	20
Leaves.....	23
Fruits.....	25
3.2 Arthropods abundance, diversity and biomass.....	27
Representative Taxa.....	32

<b>Chapter 4. Discussion / Conclusions</b> .....	34
4.1 Abundance and diversity of leaves, flowers and fruits among habitats.....	36
4.2 Abundance, diversity and biomass of arthropods among habitats.....	37
4.3 Conclusions.....	40
<b>References</b> .....	42

## List of Figures

<b>Figure 1.</b> Location of the sampling areas in Central Portugal: yellow represent pine plantations (P1-P10); red-eucalyptus plantations (E1-E10); blue-mixed autochthonous woodlands (N1-N10); purple -acacia woods (A1-A10).....	12
<b>Figure 2.</b> Detail of a mixed autochthonous woodlands, dominated by <i>Quercus faginea</i> .....	14
<b>Figure 3.</b> Detail of an exotic wood, <i>Acacia dealbata</i> .....	14
<b>Figure 4.</b> Detail of an exotic plantation, <i>Eucalyptus globulus</i> (A) and of a naturalized plantation, <i>Pinus pinaster</i> (B).....	15
<b>Figure 5.</b> Pitfall trap in eucalyptus plantations.....	16
<b>Figure 6.</b> Mean number of total flowers in each habitat $\pm$ SD. Bars with different letters are significantly different.....	20
<b>Figure 7.</b> Variation of flower production on each of the four habitat types along one year (mean $\pm$ SD, data log transformed).....	22
<b>Figure 8.</b> Mean of months with more than 5% of flowers $\pm$ SD, produced at each habitat type. Bars with the same letters do not differ significantly between them.....	23
<b>Figure 9.</b> Mean of total young leaves in each habitat $\pm$ SD. Bars with the same letters do not differ significantly between them.....	23
<b>Figure 10.</b> Variation in the mean number of young leaf production (mean $\pm$ SD, data log transformed) over one year per habitat type.....	24
<b>Figure 11.</b> Mean number of months ( $\pm$ SD) with more than 5% of young leaves produced at each habitat type. Bars with the same letters do not differ significantly between them.....	25
<b>Figure 12.</b> Number of total fruits in each habitat ( $\pm$ SD). Bars with the same letters do not differ significantly between them.....	25

<b>Figure 13.</b> Variation in the mean number of fruits (mean $\pm$ SD, data log transformed) over one year per habitat type.....	26
<b>Figure 14.</b> Mean number of months ( $\pm$ SD) with more than 5% of fruits produced at each habitat type. Bars with the same letters do not differ significantly between them.....	27
<b>Figure 15.</b> Mean Arthropods biomass for each habitat type and season. Error bars represent the standard deviation.....	28
<b>Figure 16.</b> Abundance of arthropods for each habitat type and season. Error bars represent the standard deviation.....	29
<b>Figure 17.</b> Species richness for each habitat type and season. Error bars represent the standard deviation.....	29
<b>Figure 18.</b> Shannon index mean for each habitat type and season. Error bars represent the standard deviation.....	30
<b>Figure 19.</b> Evenness mean of arthropods for each habitat type over seasons. Error bars represent the standard deviation.....	31
<b>Figure 20.</b> Insect biomass for each habitat type and season. Error bars represent the standard deviation.....	31
<b>Figure 21.</b> Percentage of biomass of each Arthropod class per habitat type on each season.....	32
<b>Figure 22.</b> Total arthropod biomass and number of primary resources (young leaves, ripe fruits and flowers) produced at each habitat type.....	33

## LIST OF TABLES

<b>Table 1</b> Species of trees and shrubs along the vegetation transects; mean number of flowers, young leaves and ripe fruits with the standard deviation and their estimated total number in each habitat type.....	21
--	----

# **Chapter 1**

## **Introduction**

Forests are vital ecosystems for sustaining life on earth. On recent centuries there has been an accelerated spread of exotic forests, which is likely to change the diversity and abundance of resources available to the fauna living on forests and on the other to change the temporal patterns of resource availability. About 60,000 km<sup>2</sup> of world's primary forest are lost annually by human interventions. This modification of natural forest has been offset by fast-growing tree plantations (Aubin et al. 2008). Thus, there is a need to determine how important are forest plantations and exotic forests for the maintenance of biodiversity. It is also important to know if plantations can develop ecological attributes similar to naturally regenerated forests (Aubin et al. 2008). However there is very little information on the diversity, abundance and availability of resources provided by native and exotic forests. I evaluated these patterns on four forests types in central Portugal.

### **1. 1 Forest Ecosystem Services**

Three main attributes of biodiversity: composition, structure and function, can be used to represent the complexity of ecosystems (Aubin et al. 2008; Noss 1990). Humans depend on the ecosystems services, which contribute, directly and indirectly to their well-being and thus represent a huge economic value (Kremen and Ostfeld 2005). The efficiency of most ecosystem services is directly related to biodiversity, which is essential to maintain the value of ecosystems for humanity (Hartmann et al. 2010; Paillet et al. 2009; Thompson et al. 2011). However, human actions have been rapidly modifying the composition, structure and function of most ecosystems, leading to changes in the services essential to human survival (Hartmann et al. 2010; Kremen and Ostfeld 2005; Paillet et al. 2009). These alterations lead to biodiversity and habitat loss and severe modification (Sayer et al. 2004; Paillet et al. 2009; Pereira et al. 2012; Hobbs and Huenneke 1992).

Forests are considered the most important ecosystems in providing services to Humanity. Indeed, forests provide many ecosystem services, such as wood supply, essential to economic development, but also contribute to climate and water regulation, hold soils and humidity, recreational and cultural opportunities, oxygen production, nutrient cycling, shelter, food production and create microclimates

(Constanza et al. 1997; Daily et al. 2000; Bremer and Farley 2010; Thompson et al. 2011).

These services are essential to economic, ecological and social level and translate the value of biodiversity (Azevedo 2012; Pereira et al. 2009). Forest ecosystem services can be included in the four categories presented by Millennium Ecosystem Assessment (2003): Supporting, Provisioning, Regulating and Cultural (Azevedo 2012; Brauman and Daily 2007; Pereira et al. 2009). Support services create the conditions necessary for other ecosystem services (Brauman and Daily 2007). Support services of forests include soil formation and preservation. Biogeochemical cycles provide nutrients essential for plant growth and ensure the functioning and diversity of ecosystems (Azevedo 2012). The provision services relate to benefits from the use of goods produced by ecosystems such as food, water and wood (Azevedo 2012; Brauman and Daily 2007; Pereira et al. 2009). These services are usually commercialized services and have economic value (Azevedo 2012). Regulating services include climate regulation, disease regulation, water purification and carbon sequestration (Azevedo 2012; Brauman and Daily 2007; Krieger 2001). Cultural services of forests include their aesthetic, spiritual and religious values. Forest ecosystems are habitat for game animals and fish sought by hunters and fishers. They also are sought for recreational activities such as hiking, bird watching, and wildlife viewing (Brauman and Daily 2007; Krieger 2001).

## **1.2 Natural Forests vs. Plantation Forests (exotic or non-exotic)**

Forest ecosystems constitute a key to the Earth's biological diversity and their destruction, alteration and homogenization are responsible for the loss of species, and deterioration of forest ecosystem functioning (Stephens and Wagner 2007). The coexistence of different species will depend on the availability of sufficient resources, both in quality and in quantity, to sustain those species (Pereira et al. 2012). Overall, landscape complexity is positively related to the availability of ecological niches (Silva et al. 2008) and consequently with the number of species that can coexist (Pereira et al. 2012).



In general, natural forests are complex and dynamic systems, with strong vertical and horizontal heterogeneity where native species regenerate themselves naturally (Aubin et al. 2008). Unlike natural forests, plantation forests are established during afforestation or reforestation by planting or seeding native or introduced tree species with approximately the same age and homogeneously distributed in space. Forest plantations are usually managed on a relatively short production cycles, which contrasts with the long-term dynamics of natural forest (Aubin et al. 2008; Brockerhoff et al. 2008; Hartley 2002; Proença et al. 2010).

Natural forests tend to provide higher quality habitat than plantation forests for a wide range of native species (Calviño-Cancela et al. 2012). However there is also some evidence that plantation forests can provide valuable habitat, even for some endangered species, and may contribute to the conservation of biodiversity (Brockerhoff et al. 2008). Usually, forestry plantations depend on fast-growing species, such as the genera *Pinus* and *Eucalyptus* in the Iberian Peninsula, although the diversity of planted tree species is increasing (Calviño-Cancela et al. 2012; Calviño-Cancela and Rubido-Bará 2013; Carnus et al. 2006).

Some exotic species have the possibility to spread and became invasive, which can be prejudicial to environment. The exotic plants have invaded almost all ecosystems and are, in most part, responsible for the global ecological changes (Litt et al. 2014). Biological invasions have been considered one of the causes of biodiversity loss, in addition to habitat loss (Lorenzo et al. 2012). Plantation forestry is highly productive and in many countries is mostly based on fast-growing exotic species (eucalyptus and pine) that can become invasive in the surrounding communities (Calviño-Cancela and Rubido-Bará 2013). Invasive plant species can modify the structure and composition of ecosystems, leading to shifts in the animal communities and therefore inducing important changes in the ecological processes of forest ecosystems (Calviño-Cancela and Rubido-Bará 2013; Heleno et al. 2008; Litt et al. 2014; Lorenzo et al. 2012). Previous work showed that the richness of plants and insects and insect biomass might decrease with the spread of exotic plants while total insect abundance remained unaltered (Heleno et al. 2008).

Biodiversity is frequently negatively affected when native forest is replaced by exotic monoculture plantations (Hartmann et al. 2010; Zhang and Fu 2009). The

monoculture plantations have been considered "biological deserts" without vegetation diversity (Hartley 2002). However, plantation forests, particularly of mixed species, can have positive impacts on biodiversity, for example when planted on degraded areas (Bremer and Farley 2010; Gómez- Aparicio et al. 2006; Pereira et al. 2012; Stephens and Wagner 2007). The increased complexity of a planted forest is an important factor for enriching the diversity because of the importance of habitat heterogeneity to attract species (Carnus et al. 2006; Parrota et al. 1997).

Research showed that plantations might be important for biodiversity conservation and restoration of forest species when made in degraded fields instead of substituting natural ecosystems, and preferably using native species (Bremer and Farley 2010; Brockerhoff et al. 2008; Hartley 2002; Parrotta et al. 1997). Plantations may facilitate forest succession by stimulating the organic carbon accumulation in the superficial layers of the soil and the increase of the structural complexity (Parrotta et al. 1997). Plantations may also provide habitat for a variety of species, such as birds, fungi and invertebrate species (Hartmann et al. 2010), including endangered species and serve as wildlife corridors (Bremer and Farley 2010), and may be particular useful at certain periods of the year when natural forests provide fewer resources.

One of the greatest threats to forests is not only deforestation, but also the fact that their biota is suffering from simplification, where rich native forests are converted to simplified secondary plantations (Noss 1999).

### **1.3 The evolution of Portuguese forests**

After the beginning of the Holocene (approximately 10.000 years ago), the Iberian Peninsula natural forests were dominated by *Quercus* sp., and Pine tree species that were converted mostly into agriculture fields (Aguiar and Pinto 2007; Reboredo and Pais 2014). *Quercus* sp. has a high potential for production, since the timber was used in the construction. In the present, the extensive stands of oaks trees are reduced to small patches, especially in mixed stands with holm and other oaks (Carvalho 1996). The decline of this species occurred in the twentieth century due to land use change: forest for agriculture and plantations (Carvalho. 1996). These changes accelerated over the last century, when some of the native forests were

gradually replaced by species with faster growth and more profitable, such as the pine tree (*Pinus pinaster*) and eucalyptus (*Eucalyptus globulus*) (Barrocas et al. 1998; Proença et al. 2010; IFN 2013). Eucalyptus was firstly introduced in Portugal as an ornamental tree, but then its properties as raw material for the paper industry were discovered (Pina 1989). In 2010, 35% of the land in Portugal was occupied by forests. Eucalyptus plantations take up the largest forest area in Portugal (26%) followed by cork forests (23%) and pine plantations (23 %). Holm oak occupies an area of 11%, other oaks represent only 2% of the country, chestnut is 1%, and other hardwoods occupy 6% and other resinous 6% (IFN 2013). Both remaining natural forests and forestry plantations have been subjected to strong disturbances, particularly fires (chiefly in Pine forest and Eucalyptus forest) (Godinho-Ferreira et al. 2006) and diseases such as pine wood nematode (IFN 2013).

Between 1995 and 2010, the area of *Pinus pinaster* showed a decrease of approximately 27%, while the area of eucalyptus increased by 13%. The area of the remaining species suffered fewer losses (IFN 2013). Most of the total area occupied by pine turned into woods and pasture land, eucalyptus plantations, urban spaces and areas with other tree species. The area dominated by *Acacia* sp. increased by 98% between 1995 and 2010 (IFN, 2013). *Acacia* species have been introduced, in the second half of 19th century, into coastal areas for sand dune stabilization (*Acacia longifolia*), or into interior forested areas (*Acacia dealbata*) (González-Muñoz et al. 2012; Sousa et al. 1998).

#### **1.4 Biodiversity in natural forests, forestry plantations and exotic forests**

In this study we will compare the abundance and diversity of resources on four types of woods: native woods dominated by *Quercus faginea*, pine plantations (*Pinus pinaster*), eucalyptus plantations (*Eucalyptus globulus*) and woods of *Acacia dealbata*.

The *Quercus faginea* Lamarck (Portuguese oak) is a native species found principally in the Iberian Peninsula, but also in northern Africa with its very rich forests in biodiversity. Its wood is presently not used and about which little is known (Quilhó et al. 2013).

Oak biotopes usually present high biodiversity compared to pine and eucalyptus forests (Proença et al. 2010). Research shows that oak patches are richer in species of forest plants and non-forest plants than patches of pine and eucalyptus forest (Proença et al. 2010). The high dynamics and heterogeneity of native forests explains these differences. Species of forest birds and non-forest birds have higher value species richness in oak forests compared with eucalyptus forests (Proença et al. 2010). In turn oak and pine patches do not differ significantly in relation to the species richness of birds because they are important habitats and food supply (Proença et al. 2010).

*Pinus pinaster* Aiton is indigenous tree of Western Mediterranean region, that has been extensively planted in the Iberian Peninsula during the 19<sup>th</sup> and 20<sup>th</sup> centuries, mainly between the years 1960-1980 (Fernandes and Rigolot 2007; Calviño-Cancela and Rubido-Bará 2013; Gómez-Aparicio 2006; Proença et al. 2010). Pine plantations have been largely used to restore the forest area lost over the years, of human timber exploration and conversion to agricultural lands (Gómez-Aparicio 2006). Mature pine forests have several types of arthropods that can serve as food for forest birds (Proença et al. 2010; Tellería and Galarza 1990).

*Eucalyptus globulus* Labill is an exotic species, originally from southeastern Australia. It's one of the most widely planted hardwood species in the world, due to its rapid growth, good adaptability, high productivity and increase wood search for paper and timber production (Calviño-Cancela and Rubido-Bará 2013; Diaz-Balteiro et al. 2009; Larcombe et al. 2012; Proença et al. 2010; Zhang and Fu 2009). *Eucalyptus* sp. has been considered invasive in southern Europe, North and South America, the Pacific Islands, and New Zealand (Calviño-Cancela and Rubido-Bará 2013). The substitution of native forests by *Eucalyptus globulus* is frequently associated with negative effects on biological communities (Martins et al. 2013).

Monocultures of eucalyptus may lead to accumulation of phytotoxins in the soil, causing its degradation and, consequently, the loss of productivity, in spite the economic benefit of biomass production. The leaves, bark and roots of eucalyptus have allelopathic effects on other species, due to the release of phenolic acids and volatile oils (Martins et al. 2013; Zhang and Fu 2009). The essential oils released in eucalyptus leaf degradation may have important consequences on leaf microbial and

invertebrate-mediated degradation, secondary production and ecological services (Martins et al. 2013).

*Acacia dealbata* Link is an exotic woody leguminous tree from Australia and introduced in Europe around 1800 as an ornamental species (González- Muñoz et al. 2012; Lorenzo et al. 2010; Lorenzo et al. 2012; Marchante et al. 2007). *Acacia dealbata* is a fast growing species, non-deciduous, with preference for acid soils. It's capable to develop symbiotic associations with N-fixing bacteria, can form mycorrhiza in invaded sites and changing soil chemical characteristics and biological dynamics (González-Muñoz et al. 2012; Lorenzo 2011). González-Muñoz et al. (2012) verified that *Acacia dealbata* reduced the species richness of the soil seed bank and the species richness and abundance of the established vegetation, compared to native forests.

### **1.5 Effects of forest modification in the arthropods communities**

Living organisms transport energy and organic matter that drive ecosystem functioning (Carnus et al. 2006). Plants in particular have a critical role in terrestrial food webs as they arrest the energy of the Sun on their chloroplasts and make this energy available to higher trophic levels of consumers (Power 1992).

Invasive plants can affect vegetation communities and alter the quantity and quality of the habitat and the resources available for animal species, chiefly to herbivores, and secondarily to their consumers, and therefore to all terrestrial food chains all the way up to top predators (Litt et al. 2014; Tang et al. 2012). These changes may be particularly negative for arthropods because many species feed on specific plants or need them for reproduction (Litt et al. 2014). On the other hand exotic plants may provide extra resources, such as flowers and fruits, at certain times of the year when native forests are in the dormant stage. For instance, *Acacia* trees flourish in winter, and produces seeds in spring, which is a time when most native deciduous plant species in southern Europe are dormant or began producing the first new shoots and leaves. Therefore, these sudden appearances of highly abundant novel resources might be important for arthropods and other taxa.

The functioning of forest ecosystems and the maintenance of stable communities of soil arthropods depend on the periodic input of leaf material to the soil surface (Sousa et al. 1998). Invertebrates are essential for a wide range of ecosystem functions: pollination, decomposition, nutrient cycling, seed dispersal, etc (Wilson 1987). Invertebrates also provide food for large animals and can function as biodiversity indicators (Norton et al. 2014). The substitution of native plants by exotic species can thus affect higher trophic levels, via changes on phytophagous insects (Heleno et al. 2008). Insects represent between 65 to 85% of all species (Brockerhoff et al. 2001). Martins et al. (2013) showed that replacements of native Portuguese forests by eucalyptus induce strong losses in the diversity of the edaphic fauna, including losses of endemic invertebrates, and in the total abundance and the taxonomic richness of arthropods, probably due to the direct effects on the decrease of plant diversity (Litt et al. 2014). Several studies evaluated the impact of invasive plants on arthropods, but there is very little information about the seasonal variation in leaf, flower and fruit resources, as well as in arthropods, between native and exotic forests in the Mediterranean area. Some of these exotic forest, such as *Acacia*, are very novel habitats and not been researched. Therefore, it is not known how such food resources vary in these forests in relation to native forest and forestry plantations (Litt et al. 2014).

This study compares the abundance, diversity and temporal availability of resources for the fauna among exotic woods (*Eucalyptus* plantations and *Acacia* woods) and native and naturalized woods (Oak woods and pine plantations, respectively). I focus on four main resource types, namely: young leaves, flowers, fruits and arthropods. Flowers, young leaves and fruits are primary resources and they are the basis of many functions of ecosystems. These resources show seasonal fluctuations according to the plant life cycle and they are available for most arthropods. On the other hand, arthropods represent an important food source for other trophic levels and also are very important for a wide range of ecosystem functions.

Once that plantations are more homogeneous in plant diversity (one or two dominant species) compared with native woods (several dominant plant species), we expect that resources are more diverse, abundant and widely spaced in time in native woods than in plantations. We hope a decreasing diversity of resources from oak

woods with the highest values, followed by pine plantations and eucalyptus plantations and acacia woods. Particularly, we also expect more stable resources throughout the year in native than in exotic woods and that exotic woods will present strong bursts of low diversity resources.

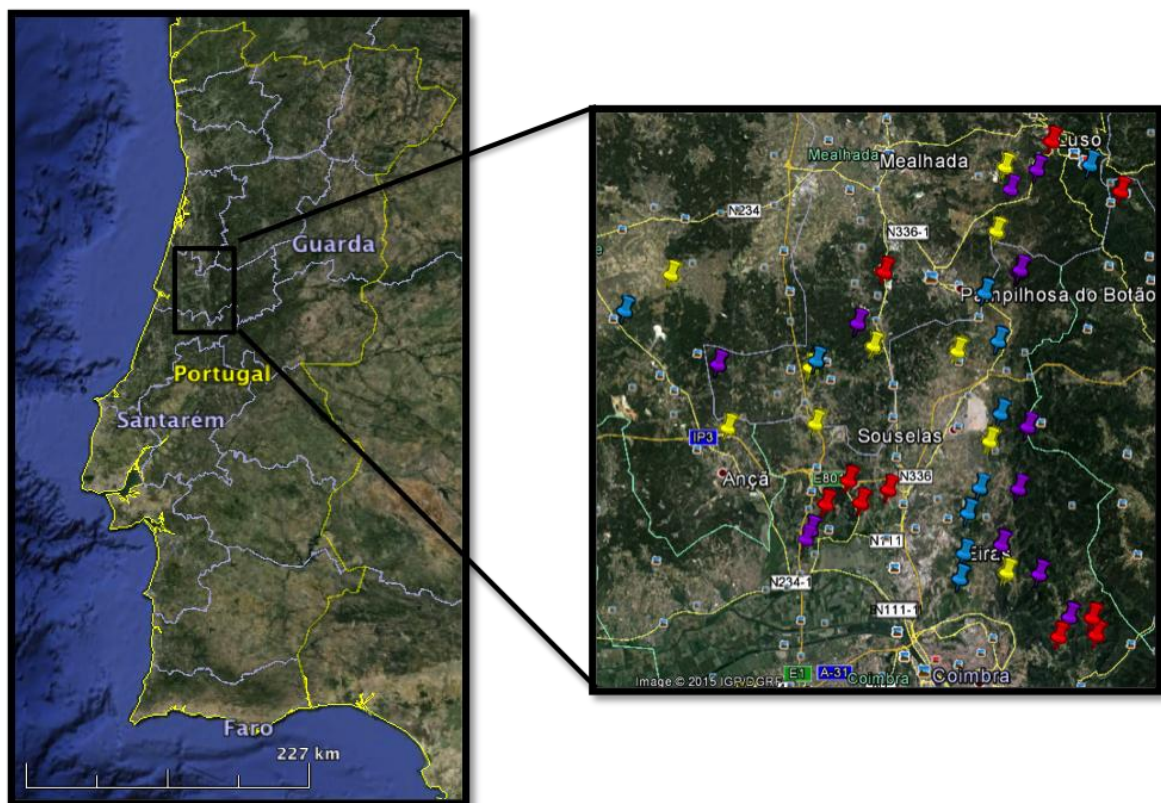
# **Chapter 2**

## **Materials and Methods**



## 2. 1 Study sites and experimental design

The study area is located in the districts of Coimbra and Aveiro and includes the woodlands between the lower Mondego and the lower Vouga basins (Figure 1). The areas chosen are highly fragmented and include four different woodland types: eucalyptus (*Eucalyptus globulus*) and pine (*Pinus pinaster*) plantations, acacia (*Acacia dealbata*) woods, and mixed autochthonous woodlands dominated by oaks (*Quercus faginea*). The climate is typically Mediterranean with Atlantic influences characterized by hot and dry summers and mild and humid winters.



**Figure 1.** Location of the sampling areas in Central Portugal: yellow represent pine plantations (P1-P10); red-eucalyptus plantations (E1-E10); blue- mixed autochthonous woodlands (N1-N10); purple -acacia woods (A1-A10).

We selected 10 plots in each type of woodland making a total of 40 plots (A1-A10; E1-E10; N1-N10; P1-P10) represented in Figure 1. Each plot had a size of approximately 100\*100 m and the plots of the same type of woodland were at least 1 km apart.

We evaluated the quantity and diversity of resources available in each type of woodlands over an entire year. We then considered two main analyses: one to evaluate the food resources available from the first trophic level, i.e. producers: namely leaves, flowers, fruits, and another considering the resources available to higher trophic levels, namely arthropods.

## 2.2 Leaf, flower and fruit sampling

We selected three plots of each type of woodland to assess food resources of the first trophic level (leaves, flowers and fruits). These resources were quantified monthly between January and December 2014. In each of these plots, three transects were marked randomly each one with 10 x 2 meters. Along each transect, all trees and shrub were identified and also the resources produced by each plant species were quantified. Specifically, we quantified the number of young leaves (newly formed), open flowers and mature fruits, since only on these stages the resources are available for consumption.

In some cases it was difficult to count all flowers, because they were far from our field of vision and often covered up by leaves. This happened particularly on *Acacia dealbata*, *Pinus pinaster* and *Quercus faginea* plots, in which case the inflorescences were counted and not individual flowers. Hereafter, these inflorescences will be referred as flowers, for consistency. Similarly, due to the high density of many shrubs and tree species, small branches were been quantified as a proxy of leaf production, hereafter referred as leaves. In all observed species we counted fruits, except in *Pinus pinaster* where we recorded the cones. Although gymnosperms do not produce fruits, hereafter we will refer to fruits and cones, collectively as fruits. All resources were counted with the visual aid of binoculars.

In this study we only counted the resources provided by the shrubs and tree species, because in these habitats the herbaceous layer was very small and therefore did not provide a significant amount of resources. Mixed autochthonous woodlands were dominated mainly by *Quercus faginea* (Figure 2) and several other native trees and bushes. Acacia woods were very dense and occupied almost exclusively by *Acacia dealbata* (Figure 3), with the exception of a few herbaceous species. Eucalyptus plantations dominated by exotic *Eucalyptus globulus* (Figure 4A) had a poor understory formed by some herbaceous species and some *Ulex* sp. and young

*Pinus pinaster* (Figure 4B). Pine plantations by the naturalized *Pinus pinaster* had an understory dominated by *Pteridium* sp. Although the underground had other species, in the marked transects of the pine and eucalyptus plantations there were no other species besides to the dominated species.



**Figure 2.** Detail of a mixed autochthonous woodlands, dominated by *Quercus faginea*.



**Figure 3.** Detail of an exotic wood, *Acacia dealbata*.



**Figure 4.** Detail of an exotic plantation, *Eucalyptus globulus* (A) and of a naturalized plantation, *Pinus pinaster* (B).

### 2.3 Arthropods sampling

Arthropods were sampled during three seasons: summer (2013), winter (2014) and spring (2014). No sampling was carried out during autumn due to the hunting pressure on several plots. The sampling techniques used in this study were pitfall traps (Figure 5). These traps consisted on plastic containers (diameter =6.5 cm, height = 4 cm) dug into the soil, with the container opening just below the ground surface. A plastic dish was positioned 30–50 mm above the pitfall trap to prevent flooding by rainwater.



**Figure 5.** Pitfall trap in eucalyptus plantations.

Five pitfall traps were installed in each of the 40 plots. One pitfall in the center of the plot and the other four orientated according to the cardinal points (North, South, East and West). All pitfalls were separated by a distance of 5 to 25 m. Traps were filled with an ethylene glycol solution (10%) in order to preserve the specimens. In the end of each sampling week, traps were filled with ethanol (70%), identified, and taken to the laboratory until further analysis.

It was not possible to sample for arthropods in the Winter and Spring in two plots (A5 and A6) due to the logging of these *Acacia* woodlands in the late summer

In the laboratory, all invertebrates were sorted to morphospecies within each order, measured and quantified. Body length was measured from the fronts to the tip of the abdomen using a binocular microscope. Antennae and wings extending beyond these points were not included in the total length measurement.

Whenever possible, specimens from some orders were identified to the family or to the genus level. All specimens from the orders Malacostraca, Collembola, Chilopoda and some orders of Insecta were identified to the family level. The Formicidae (ants) were all sorted to genus level, as well as some Coleoptera. Larvae

were not included in the analysis, as these were not properly sampled with pitfall traps.

Nomenclature and identification was based on identification keys (Borror and Delong 1988; Collingwood and Prince 1998; Quigley and Madge 1988) and some books: Chinery, Michael (2007) *Insects of Britain and Western Europe*. Domino Guides and Pereira et al. (2012) *Insectos em Ordem*. ISBN: 978-972-95047.

## 2.4 Data analysis

The number of leaves, flowers and fruits were averaged in order to compare the abundance of different resources over a year. The data were (LOG x+1) transformed to homogenise extreme values. A two-way ANOVA was used to evaluate the effect of habitat type, season and their interaction on the abundance of plant resources (leaves, flowers and fruits). In addition, we summed the total amount of resources for each plot and calculated the number of months with more than 5% of each type of resource. We used one-way ANOVA to evaluate the effect of habitat type on this measure for each resource type. When significant differences were found for any of these variables, we conducted a Tukey multiple comparisons of means to identify significant differences between groups. These analyses were performed in R (R Core Team 2015).

To characterize arthropod diversity across habitats and seasons we used Species richness (S), the Shannon diversity index ( $H'$ ) and the Evenness ( $J'$ ). For the calculation of diversity indices the following formulas were used:

$$H' = - \sum_{i=1}^S (p_i \ln p_i)$$

Where  $p_i$  is the proportion ( $n/N$ ) of individuals of one particular morpho-type divided by the total number of individuals (N).

$$J' = \frac{H'}{H'_{max}}$$

Where  $H'$  is the number derived from the Shannon diversity index and  $H'_{\max} = \ln(S)$ , where  $S$  is the number of species.

In addition to the diversity indices, we also estimated total arthropod biomass for each plot and Insect biomass. Apart from resource diversity and abundance (number of individuals/prey), biomass is a very important measure for studies of ecosystem processes, particularly to quantify the potential energy transferred between trophic levels (Wardhaugh et al. 2013; Sample et al. 1993). We used two formulas for estimating arthropod biomass from length one from Rogers and another from Hódar (Hódar 1996).

$$\text{Rogers: } \textit{biomass} (mg) = a \cdot BL^b$$

(a=intercept; b=slope and BL=body length (cm))

This equation includes specific indices to accurately estimate biomass for certain taxonomic groups, such as: Araneae, Blattodea, Diplopoda, Coleoptera, Diptera, Collembola, Formicidae, Hymenoptera non Formicidae, Isopoda, Opiliones, Lepidoptera, Chilopoda, Pseudoscorpiones, Orthoptera, Thysanoptera, Solifugae and Thysanura.

For the taxonomic groups not included in the equation above, we used a more general equation from Hódar (1996), namely for: Archaeognatha, Hemiptera, Isoptera, Plecoptera and Raphidioptera.

$$\textit{biomass} (mg) = 0.0315 \cdot L^{2.491}$$

(L=length (cm))

Species richness, Shannon diversity index, Evenness and arthropod biomass were computed for each season and for each habitat and compared with a two-way ANOVA. When significant differences were found on any of these variables, we conducted a Tukey multiple comparisons of means to identify significant differences between groups. These analyses were performed in R (R Core team 2015).

# **Chapter 3**

## **Results**

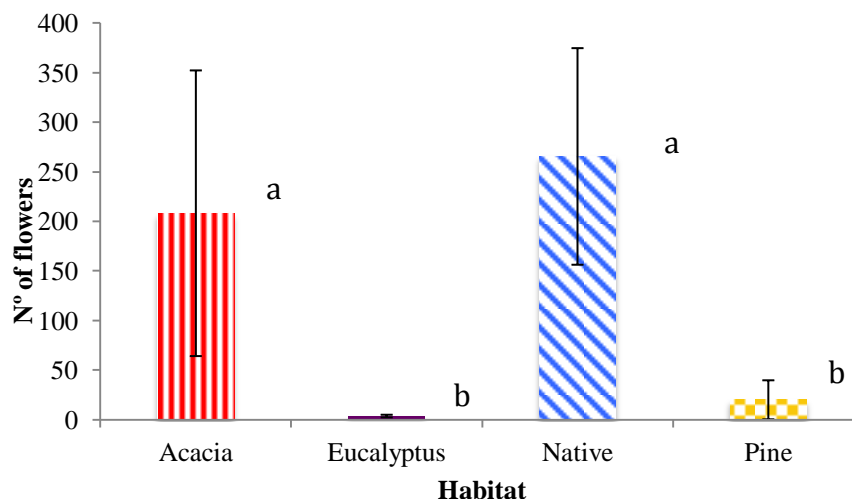


### 3.1 Abundance and diversity of leaves, flowers and fruits

Table 1 shows the identity of the shrub and tree species found in each habitat type. Plant richness was higher in the native woods than in any other habitat type. In the acacia woods we mostly found *Acacia dealbata*, although *Acacia longifolia* was also present in plot A3. The eucalyptus and pine plantations are specifically managed monoculture plantations for wood production and no other trees or shrub were observed along these transects. Native woods had a higher mean of flowers and fruits over the studied year, while the eucalyptus plantations and acacia woods had a higher mean of leaves. Pine plantations had a lower mean of flowers, leaves and fruits, over a year, compared with the other habitat types.

#### Flowers

Flower production differed between habitat type ( $F_{3,96} = 5.61$ ,  $p < 0.001$ ), season ( $F_{11,96} = 3.25$ ,  $p < 0.0008$ ), and there was also a significant interaction between these two variables ( $F_{33,96} = 2.93$ ,  $p < 0.0001$ ). Native and acacia woods produced more flowers than pine and eucalyptus plantations. There was a considerable significant difference between acacia and native woods and the other two wood types (Figure 6).

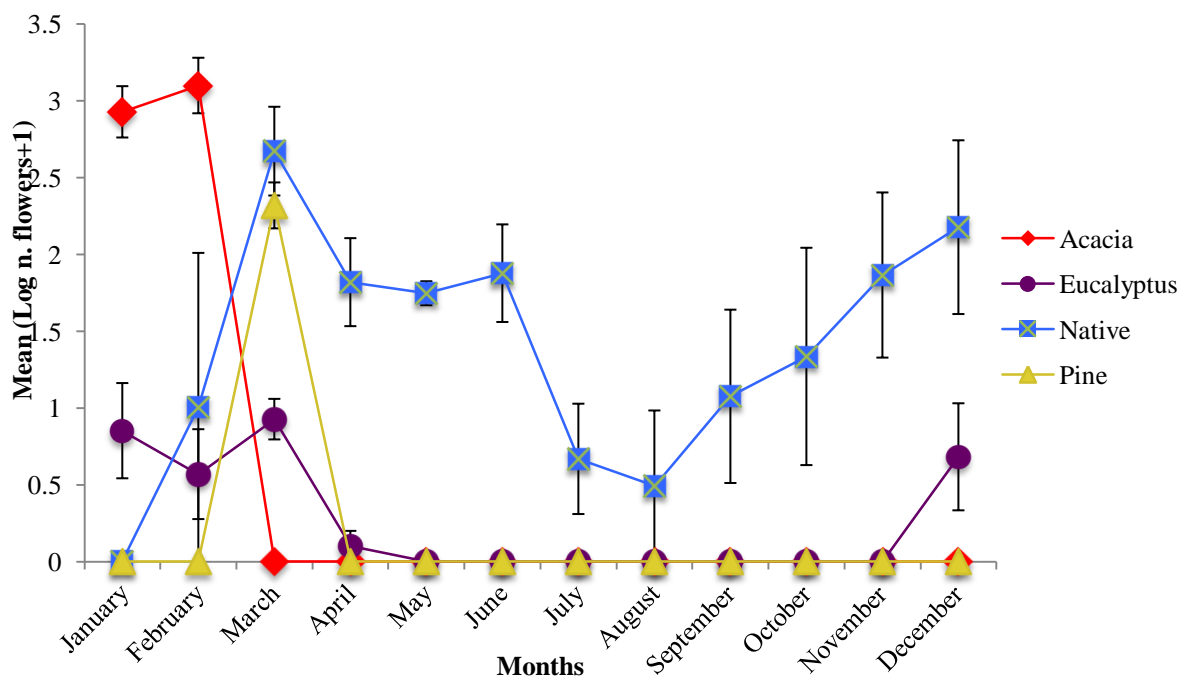


**Figure 6.** Mean number of total flowers in each habitat  $\pm$  SD. Bars with different letters are significantly different.

**Table 1** Species of trees and shrubs along de vegetation transects; mean number of flowers, young leaves and ripe fruits with the standard deviation and their estimated total number in each habitat type.

Habitat	Shrub and tree species	Origin	N° of species observed	mean N. of flowers	mean N. of leaves	mean N. of fruits	Total flowers	Total leaves	Total fruits
Acacia	<i>Acacia dealbata</i>	Exotic	2	207.89 ± 499.27	401.48 ± 323.55	29.82 ± 47.22	22452	47550	2594
	<i>Acacia longifolia</i>								
Eucalyptus	<i>Eucalyptus globulus</i>	Exotic	1	2.47 ± 3.82	134.28 ± 80.42	2.07 ± 5.04	214	14502	206
	<i>Coronilla glauca</i>								
Native	<i>Crataegus monogyna</i>								
	<i>Erica arborea</i>								
	<i>Hedera helix sl.</i>								
	<i>Lonicera periclymenum</i>								
	<i>Myrtus communis</i>								
	<i>Olea europaea</i>								
	<i>Pistacia lentiscus</i>								
	<i>Quercus faginea</i>	Native	18	194.21 ± 238.73	63.85 ± 92.57	80.72 ± 82.48	28230	36623	19836
	<i>Quercus suber</i>								
	<i>Rhamnus alaternus</i>								
	<i>Rosa canina</i>								
	<i>Rubia peregriana</i>								
	<i>Rubus ulmifolius</i>								
	<i>Smilax aspera</i>								
	<i>Tamus communis</i>								
	<i>Ulex europaeus</i>								
	<i>Viburnum tinus</i>								
	Pine	<i>Pinus pinaster</i>	Naturalized	1	19.66 ± 69.10	52.36 ± 94.63	1.04 ± 3.59	2123	5655

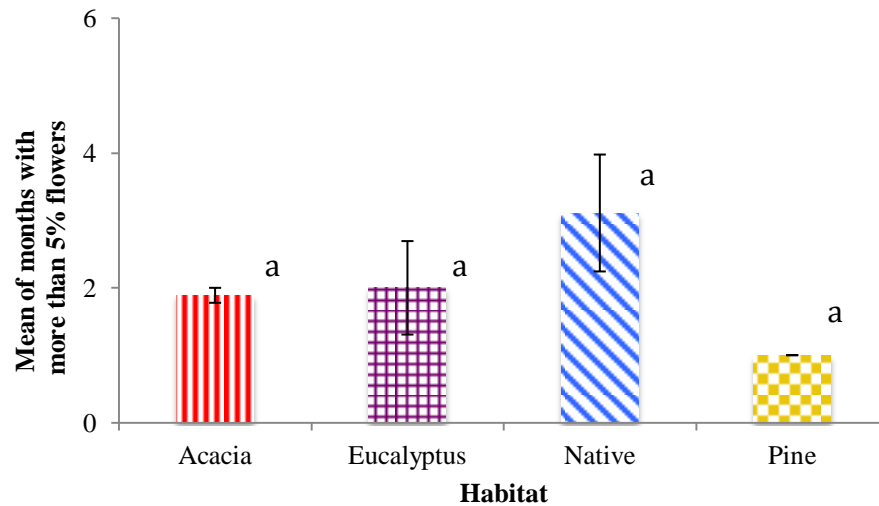
There were an increased number of flowers in native woods from January to March and from August to December. The maximum value was observed in March while the lower values correspond to the months of July and August. The native woods presented flowers during all months of the year except January. In eucalyptus plantations we found flowers in January, February, March and April, although a very small amount was found in the last month. In pine plantations, the flowers were found exclusively in March and in the acacia woods they were present only in January and February (Figure 7).



**Figure 7.** Variation of flower production on each of the four habitat types along one year (mean  $\pm$  SD, data log transformed).

Post-doc comparisons identified differences mostly between native woods and the other habitats types over the spring and summer periods, and between acacia woods and eucalyptus plantations.

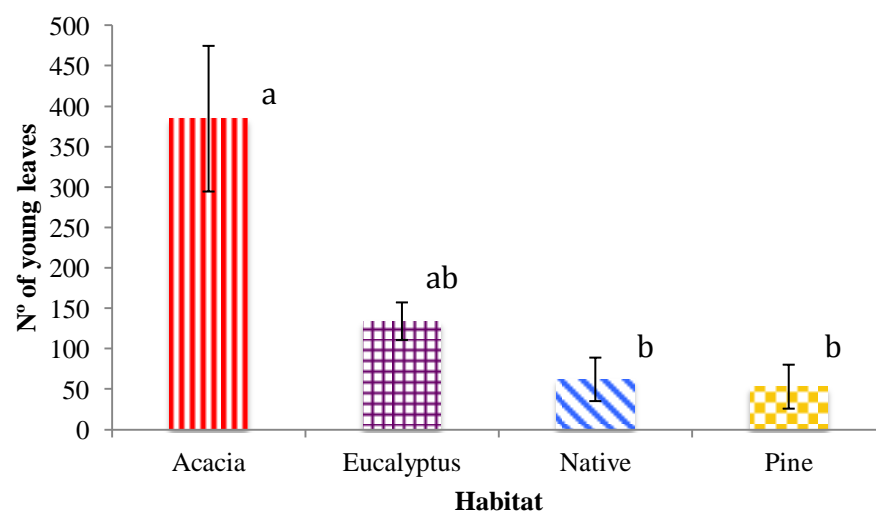
The number of months with more than 5% of flowers did not differ between habitat type ( $F_{3,8} = 2.40$ ,  $p = 0.143$ ). However, it is noticeable that native woods provided flowers for more months when compared with the other habitats, particularly when compared with pine plantations (Figure 8).



**Figure 8.** Mean of months with more than 5% of flowers  $\pm$  SD, produced at each habitat type. Bars with the same letters do not differ significantly between them

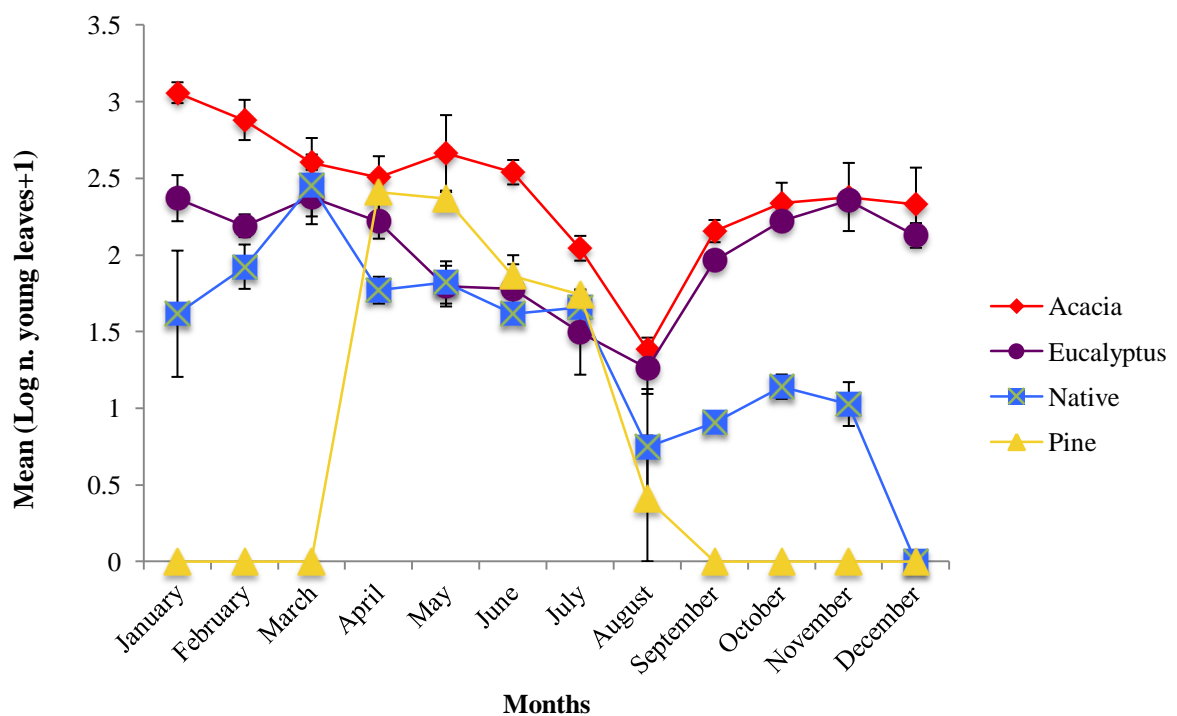
### Leaves

Leaf production differed between habitat type ( $F_{3,96} = 69.02$ ,  $p < 0.0001$ ), season ( $F_{11,96} = 9.73$ ,  $p < 0.0001$ ) and there was also a significant interaction between these two variables ( $F_{33,96} = 6.03$ ,  $p < 0.0001$ ). Pos-hoc comparisons for the factor habitat type showed that acacia woods produced more young leaves when compared with the other habitat types (Figure 9).



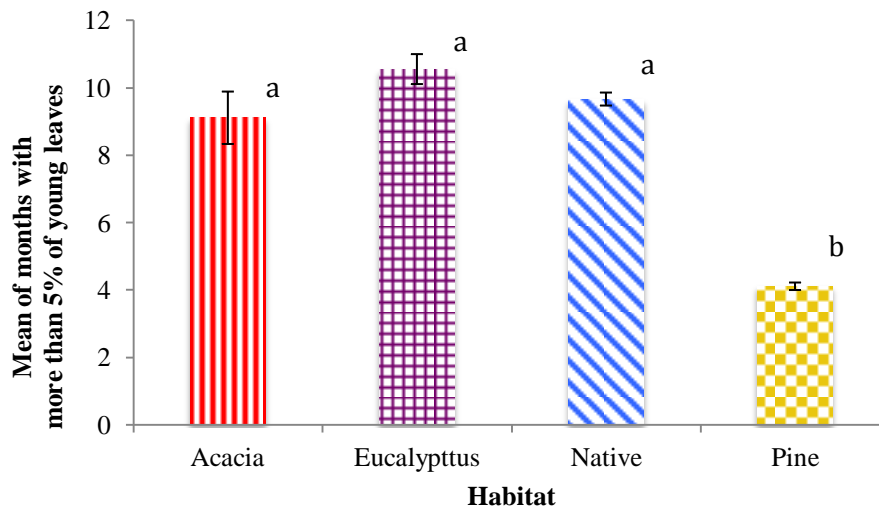
**Figure 9.** Mean of total young leaves in each habitat  $\pm$  SD. Bars with the same letters do not differ significantly between them.

In relation to the season effect and the interaction habitat type \* season the post-doc comparisons identified the following most important differences: a) for season the main differences were between the months of January-May, when more leaves were produced in all habitats types, and the remaining months, and c) for the interaction the main difference was for pine plantations in winter, when virtually no leaves were produced, and the other habitat types for the remaining months. Young leaves were more abundant in acacia woods than in any other habitat for all months of the year. Eucalyptus also produced leaves all year round. Between the months of August and December, there were not significant differences between the acacia woods and eucalyptus plantations. In native woods there was no leaf production only in December. The production of young leaves in pine plantations was concentrated between April and August (Figure 10).



**Figure 10.** Variation in the mean number of young leaf production (mean  $\pm$  SD, data log transformed) over one year per habitat type.

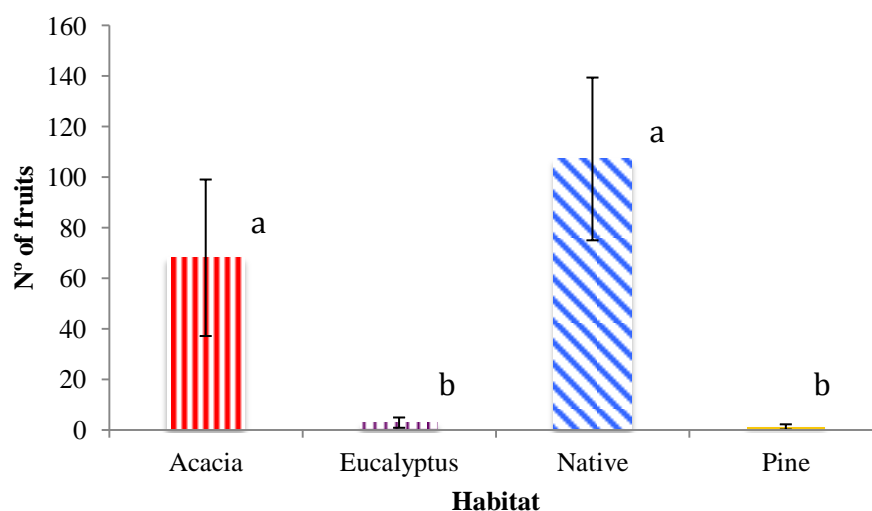
The number of months with more than 5% of young leaves differed between habitat type ( $F_{3,8} = 25.03$ ,  $p < 0.0001$ ). Post-doc comparisons identified differences between pine plantations and the other habitats types (Figure 11).



**Figure 11.** Mean number of months ( $\pm$  SD) with more than 5% of young leaves produced at each habitat type. Bars with the same letters do not differ significantly between them.

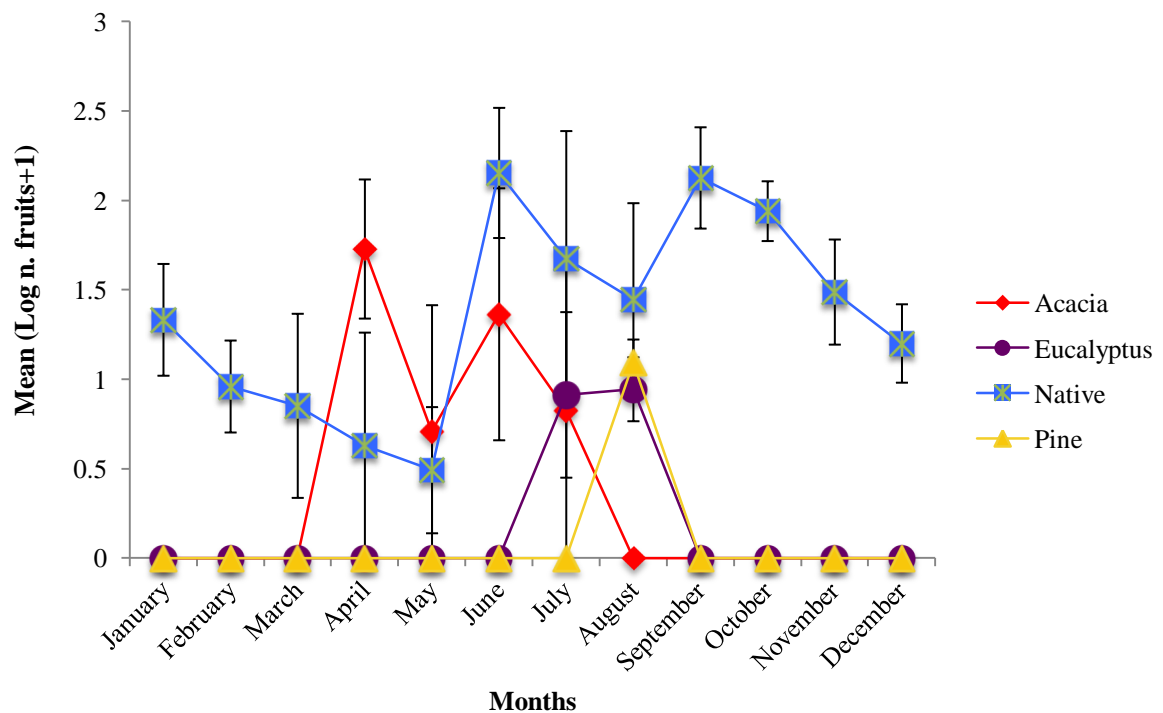
### Fruits

Fruit production differed mostly between habitat type ( $F_{3,96} = 9.84$ ,  $p < 0.0001$ ) and only marginally between seasons ( $F_{11,96} = 1.82$ ,  $p = 0.06$ ). There was not a significant interaction between these two variables ( $F_{33,96} = 1.17$ ,  $p = 0.27$ ). Pos-hoc tests showed that native and acacia woods produced more fruits than pine and eucalyptus plantations (Figure 12).



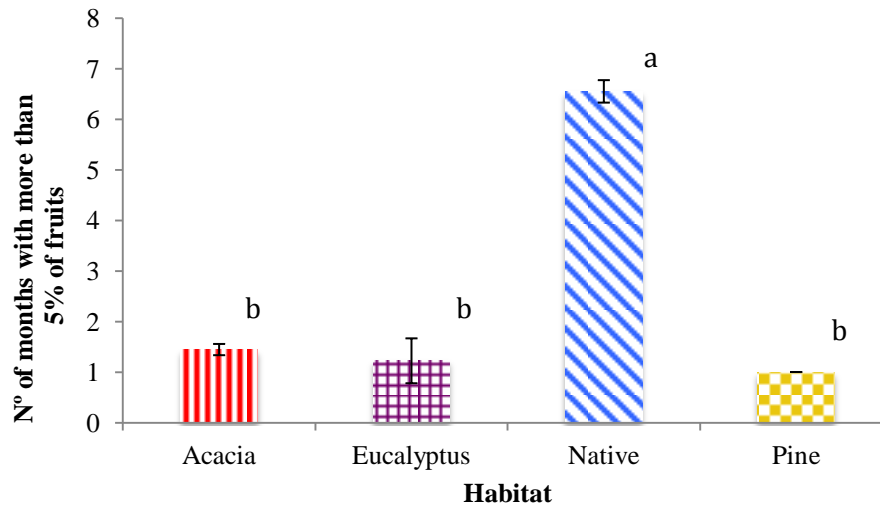
**Figure 12.** Number of total fruits in each habitat ( $\pm$  SD). Bars with the same letters do not differ significantly between them.

Native woods had fruits in all months of the year. In the other three habitats, fruit production occurred only in very specific months/seasons. Acacia woods had fruits between April and July, eucalyptus plantations between July and August and pine plantations only in August (Figure 13).



**Figure 13.** Variation in the mean number of fruits (mean  $\pm$  SD, data log transformed) over one year per habitat type.

The number of months with more than 5% of fruits differed between habitat type ( $F_{3,8} = 110.20$ ,  $p < 0.0001$ ). Post-doc comparisons identified differences between native woods and the other habitats types; as native woods provided fruits for more months (Figure 14).

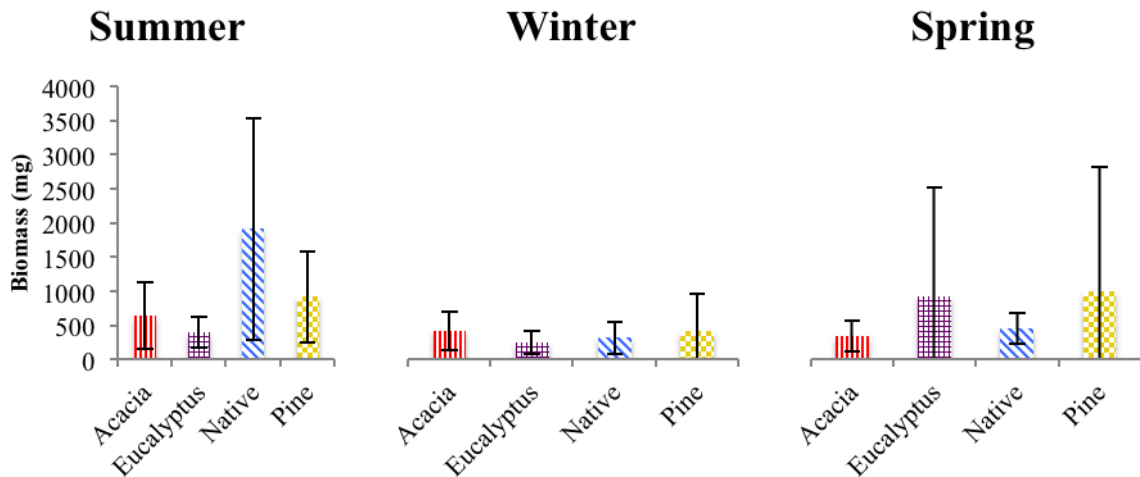


**Figure 14.** Mean number of months ( $\pm$  SD) with more than 5% of fruits produced at each habitat type. Bars with the same letters do not differ significantly between them.

### 3.2 Arthropod abundance, diversity and biomass

In summer, the total arthropod biomass was higher for the native woods, followed by pine plantations, acacia woods and eucalyptus plantations, although this difference was not statistically significant, mostly because the variability of the data was very high for the native habitat. In summer the biomass of arthropods was significantly higher than in winter and spring. In winter, acacia woods and pine plantations presented higher arthropod biomass. In spring, eucalyptus and pine plantations had the highest mean values, although with a large inter-site variation (Figure 15).

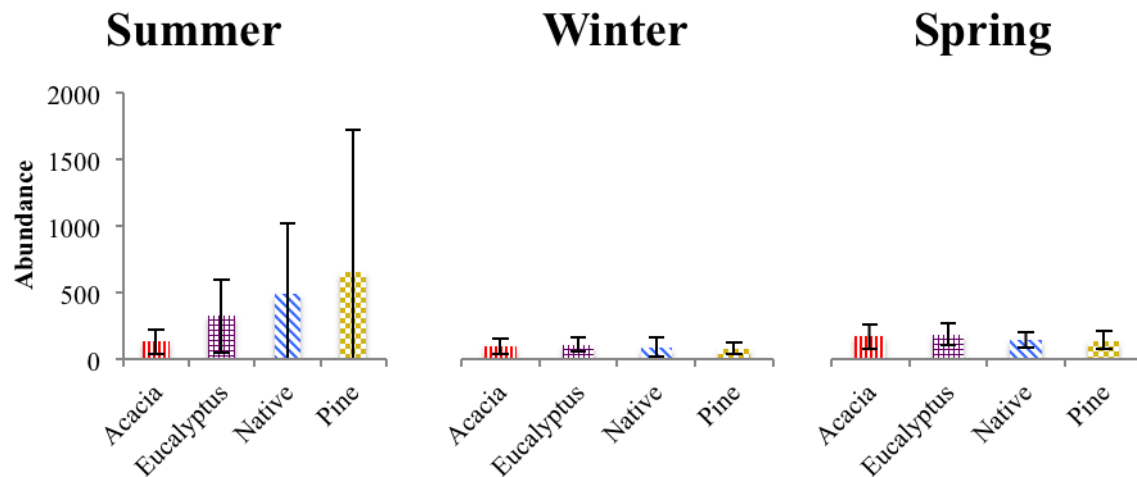




**Figure 15.** Mean Arthropods biomass for each habitat type and season. Error bars represent the standard deviation.

Arthropod biomass differed among seasons ( $F_{2,104} = 4.62$ ,  $p < 0.001$ ), but not among habitat type ( $F_{3,104} = 1.33$ ,  $p = 0.27$ ). However, there was an interaction habitat\*season ( $F_{6,104} = 2.51$ ,  $p < 0.022$ ). Post-doc comparisons identified differences between winter and summer, and between the native habitat in summer and the other habitats in winter.

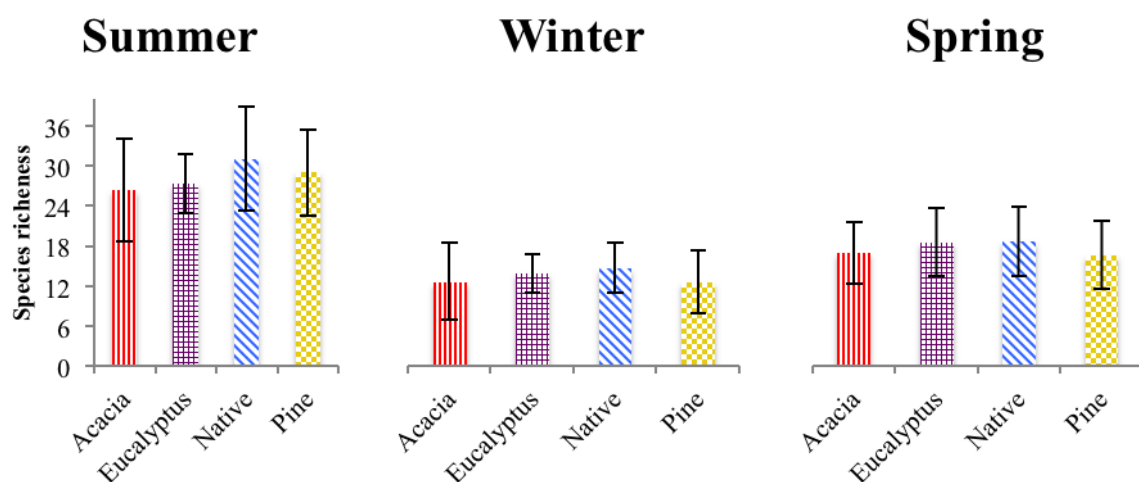
The abundance of arthropods, in summer, was higher for the pine plantations, followed by native woods, eucalyptus plantations and acacia woods. These differences were not statistically significant because of the high variability on the number of arthropods found in pine plantations and also in the native woods (figure 16). In summer the abundance of arthropods was significantly higher than in winter and spring. In winter and spring eucalyptus plantations, showed a slight increase in the abundance of arthropods, followed by acacia woods.



**Figure 16.** Abundance of arthropods for each habitat type and season. Error bars represent the standard deviation.

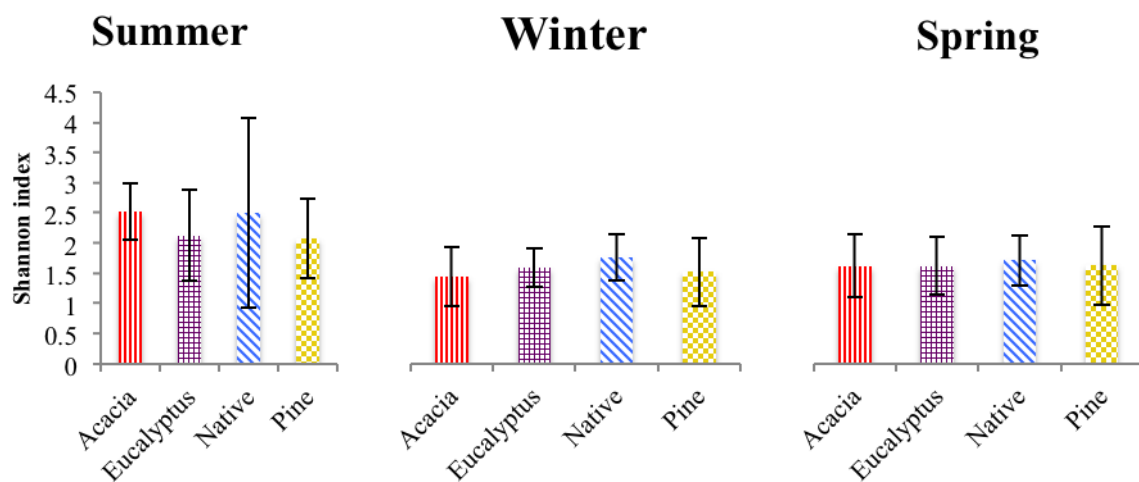
Arthropod abundance differed among seasons ( $F_{2,104} = 7.86$ ,  $p < 0.001$ ), but not among habitat types ( $F_{3,104} = 0.91$ ,  $p = 0.44$ ), and the interaction habitat\*season was not significant ( $F_{6,104} = 1.32$ ,  $p = 0.25$ ). Post-doc comparisons identified differences between winter-summer and summer-spring.

Species richness differed among seasons ( $F_{2,104} = 78.35$ ,  $p < 0.001$ ), but not among habitat types ( $F_{3,104} = 0.98$ ,  $p = 0.41$ ), and the interaction habitat\*season was not significant ( $F_{6,104} = 0.33$ ,  $p = 0.92$ ). Post-doc comparisons identified differences between the summer (with higher number of species) and winter and spring, with lower diversity (Figure 17).



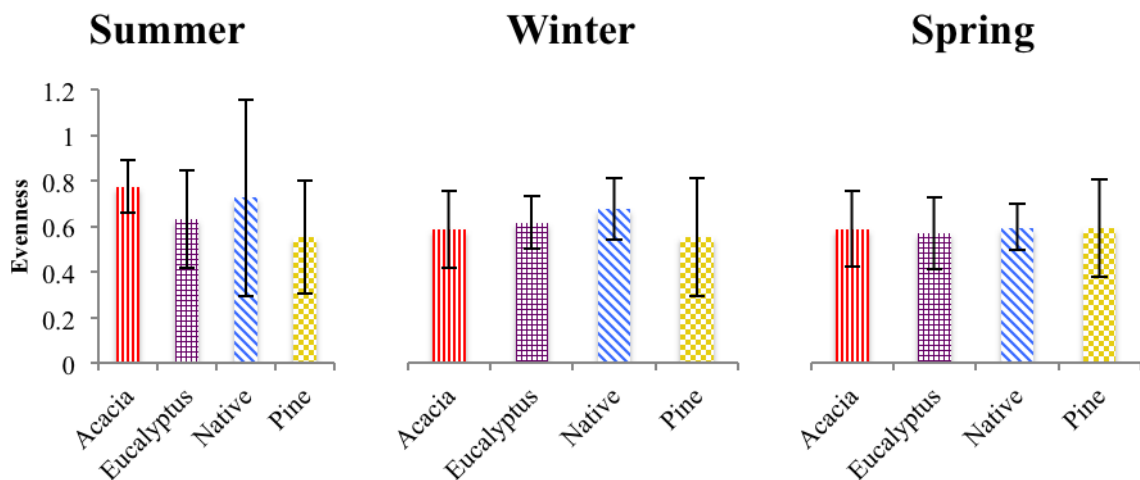
**Figure 17.** Species richness for each habitat type and season. Error bars represent the standard deviation.

Figure 18 presents the Shannon index for each habitat type and season. Shannon index for arthropods differed among seasons ( $F_{2,104} = 12.14$ ,  $p < 0.001$ ), but not among habitat types ( $F_{3,104} = 0.82$ ,  $p = 0.48$ ) and there was no interaction habitat\*season ( $F_{6,104} = 0.40$ ,  $p = 0.89$ ). There was no variation between habitat types, but clearly, the summer presented the highest values of the Shannon index for all habitat types. Post-doc comparisons identified the following differences for season between winter and summer and summer and spring.



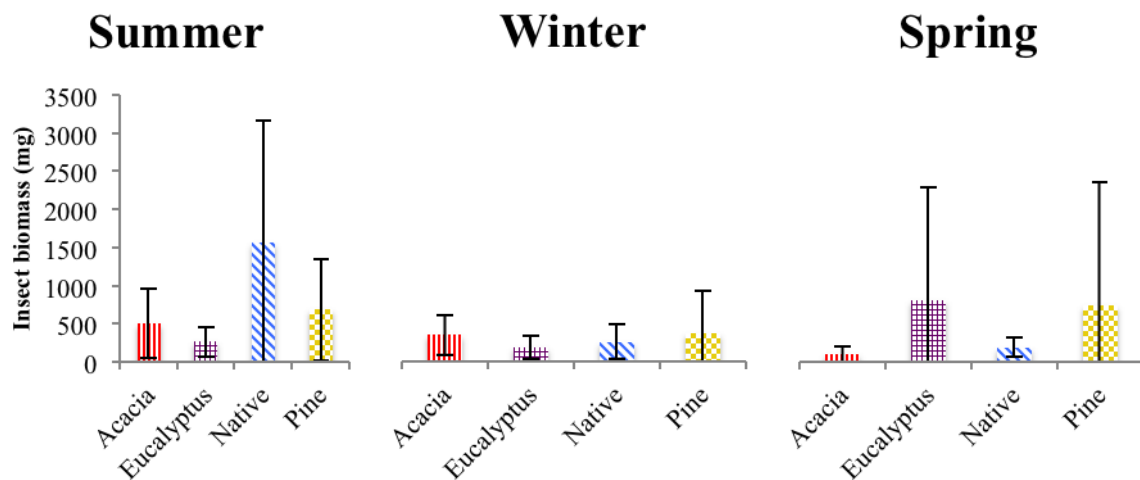
**Figure 18.** Shannon index mean for each habitat type and season. Error bars represent the standard deviation.

The Evenness for arthropods (Figure 19) did not differ among habitat types ( $F_{3,104} = 1.40$ ,  $p = 0.25$ ), season ( $F_{2,104} = 1.62$ ,  $p = 0.20$ ) and there was no interaction habitat\*season ( $F_{6,104} = 0.68$ ,  $p = 0.67$ ).



**Figure 19.** Evenness mean of arthropods for each habitat type over seasons. Error bars represent the standard deviation.

For the insect biomass, the results were similar with those of the overall arthropod biomass (Figure 20).

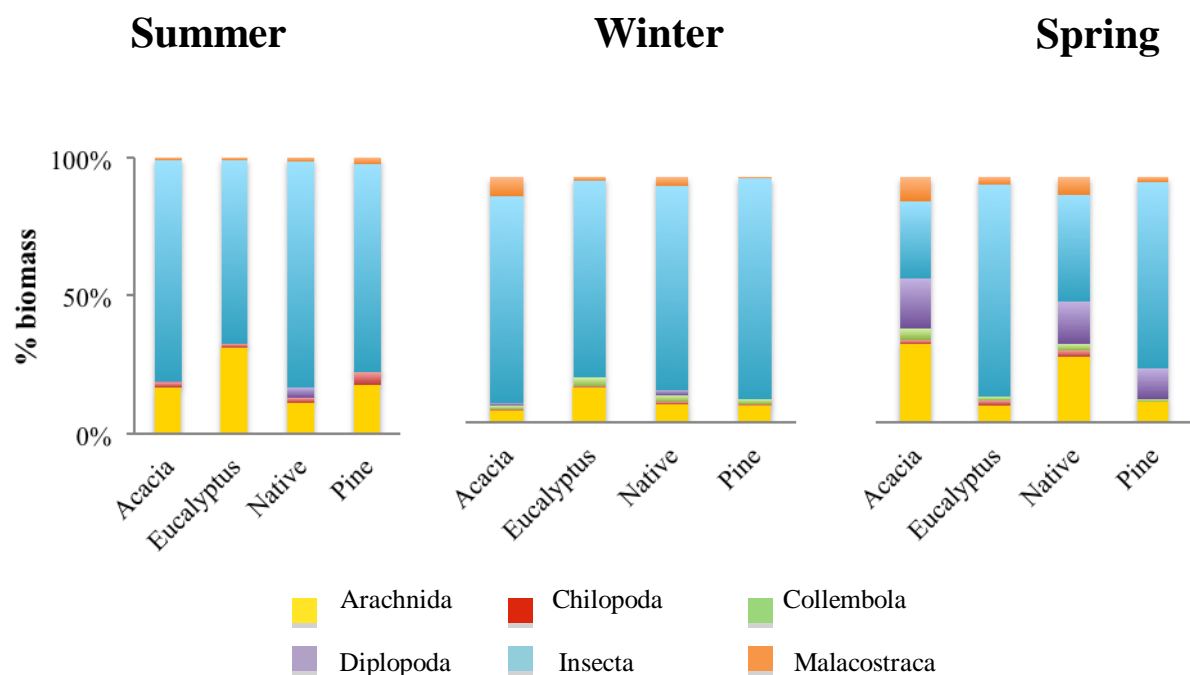


**Figure 20.** Insect biomass for each habitat type and season. Error bars represent the standard deviation.

Insect biomass differed among seasons ( $F_{2,104} = 3.09$ ,  $p < 0.04$ ), but not among habitat type ( $F_{3,104} = 0.95$ ,  $p = 0.42$ ). However, there was an interaction habitat\*season ( $F_{6,104} = 2.56$ ,  $p < 0.02$ ). Post-doc comparisons identified differences between winter and summer and between native habitat in summer and acacia woods in spring.

### Representative Taxa

A total of 25.865 arthropod individuals were captured in the three seasons and identified into 328 different morphospecies, belonging to six classes: Arachnida, Chilopoda, Collembola, Diplopoda, Insecta and Malacostraca (Figure 21). In the summer, and winter the class with the highest percentage of biomass was Insecta in all habitats, generally followed by Arachnida. In spring, we found higher differences among habitats. In eucalyptus and pine plantations, the class with highest percentage of biomass corresponds to Insecta, followed by Arachnida in eucalyptus and Diplopoda in pine. Acacia and native woods presented a higher heterogeneity. In Acacia woods the largest percentage of biomass corresponded to Arachnida followed by Insecta (with fewer significant differences). In native woods the values were highest in Insecta followed by Arachnida and Diplopoda.

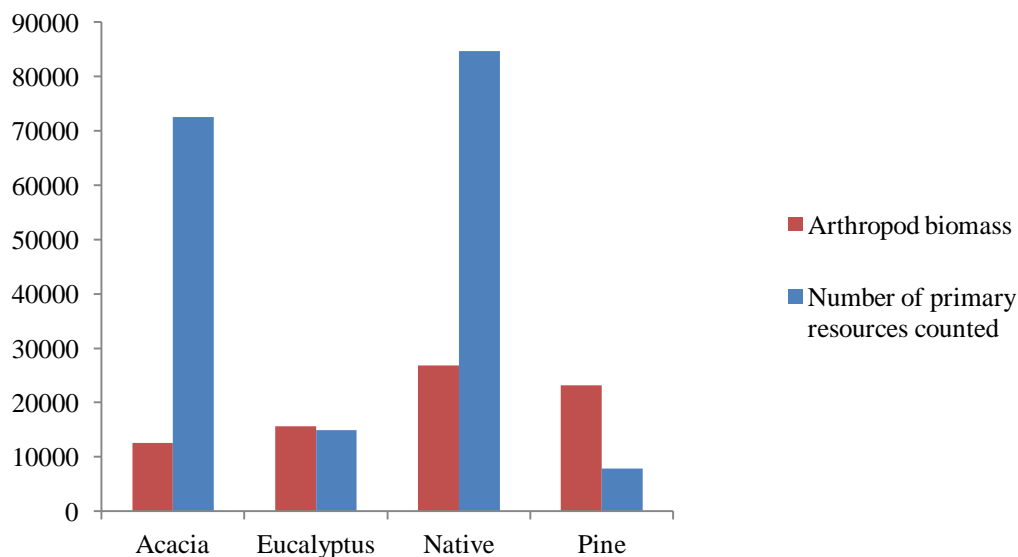


**Figure 21.** Percentage of biomass of each Arthropod class per habitat type on each season.

These classes include 28 distinct arthropod orders. In summer, the order with higher abundance was Hymenoptera for all habitat types, followed by Araneae for acacia woods, eucalyptus and pine plantations. Orthoptera was the second order with higher abundance but only in the native woods. In winter, Entomobryomorpha was

the order with higher abundance in all wood types. Araneae was the second order with higher abundance in pine and eucalyptus plantations. The second more abundant orders were Coleoptera and Isopoda in native and acacia woods respectively. In spring, the more abundant orders were Entomobryomorpha followed by Hymenoptera in all wood types studied. Thysanura only appears in the native woods in spring, Thysanoptera in the native woods in summer, Raphidioptera in the native woods in winter, Plecoptera in the acacia woods in summer, and Isoptera only in pine plantations in spring and winter.

The figure 22 shows the relationship between arthropod biomass and the production of primary resources. The sum of all available resources was higher for native woodlands, followed by acacia woods and reached the lower values in the pine and eucalyptus plantations. We found that arthropod biomass was higher in native woods, followed by pine and eucalyptus plantations and finally in acacia woods.



**Figure 22.** Total arthropod biomass and number of primary resources (young leaves, ripe fruits and flowers) produced at each habitat type.

# **Chapter 4**

## **Discussion**

This study shows that native woods provide a greater and more constant production of primary resources throughout the entire year than other forest habitats in central Portugal. In relation to the diversity of arthropods the differences among habitats were not so clear, however the biomass of arthropods was also higher on native woodlands than in the other habitats types in summer, but the differences were not significant for the other seasons. The lack of significant differences was clearly related with a very high variability in the arthropod abundance and biomass found on the three native plots. It is the first time that such resources are quantified and compared for these habitats types. This is of great importance given the fact that native forest have been replaced by other forest type habitats dominated by exotic species all over Europe (Barrocas et al. 1998; Zahn et al. 2010), and thus one needs to understand how important are these novel habitats for biodiversity.

We outline here first the main limitations of this study before a discussion of the results. In this study, only terrestrial arthropods were recorded, as these were monitored with buried pitfall traps. In order to provide a more holistic view of all resources (including for example flying phytophagous insects and pollinators), it would be necessary to use other traps adapted to flying insects, and beating trays. Also, this study was performed on a highly fragmented landscape dominated by a very rich mosaic of small habitats. Such landscape implies a strong influence of neighboring habitats on biodiversity (Teixido et al. 2010), and therefore it would be important, although extremely challenging, to consider such boundary effects on the patterns identified here. In fact such fragmentation may be responsible for the high data variability that we found in the arthropod abundance for the native habitat. The remaining forest of native habitats can be surrounded by a matrix of modified habitats that may contribute to the loss of some species or the increase of new species (Calviño-Cancela et al. 2012). Other important factor is that 2013 had a very dry summer and the plot N2 of native woods had a very high biomass (5542.1 mg) due to the apparent high humidity of that plot. In contrast the plot N5, which was less shaded and drier, had a very low biomass (256.5 mg). Furthermore, the detected variability also reflects the limited number of replicates (i.e. plots) of each habitat type, which were contingent on the number of habitats included in the study and on the quantity and quality of data collected.



#### 4.1. Abundance and diversity of leaves, flowers and fruits among habitats

As expected in this study we verified that native woodlands sustain a much greater diversity of plants than any other habitat, and also a much greater diversity of all primary resources available to herbivores. These results agree with previous studies where the diversity was generally higher in native forests and shrublands and lower in eucalyptus plantations (Calviño-Cancela et al. 2012). Proença et al. (2010) found a higher richness and diversity of forest plant species in native forest when compared with pine and eucalyptus plantations and Gómez-Aparicio et al. (2006) also found higher plant species diversity in natural forest than in pine plantations. Similarly, we show that native woodlands produced a greater abundance of flowers and fruits than all other habitat types, consistently along most months. One remarkable exception was the outstanding production of *Acacia dealbata* flowers on the acacia woods habitat during winter. Young leaves, however, were more common on Acacia and Eucalyptus stands throughout the year. More importantly, native woodlands provided a much more constant source of resources throughout the year, since in all other habitats there were several consecutive months where at least one primary resource was completely absent: for example, no fruits in the Acacia woods and Pine plantations between September and February, and no flowers on Acacia, Eucalyptus or Pine stands between May and November. Several tree and shrub species from native woodlands produce flowers and fruits at different times, depending on their life cycle, providing resources over all months of the year. The remaining habitats in our study, practically formed by a single tree species present only one and well defined temporal window of flowering and fruiting, offering no alternative resources outside such period.

The total quantity of primary resources available to higher trophic levels was higher in the native woodlands, followed by acacia woods, eucalyptus and pine plantations. However the differences between eucalyptus and pine plantations were minor and they did not follow our expected results. It is important to emphasize that plantations had an understory predominantly of herbaceous plants that were not taken into account in our study, because we only counted resources provided by shrubs and tree species. Plant diversity and biomass changes with the age of plantations and type of management (Maclean and Wein 1977). In this study, pine and eucalyptus plantations were both managed in order to maximize the rapid growth of trees for the

production of wood. This included the plantation of trees of the same age, thus forming a single homogenous vegetation stratum and also the periodic cut of understory vegetation in order to prevent fire damage (Aubin et al. 2008 and Proença et al. 2010). The plantations with higher levels of management will have a higher negative influence in the soil communities (Barrocas et al. 1998).

In addition, our study shows that acacia woods and eucalyptus plantations may provide a very high abundance of primary resources, but only during small periods, mostly up to 2-3 months maximum. This might be a strong limitation for the arthropod and vertebrate communities that live in those habitats, as they would need to complete their life cycle in very short periods where the availability of resources is highly limiting. In addition, the allelopathic compounds of *Acacia dealbata* can reduce the species richness and abundance of plant species (González-Muñoz et al. 2012; Lorenzo et al. 2010), and this should influence the upper trophic levels. For example, *Eucalyptus globulus* plantations only produce flowers in winter, and, although birds feed on the nectar provided by those flowers (authors own data), they would have few food resources available in summer and spring (Tellería and Galarza 1990). Monocultures of eucalyptus due to accumulation of phytotoxins in the soil can also be responsible for the loss of soil productivity (Martins et al. 2013) and a consequent decrease of plant species and arthropod richness. However, in relation to pine plantations, Carrascal and Tellería (1990) found that mature pine forest possess arthropods in the needles, shrubs and in the soil that may provide food resources for forest birds throughout the year.

#### **4.2. Abundance, diversity and biomass of arthropods among habitats**

Arthropods are very important for a wide range of ecosystem functions such as pollination, pest control and decomposition. They are also very important food sources for others animals (Norton et al. 2013). We hypothesised that native woods would have more primary resources, and that this would also translate into more resources for the upper trophic levels. We expected that native woods would contain the highest diversity of Arthropods, however our results were not so clear cut in this respect because we did not find differences across habitats neither on arthropod Species richness, nor on Abundance, nor on Shannon-Wiener diversity index, nor on

the Evenness. These differences were only record between seasons. However we record that the orders Thysanura, Thysanoptera, Raphidioptera were only found in native woods, while Plecoptera was only recorded in Acacia woodlands and Isoptera in pine plantations. These results may indicate that these orders are specific for each habitat type, however more detailed studies would be needed to confirm these patterns.

On the other hand we found that arthropod biomass was higher in the summer and significantly lower in winter on all habitat types. Although there were no significant differences among habitats, the a significant interaction between habitat\*season show that native woodlands possess a higher biomass of arthropods in the summer, while in pine and eucalyptus plantations the biomass was higher in spring. Norton et al. (2013) found that the sampling period with higher amount of arthropods occurred in summer for all micro habitat types of their study (bare ground, leaf litter, woodchips and grass), when these animals are more active (e.g. main reproductive and dispersive season for many taxa). These data show that the values of arthropod biomass are synchronized with the climate and the availability of food resources varies seasonally, depending on weather conditions. Some studies showed that temperature, photoperiod, humidity and food resources play a crucial role in the life of insects, which may affect the development, survival and reproduction (Gonçalves et al. 2008; Rodrigues 2004). The optimum temperature for development of insects is close to 25°C, which usually corresponds to a more rapid development and increases the number of progeny (Rodrigues 2004). The months from June to August (2013) have a mean temperature of 22.02°C in continental Portugal ([www.ipma.pt](http://www.ipma.pt)), promoting the abundance and arthropods biomass in all habits of our study.

The predicted negative effects of eucalyptus plantations on arthropod communities were not confirmed in our study because there were no differences in the abundance and diversity of arthropods between native woods and eucalyptus plantations. Similarly, Sax (2002) compared the number of invertebrate species in autumn and winter in native woods and eucalyptus plantations in California and found that the mean numbers of species was almost identical in the two habitat types.

Nsabimana (2013b) showed that seasonality played a strong effect in the abundance and diversity of litter arthropods in some eucalyptus plantations at the arboretum of Ruhande in Rwanda, where the greater abundance of arthropods coincided with the wet season (Nsabimana 2013a; Nsabimana 2013b). Other studies realized by Nsabimana (2013a) indicated that eucalyptus species might have a litter insect diversity higher than that of native sites if high vegetation diversity is present in those areas.

The abundance of litter arthropods is higher when environmental conditions are more humid (Nsabimana 2013a; Nsabimana 2013b). Humidity and temperature are related with the understory light, which is dependent on the structure of forests (Barbier et al. 2008). These abiotic conditions will contribute to determine decomposition of the underground vegetation. In fact, the arrangement of leaves in the eucalyptus and pine plantations allows the entrance of more light comparing to oak forests (Calviño-Cancela et al. 2012). Thus, oak forests are more humid due to their rich and dense understory, which can contribute to a higher abundance of arthropods, particularly over summer, when acacia woods and eucalyptus plantations are very dry. In fact, our data shows that the arthropod biomass values were high in the native habitat during the summer. The fact that values did not differ from those of the other habitat types might be attributed to a very dry summer (rainfall value of 24.2 mm in 2013 vs. normal rainfall of 35.5 mm; ([www.ipma.pt](http://www.ipma.pt))). Norton et al. (2013) also found that drought conditions are known to reduce the abundance of soil arthropods.

By contrast, despite the large production of leaves by exotic woods in winter, there was not a correlation with the abundance and diversity of arthropods biomass. Barrocas et al. (1998) studied the impact of reforestation with *Eucalyptus globulus* on collembolan edaphic fauna of Serra de Monchique, Algarve. The forests of *Quercus* sp. had higher values of species richness, diversity, and higher numbers of unique species, but there were no differences in the abundance of individuals. Clearly, eucalyptus plantations compared to oak woods in Monchique had a very different fauna spectrum, and their results were not due to the lack of resources provided by de eucalyptus plantations but due to changes in the microhabitat (Barrocas et al. 1998). Presumably, as explained above the quality of the leaf litter may not be the most suitable for the arthropods (Martins et al. 2013), which should influence the longevity, rate of development and fecundation of insects (Rodrigues 2004).

A great number of arthropods belonging to different taxa were recovered in all habitat types, although captures were numerically dominated by Insecta at all seasons, except during spring for the Acacia woods, where Arachnida were most abundant. Many specialist insects developed tight relationships with particular plants and some only feed on a few plant families (Litt et al 2014). For this reason we conducted a more detailed study in this taxonomic group. The observed pattern was similar to that of arthropods: i.e. there were no significant differences between habitats, but there was a significant interaction habitat\*season. We can infer that the availability of resources in each habitat fluctuates seasonally, depending on weather conditions. Similarly, Wolda (1980) referred that patterns of abundance of insects was synchronized with the weather and food availability, which varies seasonally.

Previous studies on the effects of exotic plants in invertebrates showed that the richness, composition and abundance of phytophagous insect's communities are significantly affected in some cases (Litt et al 2014). Heleno et al. (2008) showed that species richness of plants and insects decreased with plant invasion and verified a significant decline in insect biomass along an invasion gradient. It was also found that specialist herbivores insects were replaced by more generalist species along such gradient, which also forage on exotic plants (Heleno et al. 2008). Murray et al. (2009) conducted comparative studies in insect and arachnida assemblages in southeastern of Australia and demonstrated that the seasonal template may interfere with richness species. These authors showed also that exotic plantations had lower species richness in several taxonomic orders of insects compared with native woods in autumn. In winter, there was low species richness for both habitat types. Arachnida assemblages, in winter, had lower species richness in exotic woods, but there were no significant differences for autumn (Murray et al. 2009).

### **4.3. Conclusions**

The large difference on the production of primary resources between native and exotic forests was partially reflected in the production of arthropods to consumers. Thus, arthropod diversity was generally higher on native woodlands although differences were often not significant. These differences can be explained by the presence of more primary resources throughout the year, and particularly in

summer, where the climatic conditions are favorable for the reproduction of arthropods (Rodrigues 2004).

We found that acacia and eucalyptus stands provide a large number of flowers and leaves but, that these are largely concentrated on very few winter months. However such strong increase in resources was not matched by an increase in the biomass and richness of arthropods, because environmental conditions are much less favorable to arthropods at this time of the year. This suggests that although stands with exotic plant species provide many resources at specific periods of the year, these should be little used by arthropods. The abundance and biomass of arthropods appears to be more directly related to seasonality and is mostly influenced by weather conditions (Gonçalves et al. 2008; Rodrigues 2004; Wolda 1980).

In this study, we conclude that the native woods permit the establishment of a wider range of resources than plantations and exotic woods, especially a greater variety of primary resources that are the basis of terrestrial trophic webs. While exotic woods might provide occasional peaks on primary and secondary resources, native woods offer much more reliable and diverse resources that are available throughout the year. Therefore, the small native forest fragments in this region provide critical biodiversity reservoirs that are increasingly being threatened by the expansion of exotic forests.

## **References**

Aguiar and Pinto (2007) Paleo-história e história antiga das florestas de Portugal Continental - Até à Idade Média. Jornal Público, Fundação Luso-Americana para o Desenvolvimento, Liga para a Proteção da Natureza. p.15-53. ISBN 978-989-619-104-7

Aubin, I., Messier, C and Bouchard, A. (2008) Can plantations develop understory biological and physical attributes of naturally regenerated forests? *Biological Conservation*. 141:2461-2476

Azevedo (2012) Florestas, Ambiente e Sustentabilidade. Uma abordagem centrada nos serviços dos ecossistemas. Academia das Ciências de Lisboa. ISBN:978-972-623-110-3

Barbier, S., Gosselin, F. and Balandier, P. (2008) Influence of tree species on understory vegetation diversity and mechanisms involved- A critical review for temperate and boreal forests. *Forest Ecology and Management*. 254:1-15

Barrocas, H.M., Gama, M.M., Sousa, J.P. and Ferreira, C.S. (1998) Impact of reafforestation with *Eucalyptus globulus* Labill. on the edaphic collembolan fauna os Serra de Monchique (Arlgarve, Portugal). *Miscellania Zoologica* 21(2):9-23

Borer, E.T., Seabloom, E.W. and Tilman, D. (2012) Plant diversity controls arthropod biomass and temporal stability. *Ecology Letters*. 15:1457-1464

Borror, J.D. and DeLong, D.M. (1988) *Introdução ao estudo dos Insetos*. são Paulo: Edgard Blucher. 653p.

Brauman, K.A. and Daily, G.C. (2007) The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. 32:67-98



- Bremer, L.L. and Farley, K. (2010) Does plantation forestry restore biodiversity or create green deserts? A synthesis of the effects of land-use transitions on plant species richness. *Biodivers Conserv.* 19:3893-3915
- Brockerhoff, E. G., Ecroyd, C.E. and Langer, E.R. (2001) Biodiversity in New Zealand plantation forests: Policy trends, incentives, and the state of our knowledge. *Journal of Forestry.* 46:31-37
- Brockerhoff, E.G., Jactel, H., Parrotta, J.A., Quine, C.P and Sayer, J. (2008) Plantation and biodiversity: oxymoron or opportunity? 17:925-951
- Calviño-Cancela M., Rubido-Bará, M. and Van Etten, E.J.B. (2012) Do eucalypt plantations provide habitat for native forest biodiversity? *Forest Ecology.* 270:153-162
- Claviño-Cancela, M. and Rubido-Bará, M. (2013) Invasive potential of *Eucalyptus globulus*: seedling recruitment and survival in habitats surrounding plantations. *Forest Ecology and Management.* 305:129-137
- Calviño-Cancela M., Silanes, M.E., Rubido-Bará M. and Uribarri, J. (2013) The potential role of tree plantations in providing habitat for lichen epiphytes. *Forest Ecology and Management.* 291:386-395
- Carnus, J.M., Parrotta, J., Brockerhoff, E., Arbez, M., Jactel, H., Kremer, A., Lamb, D., O'Hara, K. and Walters, B. (2006) Planted Forests and Biodiversity. *Journal of Forestry.* 104(2):65-77
- Carrascal, L.M. and Tellería, J.L. (1990) impacto de las repoblaciones de *Pinus radiata* sobre la avifauna del norte de España. *Ardeola* 37:246-266
- Carvalho A. 1996. Madeiras Portuguesas - Estrutura anatómica, Propriedades e Utilizações. Instituto Florestal, Lisbon, Portugal. Vol. I. 339 pp.

- Chinery, Michael (2007) *Insects of Britain and Western Europe*. Domino Guides
- Collingwood, C. and Prince, A. (1998) *A Guide to Ants of Continental Portugal (Hymenoptera: Formicidae)*. Boletim da Sociedade Portuguesa de Entomologia. ISSN 0871-0554
- Colwell, R. and Coddington, A. (1994) Estimating terrestrial biodiversity through extrapolation. *The Royal Society*. 345:101-118
- Constanza, R., d'Arge, R., Groot, R., Farber, S., Grasso, M., Hannon B., Limburg K., Naeem, S., O'Neill R.V., Paruelo J., Raskin R.G., Sutton, P. and Van den Belt M.(1997) The value of the world's ecosystem services and natural capital. *Nature*. 387:253-260
- Daily G. C., Söderqvist, T., Aniyar, S., Arrow, K. Dasgupta, P., Ehrlich, P.R., Folke, C., Jansson, A.M., Janson, B.O., Kautsky N., Levin, S., Lubchenco, J., Mäler K.G., Simpson D., Starrett, D., Tilman D. and Walker, B. (2000) The value of nature and the nature of value. *Science*. 289:395-396
- Diaz-Balteiro, L., Bertomeu, M. and Bertomeu, M. (2009) Optimal harvest scheduling in *Eucalyptus* Plantations. A case study in Galicia (Spain). *Forest Policy and Economic*. 11:548-554
- Fernandes, P.M. and Rigolot, E. (2007). The fire ecology and management of maritime (*Pine pinaster* Ait). *Forest Ecology and Management* 241(1-3):1-13
- Godinho-Ferreira, P., Azevedo A.M. and Rego, F. (2006) Composição, configuração e estrutura vertical das florestas portuguesas: implicações na probabilidade de ocorrência de fogos florestais. *Forest Ecology and Management*.
- Gómez- Aparicio, L., Zavala, M.A., Bonet, F.J. and Zamora, Regino, Z. (2006) Are pine plantations valid tools for restoring Mediterranean forests? An assessment along

gradients of climatic conditions, stand and distance to seed sources. *Ecological Applications* 19:2124-2141

Gonçalves, L. Almeida, F.S. and Mota F.M. (2008) Efeitos da Temperatura no desenvolvimento e reprodução de *Edessa meditabunda* (Fabricius, 1794) (Hemiptera: Pentatomidae). *Acta Biol. Par. Curitiba*. 37(1,2):111-121

González-Muñoz, N., Costa-Tenorio, M. and Espigares, T. (2012) Invasion of alien *Acacia dealbata* on Spanish *Quercus robur* Forests: Impact on soils and vegetation. *Forest Ecology and Management*. 269:214-221

Hartley, M. (2002) Rationale and methods for conserving biodiversity in plantation forests. 155:81-95

Hartman, H., Daoust, G., Bigué B. and Messier C. (2010) Negative or positive effects of plantation and intensive forestry on biodiversity: A matter of scale and perspective. *The Forestry Chronicle*. 86(3):354-364

Heleno, R.H., Ceia, R.S., Ramos, J.A. and Memmott, J. (2008) Effects of Alien Plants on Insect Abundance and Biomass: a Food-Web Approach. *Conservation Biology*. 23(2):410-419

Hobbs, R.J. and Huenneke, L.F. (1992) Disturbance, Diversity, and Invasion: Implications for Conservation. *Conservation Biology*. 6:324-337

Hódar, J.A. (1996) The use of regression equations for estimation of arthropod biomass in ecological studies. *Acta Ecological*. 17(5):421-433

IFN (2013) Áreas dos usos do solo e das espécies florestais de Portugal continental. IFN-Inventário Florestal Nacional

- Kremen, C. and Ostfeld, R. (2005) A call to ecologists: measuring, analyzing, and managing ecosystem services. *Front Ecol Environ.* 3(10):540-548
- Krieger, D.J. (2001) Economic value of forest ecosystem services: a review. The wilderness Society, 2001.
- Larcombe, M.J., Silva, J.S., Vaillancourt, R.E. and Potts, B.M. (2012) Assessing the invasive potential of *Eucalyptus globulus* in Australia: quantification of wildling establishment from plantations. *Biol Invasions.* 15:2763-2781
- Litt, A.R., Cord, E.E., Fulbright, T.E. and Schuster, G.L. (2014) Effects of Invasive Plants on Arthropods. *Conservation Biology.* 28(6):1532-1549
- Lorenzo, P., González, L. and Reigosa, M. (2010) The genus *Acacia* as invader: the characteristic case of *Acacia dealbata* Link in Europe. *Annals of Forest Science, Springer Verlag (Germany).* 67(101):1-11
- Lorenzo, P., Pérez, A.P., Reigosa, M.J. and González, Luís (2011) Allelopathic interference of invasive *Acacia dealbata* Link on the physiological parameters of native understory species. 2012:403-412
- Lorenzo, P., Pazos-Malvido, E., Rubido-Bará, M., Reigosa, M.J. and González, L. (2012) Invasion by leguminous tree *Acacia dealbata* (Mimosaceae) reduces the native understory plant species in different communities. *Australian Journal of Botany.* 60(8):669-675
- Maclean, D. A., and R. W. Wein. (1977) Changes in understory vegetation with increasing stand age in New Brunswick forests: species composition, cover, biomass and nutrients. *Canadian Journal of Botany* 55: 2818–2831

- Martins, C., Natal-da-Luz, T., Sousa, J.P., Gonçalves, M.J., Salgueiro, L. and Canhoto, Cristina (2013) Effects of Essential Oils from *Eucalyptus globulus* Leaves on Soil Organisms Involved in Leaf Degradation. 8(4):e61233
- Marchante, E., Kjølner, A., Struwe, S. and Freitas, Helena (2007) Short- and long-term impacts of *Acacia longifolia* invasion on the belowground processes of a Mediterranean coastal dune ecosystem. Applied Soil Ecology. 40(2):210-217
- Millennium Ecosystem Assessment (2003) Ecosystems and Human well-being: A Framework for Assessment (Island Press) pp.1-25
- Murray, B.R., Baker, A.C. and Robson, T. C. (2009) Impacts of the Replacement of Native Woodland with Exotic Pine Plantations on Leaf-Litter Invertebrate Assemblages: A Test of a Novel Framework. International Journal of Ecology. 2009:1-6
- Nsabimana, D. (2013a) Influence of Seasonality and *Eucalyptus* Plantation Types on the Abundance and Diversity of Litter Insects at the Arboretum of Ruhande in Southern Rwanda. Journal of Natural Sciences Research. 3(8): 116-122
- Nsabimana, D. (2013b) Seasonal Variation of Litter Arthropods in Some Eucalyptus Plantations at the Arboretum of Ruhande in Rwanda. Journal of Biology, Agriculture and Healthcare. 3(9):49-59
- Norton, B.A., Thomson, L.J., Williams, N.S.G. and McDonnell, M.J. (2013) The effect of urban ground covers on arthropods: An experiment. 17:77-99
- Noss, R.F. (1999) Assessing and monitoring forest biodiversity: A suggested framework and indicators. Forest Ecology and Management. 115:135-146
- Noss, R.F. (1990) Indicators for monitoring biodiversity: A hierarchical approach. Conserv. Biol. 4:355-364

- Paillet Y., Bergès, L., Hjalten J., Ódor, P., Avon, C., Bernhard-Römermann, M., Bijlsma; R., De Bruyn, L., Fuhr, M., Grandin, U., Kanka, R., Lundin, L., Luque, S. Magura, T., Matesanz, S., Mészáros, I., Sebastià, M.T., Schmidt, W., Standovár, T., Tóthmérész, B., Uotila, A., Valladares, F., Vellak, K. and Virtanen, R. (2009) Biodiversity Differences between Managed and Unmanaged Forests: Meta-Analysis of Species Richness in Europe. *Conservation Biology*. 24(1):101-112
- Parrota, J.A., Turnbull, J.W. and Jones, N. (1997) Catalyzing native forest regeneration on degraded tropical lands. *Forest Ecology and Management*. 99:1-7
- Pereira, P. G., Monteiro, E., Vala, F. and Luís, C. (2012) *Insectos em Ordem*. ISBN: 978-972-95047.
- Pereira, P., Da Silva, J.A., Matos, M., Fonseca, Carlos (2012) Coexistence of carnivores in a heterogeneous landscape: habitat selection and ecological niches. *The Ecological Society of Japan*. 27:745-753
- Pereira, H., Domingos, T., Vicente, L. and Proença V. (2009) *Avaliação para Portugal do Millennium Ecosystem Assessment*. Escolar Editora. 978-972-592-274-3
- Pina, J.P. (1989) Breeding bird assemblages in eucalyptus plantations in Portugal. *Ann. Zoologici. Fennici*. 26:287-290
- Power, M.E. (1992) Top-Down and Bottom-Up forces in food webs: Do plants have primacy? *Ecological Society of America*. 73(3):733-746
- Proença, V.M., Pereira, H. M., Guilherme, J. and Vicente, L. (2010) Plant and bird diversity in natural forests and in native and exotic plantations in NW Portugal. *Acta Oecologica*. 36:219-226
- Quigley, M. and Madge, D. (1988) *Land Invertebrates*. Oxford Basil Blackwell Hanitat Field Guides. ISBN 10:0631163786/ISBN 13:9780631163787

- Quilhó, T., Sousa, V., Tavares and F., Pereira, H. (2013) Bark anatomy and cell size variation in *Quercus faginea*. *Turk. J. Bot.* 37, 561–570.
- Reboredo, F. and Pais, J. (2014) Evolution of Forest Cover in Portugal: From the Miocene to the Present. *Forest Context and Policies in Portugal.* 1:1-37
- Rodrigues W.C. (2004) Fatores que influenciam no desenvolvimento dos insetos. *Info Insetos.* 1(4):1-4
- Rubiales, J.M., García-Amorena I., Hernández, L. Génova, Martínez, F., Manzanque, F.G. and Morla, C. (2010) Late Quaternary dynamics of pinewoods in the Iberian Mountains. *Review of Palaeobotany and Palynology.* 162(3):476-491
- Sample, B.E., Cooper, R.J., Greer, R.D. and Whitmore, R.C. (1993) Estimation of Insect Biomass by Length and Width. *American Midland Naturalist.* 129:234-240
- Sayer, J., Chokkalingam U. and Poulsen J. (2004) The restoration of forest biodiversity and ecological values. *Forest Ecology and Management.* 201:3-11
- Sax, D.F. (2002) Equal diversity in disparate species assemblages: a comparison of native and exotic woodlands in California. *Global Ecology and Biogeography.* 11:49-57
- Stephens, S.S. and Wagner, M.R. (2007) Forest Plantations and Biodiversity: A Fresh Perspective. *Journal of Forestry.* 105:307-313
- Silva, P.M., Aguiar, C.A.S, Niemelä, J., Sousa, J.P. and Serrano A.R.M. (2008) Diversity patterns of ground-beetles (Coleoptera: Carabidae) along a gradient of land-use disturbance. *Agriculture, Ecosystems and Environment.* 124:270-274
- Sousa J.P., Vingada, J.V., Loureiro, S., Gama, M.M., and Soares A.M.V.M. (1998) Effects of introduced exotic tree species on growth, consumption and assimilation

rates of the soil detritivore *Porcellio dilatatus* (Crustacea: Isopoda). *applied Soil Ecology*. 9:399-403

Tang, Y., Warren, R.J., Kramer, T.D. and Bradford, M.A. (2012) Plant invasion impacts on arthropod abundance, diversity and feeding consistent across environmental and geographic gradients. *Biol Invasions* 14:2625-2637

Teixido, A. L., Quintanilla, L.G., Carreño, F. and Gutiérrez, D. (2010) Impacts of changes in land use and fragmentation patterns on Atlantic coastal forest in northern Spain. *Journal of Environmental Management*. 91:879-886

Tellería, J.L. and Galarza, A. (1990) Avifauna y paisaje en el norte de España: efecto de las repoblaciones con árboles exóticos. *Ardeola* 37(2):229-245

Thompson, I.D., Okabe, K., Tylianakis, J.M., Kumar, P., Brockerhoff, E.G., Scheellhorn, N. A., Parrotta, J.A., and Nasi, R. (2011) Forest Biodiversity and Delivery of Ecosystem Goods and Services: Translating Science into Policy. *BioScience*. 61(12):972-981

Wardhaugh CW, Stork NE and Edwards W. (2013) Body size variation among invertebrates inhabiting different canopy microhabitats: why are flower-visitors small? *Ecological Entomology* 38, 101–111.

Wilson, E.O. (1987) The Little Things that Run the World: The Importance and Conservation of invertebrates. *Conservation Biology*, 1: 344-346.

Wolda, H. (1980) Seasonality of Tropics Insects. *Journal of Animal Ecology*. 49:277-290

Zahn, A., Rainho, A. Rodrigues, L. and Palmeirim, J.M. (2007) Low macroarthropod abundance in exotic eucalyptus plantations in the mediterranean. *Acta Chiropterologica*. 9(1):115-125



Zhang, C. and Fu, S. (2009) Allelopathic effects of eucalyptus and the establishment of mixed stands of eucalyptus and native species. *Forest Ecology*. 258:1391-1396

Zahn A., Bauer S., Kriner E. and Holzhaider J. 2010: Foraging habitats of *Myotis emarginatus* in Central Europe. *Eur. J. Wildl. Res.* 56: 395-400