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NEUROPTERA COMMUNITIES OF THE AZORES

Influence of the habitat and seasonality in the distribution, abundance and dominance.

Raquel Gonçalves Mendes

Universidade dos Açores

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Departamento de Biologia

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Influence of the habitat and seasonality in the distribution, abundance and dominance.

Dissertação apresentada à Universidade dos Açores para obtenção do grau de mestre em Biotecnologia em Controlo Biológico

Orientadora: Professora Doutora Maria Anunciação Mateus Ventura

Raquel Gonçalves Mendes

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RESUMO

Para o arquipélago dos Açores estão referenciadas duas famílias da ordem Neuroptera: Chrysopidae (*green lacewings*) e Hemerobiidae (*brown lacewings*). Estes insectos têm potencial para serem eficazes agentes de controlo biológico, predando uma grande variedade de insectos, incluindo algumas das mais importantes pragas do mundo em campos agrícolas e hortícolas.

O uso efectivo destes neuropteros como agentes de controlo biológico exige o conhecimento dos seus padrões de sazonalidade, em particular para avaliar se a sincronia entre um dado predador e a respectiva presa é adequada. É também importante conhecer a dinâmica espacial e a escolha de habitats de forma a diferenciar a sua qualidade e realizar uma gestão eficaz.

Amostragens da fauna de Neuropteros na Ilha de S. Miguel (Açores) foram realizadas ao longo de um ano, em seis habitats diferentes: Laurissilva, floresta exótica, pastagens, culturas agrícolas, jardins e pomares.

Calcularam-se os seguintes parâmetros ecológicos: abundância relativa; riqueza específica; dominância, diversidade e heterogeneidade de cada habitat; foi ainda analisada a composição da comunidade de cada habitat, bem como a sazonalidade de cada família e espécies mais representativas.

Concluímos que, quatro das espécies existentes nos Açores têm potencial para serem usadas em campos agrícolas, pomares e jardins do arquipélago; duas espécies são extremamente raras, e uma espécie não foi encontrada.

A sazonalidade das populações de Neuroptera não foi a esperada, provavelmente devido a condições climáticas alteradas. Uma pesquisa de longo prazo desta característica nos habitats alvo, em conjunto com o estudo da sazonalidade da presa, é pois aconselhada.

ABSTRACT

Among the Neuroptera order, two families, Chrysopidae (green lacewings) and Hemerobiidae (brown lacewings) are reported to the Azores archipelago. Lacewings are known to be effective biological control agents, preying upon a large range of insects, including some of the world´s most important agricultural and horticultural pests.

The effective use of lacewings as biological control agents requires the knowledge of their seasonality patterns, particularly to assess whether the synchrony between a given predator and its prey, is adequate; also the spatial dynamics and habitat choice, is important to differentiate between habitats of different quality for effective management.

Surveys of the Neuroptera fauna of S. Miguel Island (Azores) were performed along one year, in six different habitats: Laurissilva forest, exotic forest, pastures, agricultural crops, gardens and orchards.

The relative abundance, species richness, species dominance, diversity and heterogeneity of each habitat, were calculated; community composition for each habitat was also assessed, as well as the seasonality for each Neuroptera family and most representative species.

We concluded that, four of the existing species in the Azores have the potential to be used in crops, orchards and gardens of the archipelago; two species are extremely rare and one species was not found.

The seasonality of the Neuroptera populations was not the expected one, probably due to altered climate conditions. A long-term survey targeting this feature in the studied habitats, along with the assessment of the prey´s seasonality, is advised.

Chapter 1

1. INTRODUCTION

1.1. Geographic frame

The Azores archipelago is located in the North Atlantic ridge, between the latitudes 36º 45'N and 39º 43'N and the longitudes 24º 45'W and 31º 17'W. It comprises 9 islands of volcanic origin distributed by 3 groups: Western (Flores and Corvo), Central (Terceira, Graciosa, Faial, Pico and S. Jorge), and Eastern (S. Miguel and St. Maria).

During most of the year (September to March), the Azores region is frequently crossed by the North Atlantic storm-track, the main path of rain-producing weather systems. During late Spring and Summer, the Azores climate is influenced by the Azores anticyclone and there is less rain (Santos *et al.*, 2004; Quartau, 2007). The islands are characterized by an oceanic temperate climate, with mild temperatures all year round, at low altitudes, and a rather wet climate. The distribution of rain is highly controlled by topography (the precipitation is 20 to 25% higher in the northern slopes than in the southern ones), rainy at high altitudes and drier in coastal areas (Quartau, 2007).

This work was developed in S. Miguel Island, since this is the largest island on the archipelago and the most humanized.

1.2. The order Neuroptera in the Azores

The order Neuroptera is one of the smallest and primitive among the holometabolic insects, comprising about 6000 known species. The adults and larvae from most families are predators, which make them very interesting to many entomologists, since some can have a considerable value as manipulable predators to be used in biological control programs (New, 2001a).

Among this order, three families - Coniopterygidae, Hemerobiidae and Chrysopidae – stand out as being the most widespread, predominant and diverse in the northern temperate regions (New, 2001b). New (2001b) says that the biological knowledge of these three families is highly biased in favor of the Chrysopidae, followed by the Hemerobiidae and lastly the Coniopterygidae.

In the Azores only two of these families are present, the Chrysopidae with two species of the *Chrysoperla* genus, and the Hemerobiidae with five species divided by three genus *Hemerobius*, *Micromus* e *Wesmaelius* (Borges et al., 2005), one of them endemic (*Hemerobius azoricus* Tjeder, 1948).

The Chrysopidae, usually known as green lacewings, is the most diverse of the three families mentioned above (New, 2001b). Green lacewings are essentially polyphagous predators whose larvae feed on small soft-bodied arthropods, and are highly voracious (Principi & Canard, 1984). The genus *Chrysoperla* is widespread in cultivated areas almost all over the world (Duelli, 2001), and many species of the genus play an important role in biological control of field crop pests (Canard et al., 1984), a fact that has been documented in cage, greenhouse, and field environments worldwide (McEwen et al., 2001), and against a variety of pests of economic importance (Senior & McEwen, 2001). More than 140 companies in North America (Hunter, 1997) and 26 in Europe (van Lenteren *et al*., 1997) produce and sell biological control products, including lacewings.

As for the Hemerobiidae, also known as brown lacewings, the family comprises about 550 described cosmopolitan species and has a worldwide distribution (New, 2001b). Hemerobiids are always predacious both in larvae and adult stages, preying on slow-moving soft-bodied arthropods. Larvae and adults occur in the same substrates and both contribute to reduce herbivore populations. However, adults of some hemerobiids are rather omnivorous and able to feed partially, but regularly, on pollen and honeydew. The predation scheme of the hemerobiid larvae does not seem to differ from the predation scheme of the chrysopid. Larvae are highly voracious and the amount of prey eaten is always high (Canard, 2001). Most larvae are relatively active predating on soft-bodied insects or their eggs. The larvae of many species, particularly from the *Hemerobius* and *Micromus* genus, prey on insect pests economically important, in agricultural, horticultural and forest environments. Most species are thought to be generalist predators but many appear to exhibit considerable fidelity to specific habitat or plant species, which may be a reflection of restricted prey diets (Oswald & Tauber, 2001).

In general, lacewings have the potential to be effective biological control agents, preying upon a large range of insects, including some of the world´s most important agricultural and horticultural pests. Most lacewings used as biological control agents are either Chrysopidae or Hemerobiidae, although hemerobiids have received less attention. They are suitable to use in a great variety of crops, against a large number of pests, and in integrative pest management (IPM) programs, due to their resistance to several common insecticides, which gives them an advantage over other biological control agents (Senior & McEwen, 2001).

Lacewings are considered auxiliary insects, with a direct economic impact, since they provide important free ecosystem services through pollination and pest control, worthy of preservation and better exploitation (EASAC, 2009; EEA, 2010).

1.2.1. Family Chrysopidae

In the Azores archipelago the Chrysopidae family is so far represented by two species, both from the European *carnea*-complex: *Chrysoperla lucasina* (Lacroix, 1912) and *Chrysoperla agilis* Henry, Brooks, Duelli & Johnson (2003), identified both by morphology and courtship song analysis. Several studies have been conducted with these auxiliary insects in the Azores, concerning namely their biological characterization (Ventura, 2003; Mendes & Ventura, 2010), compatibility with entomopathogenic biological control agents (Ventura, 2003), and biogeographic origin (Ventura et al., 2005). These studies represent the grounds of the subsequent research with these species in the archipelago. They reinforce the importance of these species as biological control agents; show that there are some ecophysiological differences between them, although subtle and given their sympatric distribution, not enough to confirm their biological distinction; they revealed that both species occur in the same habitats (mainly corn fields and orchards infested with aphids), although *Ch. lucasina* used to be the dominant species in the archipelago and had a higher reproductive ability (Ventura, 2003). Henry et al. (2003) have also demonstrated that larvae and adults of both species are syntopic, and can be found in medium or low layers of vegetation, and that their ecological similarity indicates a potential for intense competition.

Recent surveys have detected a shift in the habitat/prey choice and relative abundance of these species, in the archipelago (Ventura et al., 2008). In these surveys the insects were mainly found in ornamental flowery plants infested with *Pseudococcus longispinus* (Mendes & Ventura, 2010); the dominant species appears to be now *Ch. agilis* whereas *Ch. lucasina*, the former dominant species, is now very hard to find (personal observation). Within 10 years, the shift observed in their habitat and prey preference, may indicate that the two species are competing in nature. From these results, it becomes obvious that a more thorough investigation of the habitat preferences and abundance was needed, if the research aiming to improve the efficacy of these species as biological control agents is to be followed.

1.2.2. Family Hemerobiidae

The hemerobiidae family in the Azores has five species, *Hemerobius azoricus* Tjeder (1948), *Hemerobius humulinus* (Linnaeus, 1758), *Hemerobius stigma* Stephens (1836); *Micromus angulatus* (Stephens, 1836) and *Wesmaelius subnebulosos* (Stephens, 1836). *H. azoricus* is endemic to the archipelago.

For this family virtually no studies have been made in the Azores, besides the faunal checklist records (e.g. Navás, 1933 and Tjeder, 1948). In fact, and despite the potential of the Hemerobiidae larvae as predators, relatively few species have attracted attention as biological control agents (New, 2001b). These unsystematic records are clearly insufficient to understand the population dynamics and patterns of these species, and consequently to be able to use them as biological control agents.

1.3. The role of habitat and seasonality on the distribution of Neuroptera

1.3.1. Seasonal patterns

Recognizing the characteristics of lacewings' seasonality is essential to enhance the efficacy of biological protection, and in particular to assess whether the synchrony between the given predator and prey, is adequate (Szentkirályi, 2001a).

In previous studies, Szentkirályi (1984, 1986) found that the mass flight period of chrysopids covers June-August under the temperate climate of Europe, while hemerobiids occur later, from mid-July to late September. This author also notices that in temperate climate regions, there are two growing periods of aphid abundance: the first one occurs between May and mid-July and the second from early September to late October. According to this, the general activity patterns of adult chrysopids are mainly associated with the first peak, while the hemerobiids are associated with the second peak, although many local variations are possible in synchrony between lacewings and aphids (Szentkirályi, 2001a).

1.3.2. Spatial patterns

There are significant changes in environmental factors (day-length, climate, vegetation, prey) that influence the spatial dynamics at the geographical scale (Szentkirályi, 2001a). Understanding the basis for habitat choices of animal species has important implications for explaining the distribution of organisms in the wild, and differentiating between habitats of different quality for effective management (Chalfou & Martin, 2007).

The study of species richness, abundance and composition across habitat types, is crucial for understanding current local diversity and promoting adequate conservation management strategies (Olden, 2006 fide Cardoso, 2009). Therefore, it is critical to understand which habitat types are required to support populations' taxa of high value for local biodiversity conservation (Cardoso, 2009).

1.3.3. Studied habitats

The habitats studied in this work were: (1) the Laurissilva, a subtropical wet forest composed mainly of trees of the Lauraceae family and endemic to the Macaronesia. In the Azores archipelago it is presently almost confined to high altitudes or inaccessible places, due to an intense humanized landscape. In the sampling sites, as with most of the Laurissilva forests, we also find many non-native plants. (2) The exotic forest, defined as a mixed forest, composed mainly of exotic invasive vegetation, some ornamental, and sometimes endemic or native species can also be found; (3) Pastures which are fields of grasses used for feeding the cattle in an intensively management regime, in which the edges are made up mainly of *Cryptomeria japonica* and invasive vegetation. (4) Crops corresponding to agricultural fields with several types of cultures (e.g., potatoes, onions, beans, corn, cabbage, etc.). (5) Gardens, constituted mainly by ornamental flowering plants in public spaces. (6) Orchards, the last type of habitat, were made of small fields with different types of fruit trees, since in the Azores there is not an intensive culture of orchards.

In annex a more detailed description of each location *per* habitat can be found.

2. OBJECTIVES

The overall goal of this work was to set the basis for the study of the population dynamics of the Neuroptera fauna in the Azores, aiming to start or improve their use as biological control agents in the archipelago, and worldwide. In this sense the specific objectives were:

- Measure the seasonal abundance and diversity of Neuroptera in different habitats of S. Miguel Island;
- Identify the habitat preferences of each species with emphasis to agricultural systems;
- Identify possible dominance relationships between species and the likelihood of competition in each habitat;
- Identify the ideal habitat for each species in the context of biological control programs.

Chapter 2

Influence of Habitat and Seasonality on the Neuroptera (Insecta) assemblages of a Macaronesian archipelago

Mendes, R.[a], Saraiva, J.[a] &Ventura, M.A.[a]

[a]CIBIO Centro de Investigação em Biodiversidade e Recursos Genéticos – Pólo Açores
Departamento de Biologia, Universidade dos Açores, Rua Mãe de Deus 13A, PT - 9501-855 Ponta Delgada

Corresponding author: raquelgmendes@gmail.com

Summary

Surveys of the Neuroptera fauna of S. Miguel Island (Azores) were performed along one year, in six different habitats: Laurissilva forest, exotic forest, pastures, agricultural crops, gardens and orchards. The habitats were chosen given their ecological significance in the context of the island biodiversity (laurisilva), or extension (exotic forest, pastures), or also due to their importance to most of the Neuroptera species (agricultural crops, gardens, orchards).

Captures were performed once a month, by suction with an entomological vacuum device, and direct prospection in the vegetation. All sites were initially geo-referenced.

The relative abundance, species richness, species dominance, diversity and heterogeneity of each habitat, were calculated; community composition for each habitat

was also assessed, as well as seasonality for each Neuroptera family and most representative species.

Key-words: species abundance; Azores diversity; habitat preference; Neuroptera; seasonality.

Introduction

Studies on habitat use and selection are essential for understanding the biological requirements of animals and the strategies they use to fulfill their needs (Manly et al., 1995). Furthermore, the study of species richness, abundance and composition changes across habitat types, is crucial for understanding current local diversity and promoting adequate conservation management strategies (Olden, 2006 fide Cardoso, 2009). Most commonly, selection studies deal with food or habitat selection. Habitat selection may be among various discrete habitats categories (e.g., open field, forest, etc.) or among a continuous array of habitat attributes (e.g., shrub density, percentage cover, etc.). Thus, when making inferences, researchers studying selection must keep in mind the level being studied (Manly et al., 1995).

The adults and larvae from most families of Neuroptera are predators, making them of great interest to many entomologists, since some can have a considerable value as manipulable predators to be used in biological control programs (New, 2001a). Two Neuroptera families are known to exist in the Azores, the Chrysopidae (green lacewings) and the Hemerobiidae (brown lacewings) (Borges et al., 2005). Lacewings have the potential to be effective biological control agents, preying upon a large range of preys, including some of the world´s most important agricultural and horticultural pests. They are suitable for use in a great variety of crops, against a large number of pests, and in integrative pest management (IPM) programs due to their resistance to several common insecticides, which gives them an advantage over other biological control agents (Senior & McEwen, 2001). For this reason, the Chrysopidae populations of the Azores have been subject of research and monitoring (e.g. Ventura, 2003; Ventura et al., 2005; Lourenço et al., 2006; Ventura et al., 2007). In recent surveys, however, we detected a shift in the habitat preference and relative abundances of these species. In these surveys the insects were mainly found in ornamental flowery plants, whereas they used to be found mainly in orchards and crops including cornfields; moreover the dominant species was now *Ch. agilis* whereas the previous dominant species, *Ch. lucasina*, was almost absent (Mendes & Ventura, 2010). For the Hemerobiidae family there are virtually no studies made in the Azores, besides the faunal checklist records (e.g. Navás, 1933 and Tjeder, 1948). In fact, and despite the potential of the Hemerobiidae larvae as predators, relatively few species have attracted attention as biological control agents (New, 2001b).

In addition to the study of habitat preference, recognizing the characteristics of lacewings seasonality is essential to enhance their efficacy on crop protection, and in particular to assess whether the synchrony between the given predator and prey, is adequate (Szentkirályi, 2001a). In previous studies, Szentkirályi (1984; 1986) found that the mass flight period of chrysopids covers June-August under the temperate climate of Europe, while that of hemerobiids occurs later, from mid-July to late September.

The Azores archipelago, located in the North Atlantic ridge, between the latitudes 36º 45’N and 39º 43’N and the longitudes 24º 45’W and 31º 17’W, has conditions to experience the above mentioned flight periods. It comprises 9 islands of recent volcanic origin distributed by 3 groups: Western (Flores and Corvo), Central

(Terceira, Graciosa, Faial, Pico and S. Jorge), and Eastern (S. Miguel and St. Maria), groups. During most of the year (September to March), the Azores region is frequently crossed by the North Atlantic storm-track, the main path of rain-producing weather systems. During late Spring and Summer, the Azores climate is influenced by the Azores anticyclone and there is less rain (Santos et al., 2004; Quartau, 2007). The islands are characterized by a rather wet oceanic temperate climate, with mild temperatures all year round at low altitudes. The distribution of rain is highly controlled by topography (the precipitation is 20 to 25% higher in the northern slopes than in the southern ones), being rainy at high altitudes and drier in coastal areas (Quartau, 2007).

In this work we studied the habitat preference of the Neuroptera fauna inhabiting North Atlantic Oceanic Islands, using S. Miguel Island (Azores) as case-study. The goal of this work was to research the dynamics and seasonality of the insular Neuroptera fauna, aiming to improve their use as local biological control agents, and also worldwide. We propose to achieve this by measuring the seasonal abundance and diversity of the Neuroptera fauna, identifying the habitat preferences of each species, possible dominance relationships between species and their ideal habitat, always in the context of biological control programs.

Materials and methods

Spatial and temporal sampling

Samples were performed in six different habitats: Endemic Forest (Laurissilva), Exotic Forest, Pastures, Agricultural Crops, Gardens and Orchards. These habitats were chosen according to their ecological significance (laurrisilva) or area occupied on the island (exotic forest, pastures), or also given their importance to most of the known Neuroptera species (agricultural crops, gardens, orchards). For each habitat we chose 3 different locations (n=3) to sample, comprising a total of 18 sampling sites. In each site, we traced 3 sinusoidal transepts 20 m long, adapted to the field conditions, each one sampled for 10 minutes. Apart from a spatial variable, we also had a temporal variable concerning the four seasons found in temperate climates. Thus, the sites were sampled on 3 different occasions (3 months in a row) per season, as follows: Autumn (September; October, November); Winter (December, January, February); Spring (March, April, May); Summer (June, July, August). Samplings began September, 2010 and ended in August, 2011.

All sites were initially geo-referenced and its higher altitude noted down.

Sampling procedures

Captures were made by suction with an entomological vacuum device and through direct prospection in the vegetation. After the captures, the insects were taken to the laboratory for identification. The adult stage was frozen and afterwards identified under a binocular microscope (Leica®). Immature stages were reared until adulthood on a substitute diet of *Ephestia kuehniella* Zeller eggs, sterilized with UV radiation, for posterior identification.

Data treatment

Neuroptera abundance (N) and the specific richness (S) were calculated for each site and sampling occasion, and for the overall habitat analysis. Biological abundance data were $\sqrt{(x + 0.5)}$ transformed for all factorial analysis, according to Zar (1996) specifications. For the overall habitat analysis a one-way ANOVA, with habitat as the factor, followed by a Tukey comparison test was used to analyze the data (JMP IN®; Sall & Lehman, 1996). For the families and species analyses, we used a two-way ANOVA, with habitat and season as factors, followed by a Tukey comparison test, to find possible effects of different habitats and/or seasons, and possible interactions between the factors. Interpretation of data was based on Zar (1996).

We computed the species richness and relative abundance of each habitat, using several well-know diversity indices: Margalef′s index (I_M) characterizes the approximate faunistic richness (Eq. 1); Shannon´s diversity index (H´) measures the relative heterogeneity of populations (Eq. 2) and ranges from 0 to Log S (Canard et al., 2010), being greater in stable ecosystems; Shannon´s evenness index (E), ranging from 0 to 1 with one representing the situation in which all species are equally abundant (Eq. 3) (Magurran, 1991); and the Simpson´s dominance index (D) which gives the probability that any two individuals, pick at random, belong to the same species. To convert this probability into a measure of diversity (Eq. 4), we used the complement of the Simpson´s index (1-D), which ranges from 0 (low diversity) to almost 1 (1 - 1/S) (Krebs, 1999);

$$I_M = \frac{(S-1)}{\log N} \quad \text{[Eq.1]}$$

$$H' = -\sum pi * \log pi \quad \text{[Eq.2]}$$

$$E = \frac{H'}{\log N} \quad \text{[Eq.3]}$$

$$1 - D = 1 - \sum pi^2 \quad \text{[Eq. 4]}$$

where, S is the species richness, N the total number of individuals in the sample and *pi* is the proportion of species *i* in the community.

Results

During the research a total of 244 insects were captured between adults, larvae and eggs, belonging to six species. Seven species of Neuroptera are given to the Azores archipelago, but the endemic species *H. azoricus* was not found during our sampling.

Habitat´s biodiversity

Average abundance (F = 1.150; df = 17; P <0.3872) and average specific richness (F = 0.148; df = 17; P <0.9768) of the global Neuroptera fauna, did not differ significantly among habitats (Table 1). This is mostly due to the great disparities found in different locations (replicates) within the same habitat, resulting in a high standard deviation of the mean.

It is noteworthy that the Crops, being a temporary habitat, had a reduced number of samples when compared to the other habitats, since it was not always available along the year, especially in winter time. Even so, it comes in third concerning the average abundance found in all habitats, and it is one of the two habitats (along with the Pastures), with a higher average specific richness.

Table 1. Average abundance (N) and average specific richness (S) per habitat (n=3). Different letters report significant differences between habitats (P<0.05).

Habitat	**N ($\bar{X}$± SD)**	**S ($\bar{X}$ ± SD)**
Laurissilva	3.00 ± 1.732 **a**	1.67 ± 1.202 **a**
Exotic Forest	6.33 ± 2.333 **a**	1.333 ± 0.333 **a**
Pastures	3.67 ± 0.882 **a**	2.00 ± 0.577 **a**
Crops	8.67 ± 4.807 **a**	2.00 ± 0.577 **a**
Gardens	17.67 ± 10.138 **a**	1.67 ± 0.677 **a**
Orchards	42.00 ± 32.005 **a**	2.00 ± 0.577 **a**

The biodiversity indices (Table 2) revealed that the Laurissilva habitat had the second greater faunistic richness (I_M = 1.37), displaying the higher heterogeneity (H′= 1.21) and evenness (E = 0.88). On the other hand, it was in this habitat that the smallest number of specimens was captured. The Pastures showed the highest faunistic richness (I_M = 1.67) but displayed a smaller heterogeneity when compared to Laurissilva forest, mostly due to a greater dominance (1-D = 0.56) and a smaller evenness (E = 0.72), indicating a strong representation of one species.

Table 2. Biodiversity indices calculated for the six habitats studied.

Index	Laurissilva	Exotic Forest	Pastures	Crops	Gardens	Orchards
Margalef´s (I_M)	1.37	0.34	1.67	0.61	0.50	0.41
Shannon´s Diversity (H´)	1.21	0.44	1.16	0.86	0.19	0.36
Shannon´s Evenness (E)	0.88	0.63	0.72	0.78	0.17	0.32
Simpson´s Dominance (1-D)	0.67	0.27	0.56	0.52	0.07	0.16
Number of specimens (N)	**9**	**19**	**11**	**26**	**53**	**126**
Species richness (S)	**4**	**2**	**5**	**3**	**3**	**3**

The Crops had the third highest faunistic richness and heterogeneity and the second best evenness. This habitat seems to be intermediate in terms of biodiversity, between the Laurissilva/Pastures and the Exotic Forest. The Exotic Forest was in fact the habitat with the smaller faunistic richness (I_M = 0.34), with just two species present; furthermore this habitat also presents a relatively low evenness (E = 0.63), making this one of the habitats with the poorest biodiversity. Gardens and Orchards are the habitats with lower heterogeneity, greatest dominance and lower evenness.

Family analysis

One of the surveyed habitats (the Crops), was removed from the factorial analysis, due to its seasonal character that made it impossible to sample every month.

The analysis of the two neuropteran families present in the Azores revealed that the Chrysopidae are more abundant than the Hemerobiidae, in all seasons (Fig.1) except in the spring, when the mean abundance of both families is smaller, but with a minor increase in the hemerobiids in relation to chrysopids.

A closer look to the Hemerobiidae results, show a permanent relatively low abundance. The greatest abundance of hemerobiids is found in the autumn (Fig 1), and the smallest in the spring. Concerning the habitat (Fig. 2), the Exotic Forest is the more relevant to this family and the less suitable are the Gardens. Nonetheless, there are no significant differences in the abundance of hemerobiids between seasons, habitat, or an interaction between the two factors (F = 1.483; df = 178; P <0.0981).

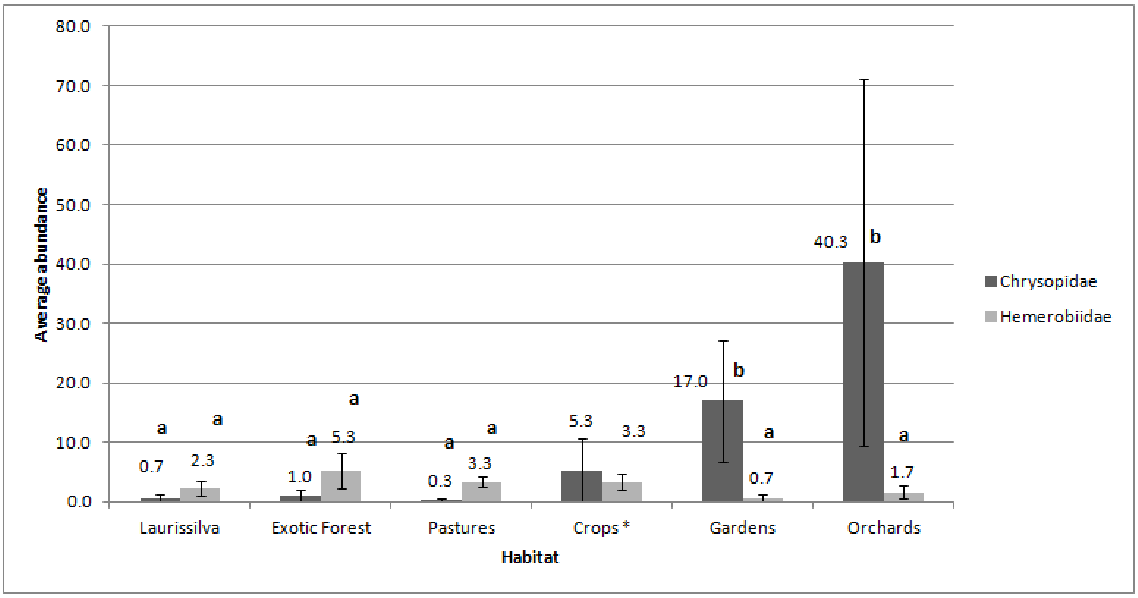

Fig 2. Average abundance (± SE) of each family in each habitat. Different letters report significant differences between habitats for the same family (P<0.05). * Excluded from the analysis due to the lack of temporal replicates.

The Chrysopidae, on the other hand, show significant differences between seasons (F = 3.319; df = 178; P <0.0000), with the highest abundance in autumn, a result that is significantly different (F = 3.132; df = 12; P <0.0273) from the abundance found in spring, but equal to the other seasons. Chrysopids' abundance also displays significant differences between habitats (F = 9.371; df = 4; P < 0.0000), recording greater abundances in Orchards and Gardens.

Species Analysis

We excluded from the species analysis the two species considered to be rare (with less than 3 specimens), *H. stigma* and *W. subnebulosos*. These species were registered only one and two times respectively.

Ch. agilis had a strong preference for Gardens and Orchards (Table 3), with an average abundance significantly higher (F = 9.292; df = 4; P <0.0000) than the one found in other habitats. In fact it is absent from Exotic Forests and Crops and its presence in Laurissilva and Pastures seems to be accidental, since it was registered only once in each habitat. This is even more likely for the Laurissilva habitat, since the specimen was found in a location at an altitude of 710 m, on a windy day of November. *Ch. agilis* is also affected by the Season. Its greatest abundance was found in Autumn, decreased in Winter and reached its lowest levels in Spring, rising again in the Summer (Table 4). Nonetheless, there are significant differences only in Autumn when compared to Spring (F = 2.985; df = 3; P < 0.0330).

Table 3. Species average abundance ($\overline{X} \pm SE$) in each habitat. Different letters report significant differences between habitat ($P<0.05$).* Excluded from the analysis due to the lack of temporal replicates.

Habitat	***Ch. agilis***	***Ch. lucasina***	***M.angulatus***	***H.humulinus***
Laurissilva	0.33±0.33 **a**	0.33±0.33 **a**	1.00±1.00 **ab**	1.33±0.88 **ab**
Exotic Forest	0.00 **a**	1.00±1.00 **a**	0.00 **a**	5.33±2.96 **b**
Pastures	0.33±0.33 **a**	0.00 **a**	2.33±1.45 **b**	0.33±0.33 **a**
Crops *	0.00	5.33±5.33	2.67±1.20	0.67±0.33
Gardens	17±10.21 **b**	0.00 **a**	0.00 **a**	0.33±0.33 **a**
Orchards	38.33±28.83 **b**	2.00±2.00 **a**	0.00 **a**	1.67±0.00 **ab**

Ch. lucasina, on the other hand, has a greater abundance in the Crops, being absent from Gardens and Pastures. A small number of specimens were found in Orchards and three specimens were caught in Exotic Forests in October. As in the case of *Ch. agilis*, the Laurissilva specimen was caught at an altitude of 710 m, but in a clear day of August. This species shows no significant differences between habitats ($F = 2.201$; $df = 4$; $P < 0.0713$), probably because its greater abundance was registered in Crops and this habitat was excluded from the factorial analysis. It is worth noting that the 16 specimens caught in the Crops all came from the same field, between three possible; the same applies to the 6 specimens captured in the Orchards. This species shows no significant differences between seasons ($F = 0.620$, $df = 3$, $P < 0.6028$). Even so its seasonal pattern resembles the ones found for *Ch. agilis* (Table 4).

Table 4. Species average abundance ($\bar{X}$ ± SE) by season. Different letters report significant differences between seasons (P<0.05).

Season	*Ch. agilis*	*Ch. lucasina*	*M. angulatus*	*H. humulinus*
Autumm	28.67±9.39 **a**	1.67±0.67 **a**	2.00±1.00 **a**	3.33±0.88 **a**
Winter	11.00±5.13 **ab**	0.67±0.67 **a**	1.00±0.58 **a**	1.33±0.33 **a**
Spring	1.33±0.33 **b**	0.33±0.33 **a**	0.00 **a**	2.00±0.58 **a**
Summer	15.00±7.23 **ab**	0.67±0.67 **a**	0.33±0.33 **a**	2.33±1.86 **a**

M. angulatus shows a greater abundance in Pastures and Crops, but since Crops were excluded from the analysis, the only significant difference found for this species, between habitats, was in Pastures (F = 4.256, df = 4, P <0.0027) compared to Gardens and Orchards, where it is absent. The season alone does not affect significantly the abundance of *M. angulatus* (F = 2.398, df = 3, P < 0.0701), but it interacts with the Habitat to produce a significantly greater abundance in the Pastures, in Autumn (F = 4.011; df =12, P <0.000). This species follows the same seasonal patterns of the chrysopids' species.

H. humulinus revealed a preference for Exotic Forests. Its abundance in this habitat is significantly higher (F = 3.831, df = 4, P < 0.0053) than the one found in Pastures and Gardens, but it is not significantly different between seasons (F = 0.645, df = 3, P <0.5873), displaying the same seasonal patterns already noticed for the other species.

Discussion

Habitat´s Biodiversity

The habitats studied did not show significant differences in terms of their relative abundance and species richness, mostly due to the heterogeneity of the results obtained (Table 1). Furthermore the analysis of the global neuropteran fauna did not allow detecting any subtle differences between habitats, at the family or species level. Nevertheless, it was possible to characterize each habitat through the diversity indices (Table 2). These indices reveal that Laurissilva is the habitat with the greatest diversity, but smaller species abundance; Orchards and Gardens present the lowest diversity and greatest species abundance. This is in agreement with the literature because most lacewing species, green or brown, are arboreal or live on woody shrubs (Duelli, 2001). Few species develop on field crops, due to its temporary character that requires an adaptation to temporary and patchy environments; but the species that do, can be extremely abundant and widespread (Duelli, 2001). This can explain why the man-transformed habitats (Crops, Orchards and Gardens) had the lowest species richness but the greatest abundance of those species.

Seasonal patterns

The analysis of the seasonal patterns revealed a similarity for both families, with a greatest abundance in Autumn, decreasing to about half in the Winter, reaching its lowest levels in the Spring, and starting to raise up again in the Summer.

Previous studies found that in general the mass flight period of chrysopids covers June-August under the temperate climate of Europe, while that of hemerobiids occurs later, from mid-July to late September (Szentkirályi, 1984; 1986 *fide* Szentkirályi, 2001a). These patterns are related to the aphid's abundance in temperate climate regimes, which displays two growing seasons: the first occurs between May and mid-July and the second from early September to late October. According to this, the general activity patterns of chrysopids are synchronized with the first peak of aphids and the hemerobiids with the second peak (Szentkirályi, 2001a). However, these patterns can vary greatly with local variations of predator-prey synchrony (Szentkirályi, 2001a) and as such with habitat (Szentkirályi, 2001b; 2001c). In the Azores, a two-years study that monitored, among other traits, the abundance of aphids and coccids from May to August in a natural habitat, has shown that aphids were more abundant than coccids and tended to appear and reach their maximum earlier in the season (May, June and July), whereas coccids reached their peak much later in August (Borges et al., 2011).

The variation of the monthly abundance of the Neuroptera families (figure 3), shows that the Azorean populations' peaks, occurred later than expected. The first 4 months of sampling occurred during 2010, a year that was characterized by a weakening of the Azores anticyclone, which resulted in a significant increase in the precipitation, when compared to the reference values. This situation continued from January to May (IM, 2010a), and in June the Azores anticyclone returned, but occasionally some cloudiness and precipitation, persisted (IM, 2010b). July was a hot and dry month, with values of precipitation below the normal average (IM, 2010c), and August had another weakening of the Azores anticyclone. Under these conditions the amounts of precipitation were significantly higher than the reference values, but air temperatures were above normal by about 1°C (IM, 2010d). In September, at the beginning of our sampling season, the Azores anticyclone had a greater activity, causing amounts of rainfall below the reference values and higher air temperatures (IM, 2010e). These abnormal climate conditions may help to explain the delay in the neuropteran peaks, verified in figure 3. We can see that the first peak of chrysopids was in September and of the hemerobiids in November. As expected according to Szentkirályi (2001a) results, the chrysopids' peak happened before that of the hemerobiids, but the months where they occur are not in agreement with this author findings. The reason may have been the increase in the precipitation verified in the archipelago, in the months prior to the neuropterans peaks.

A second smaller peak occurred in July 2011 for both families. This month is more in agreement with Szentkirályi (2001a) results, maybe due to a hotter and drier summer verified this year (IM, 2011) and a synchronization with the expected peak of aphids abundance (Borges et al., 2011).

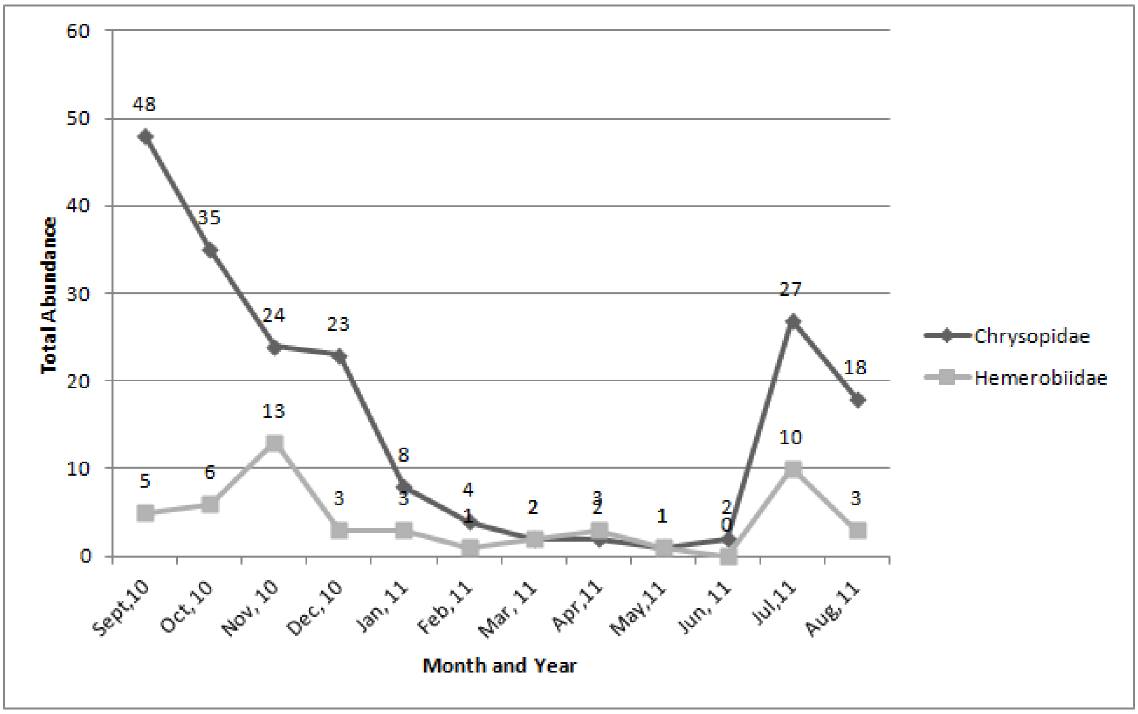

Fig 3. Monthly abundance of chrysopids and hemerobiids.

Spatial patterns

According to our results, the habitat preference of each family is the opposite of one another. The hemerobiids have a greater abundance in Laurissilva, Exotic Forest and Pastures, while the chrysopids are dominant in Crops, Gardens and Orchards. Although there is a significant amount of literature in neuropteran assemblages in different habitats, especially in agricultural fields (see Szentkirályi, 2001b; 2001c), it is quiet difficult to establish comparisons with our results, since the Azorean habitats are rather different from those found in the literature. For instance, the Orchards usually studied in continental areas are intensive monocultures of fruit trees, while in small oceanic islands like the Azores, they are small fields with a mixture of different fruit trees, delimited by vegetation shelters; the Laurisilva is a forest endemic to the Macaronesian region while the Exotic Forest is constituted by a mixture of invasive, endemic and ornamental plants.

Unlike the Hemerobiidae family, the Azorean Chrysopidae have been studied over the past two decades, and those studies found that *Ch. lucasina* used to be the dominant species in the archipelago (Thierry et al., 2011) and had a higher reproductive ability (Ventura, 2003). They also revealed that the two species share the same habitats, mainly corn fields and orchards infested with aphids (Ventura et al., 2007; Thierry et al., 2011). Recent studies detected a shift in the habitat/prey choice and relative abundance of both species in Flores (Ventura et al., 2008), later on confirmed also in the island of S. Miguel (personal observations). In these surveys the insects were mainly found in ornamental flowery plants infested with *Pseudococcus longispinus*, the dominant species being *Ch. agilis,* whereas *Ch. lucasina* was very hard to find (Mendes & Ventura, 2010).

The results of the present work seem to confirm the latter studies on these species. First of all, we confirmed a change in the habitat preferences; *Ch. agilis* continues to be abundant in orchards but is increasingly abundant in gardens, and *Ch. lucasina* is now best found in crops. Also they are nearly not found in simpatry anymore. The orchards remain one of the main habitats for *Ch. agilis* and the gardens are confirmed as an important habitat corroborating the results of Mendes and Ventura in 2010. Moreover, we registered a significant change in the abundance of each species, with 168 specimens of *Ch. agilis* against 26 of *Ch. lucasina*. Not only this means a shift in the dominance relationship between the two species, but it also means that *Ch. lucasina* records are now very low when compared to previous data (Ventura, 2003; Ventura et al., 2007).

Some hypotheses can be put forward to try to explain these results, one of them being the existence of an interspecific competition. This hypothesis is based on the fact that we began to notice a change in the corn fields, in terms of food quality for these auxiliary insects. During this work, and in former experimental surveys, we noticed that the corn fields were much cleaner both from pests and pollen, probably indicating that new varieties started to be used by the farmers. Thus a reduction in the potential prey and sources of pollen in the corn, could have forced the chrysopids to abandon this habitat and search for a more suitable one. The orchards were already a key habitat, especially for *Ch. agilis*, and the values of abundance for this species found in this habitat (Table 3), confirms it once again. Now, if *Ch. agilis* has a greater competitive ability when compared to *Ch. lucasina*, it would prevent the latter to colonize the most favorable habitats, and would push it to more temporal and patchy habitats, such as the crops.

An apparent higher competitive ability of *Ch. agilis* may be the result of a different food specificity of each species. *Ch. lucasina* is the most important species in field crops in southern Europe (Malet et al., 1994) and in most Mediterranean countries (Duelli, 2001), where it is found preying on aphids (e.g. Malet et al., 1994; Maisonneuve, 2001). *Ch. agilis*, on the other hand, also preys on coccids (Mendes & Ventura, 2010). These results, together with the smaller abundance found in this survey, may indicate that *Ch. lucasina* is more aphidiphagous than *Ch. agilis*, the latter appearing to be a more generalist predator, which would give it an advantage in the exploitation of orchards and gardens. These habitats have a more permanent character and have protective hedges that can be used as overwintering sites; these two factors combined could help *Ch. agilis* to maintain higher population levels. On the other hand the highly temporal crops without hedges would not allow the same for *Ch. lucasina*, which could explain their reduced population levels.

It should be noted that, although we have not sampled maize fields in a systematic manner due to its temporary character, we have sampled sweet corn plots included in the crop fields' habitat. In September, one of the agricultural fields consisted entirely of corn and from May to August, two crop fields sampled contained more or less extensive portions of corn; however, never a green lacewing of either species was found there. In addition, the specimens of *Ch. lucasina* caught in crops were all from the same field located in Malaca, a field that contained plots of corn in June, July and August, but the specimens were caught in October, when the field was growing tomatoes, parsley, turnip, sweet potato and cabbage.

As to the global Neuroptera fauna, and since this is the first work made in these specific habitats, we will analyze the neuropteran assemblages of each habitat to establish a frame of reference for future research, with a special focus in the agricultural and ornamental habitats (crops, orchards and gardens).

Table 5. Ordinate data and relative frequency of each species (%) in each habitat.

Laurissilva			Exotic Forest			Pastures		
Species	**n**	**%**	**Species**	**n**	**%**	**Species**	**n**	**%**
H. humulinus	4	44.44	*H. humulinus*	16	84.21	*M. angulatus*	7	63.64
M. angulatus	3	33.33	*Ch. lucasina*	3	15.79	*Ch. agilis*	1	9.09
Ch. agilis	1	11.11				*H. humulinus*	1	9.09
Ch. lucasina	1	11.11				*H. sitgma*	1	9.09
						W. subnebulosos	1	9.09
Crops			**Gardens**			**Orchards**		
Species	**n**	**%**	**Species**	**n**	**%**	**Species**	**n**	**%**
Ch. lucasina	16	61.54	*Ch. agilis*	51	96.23	*Ch. agilis*	115	91.27
M. angulatus	8	30.77	*H. humulinus*	1	1.89	*Ch. lucasina*	6	4.76
H. humulinus	2	7.69	*W. subnebulosos*	1	1.89	*H. humulinus*	5	3.97

Table 5 displays the neuropteran assemblages of each habitat and its relative frequency per species. It is clear that, besides *Ch. agilis*, all other neuropteran species have low populations levels, making this species a valuable biological control agent to be used in Gardens and Orchards. But we can identify other species with potential to be used as biological control agent. *H. humulinus* is the only species present in all habitats, which makes it a more eurytopic species. This species is present in the agricultural systems (Crops, Orchards and Gardens) in reduced numbers, but it shows greater abundances in Laurissilva and Exotic Forest (arboreal habitats). *H. humulinus* is known to develop on deciduous trees and shrubs and is found in open woodland and hedges, being a common predator of aphids and psyllids, especially in orchards and parks (Stelzl & Devetak, 1999). It is possible that the use of more attractive vegetation for this species, for instance the hedges, would increase its abundance in agricultural fields. *Ch. lucasina* and *M. angulatus* show some potential to be used in Crops. *M. angulatus* is mainly found on low vegetation such as grass and herbs, but can also move into shrubs and deciduous trees (Stelzl & Devetak, 1999). The use of these two species as biological control agents in the Azorean crops requires further research on their biological and ecological traits. It is essential to understand how to increase their numbers in the fields and if they can be used together or, on the contrary, there is the possibility to engage in interspecific competition or intraguild predation, which would then reduce their effect.

Overall we concluded that there are four species in the Azores archipelago with potential to be effective biological control agents: *Ch. agilis*; *Ch. lucasina*; *H. humulinus* and *M. angulatus*. However, for this to be possible, further studies are needed. These studies should focus in the conservation and augmentation of lacewings in the target habitats, on the compatibility between the different species found in each habitat and in assessing the predator-prey synchrony.

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Chapter 3

FINAL REMARKS

This work, though it did not completely clear out the seasonal patterns of the neuropteran populations and their synchrony with its prey, is a step forward in the clarification of the lacewings' role in the Azorean agricultural ecosystems, and allows to establish a framework for future research.

We found that four of the Neuropteran species given to the Azores often occur in agricultural ecosystems, abundant enough to become effective biological control agents. *Ch. agilis* is mostly found in gardens and orchards, *Ch lucasina* and *M. angulatus* are found in crops, and *H. humulinus* is present in all habitats. However, to be possible to effectively use these species as biological control agents, further research is needed. The studies should address the biology and ecology of each species, especially in relation to the hemerobiids that have been less studied. It is also essential to study the relationship between different species to be use in the same habitat, to ensure that its effect is complementary, or whether they might incur in competition or intraguild predation (Snyder & Ives, 2009). In addition, it is essential to find out how to increase the abundance of these populations in the wild. For instance, the fact that some species (*H. humulinus* and *M. angulatus)* appear with a certain frequency in natural (Laurissilva) or semi-natural (Exotic Flowers) habitats may indicate that the shrub vegetation found there can be used in agricultural ecosystems to attract these species.

The temporary character of one habitat, the Crops, made it difficult to analyze within the frame of this work, therefore future studies should undergo a more systematic sampling of this habitat in the months in which it is available.

Perhaps most importantly, is to make a long-term survey to establish the seasonality of the lacewing populations; since this study took place over just one year, the existence of a regular periodicity or fluctuation patterns must be confirmed over a longer time series (Szentkirályi, 2001a).

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Annexes

HABITATS CHARACTERIZATION

Laurissilva

Code: #1.1

Location: Encosta Sul Lagoa do Fogo

Coordinates: 661290 N and 4185128 W

Altitude: 710 m

Main Vegetation: Typical laurrisilva forest (e.g., *Erica scoparia azorica; Ilex perado*; *Culcita macrocarpa*; *Viburnum treleasei; Juniperus brevifolia; Leontodon filii; Leontodon rigens; Tolpis succulenta; Myrsine retusa; Laurus azorica; Caluna vulgaris; Hedera azorica; Piconia azorica; Vaccinium cylindraceum;* etc.) some invasive or native (e.g. *Duchesnia indica; Leycesteria formosa; Erigeron karvinskianus; Cryptomeria japonica; Hedychium gardnerianum,* etc.).

Code: #1.2

Location: Parque de Endémicas da Tronqueira

Coordinates: 661290 N and4185128 W

Altitude: 586 m

Main Vegetation: Typical laurrisilva forest (e.g., *Erica scoparia azorica; Frangula azorica; Hedera azorica; Piconia azorica; Prunus azorica; Tolpis azorica; Vaccinium cylindraceum; Persea indica, Viburnum treleasei; Juniperus brevifolia;* Ilex perado; *Leontodon filii ;Laurus azorica; Myrsine retusa; Myrica faya; Caluna vulgaris;* etc.) some invasive or native (e.g. *Duchesnia indica; Woodwardia radicans; LeycesteriafFormosa; Erigeron karvinskianus; Gunnera tinctoria; Cryptomeria japónica; Hedychium gardnerianum,* etc.).

Code: #1.3

Location: Lombadas

Coordinates: 635674 N and 4182121 O

Altitude: 572 m

Main Vegetation: Typical laurrisilva forest (e.g., *Viburnum treleasei; Juniperus brevifolia; Leontodon filii; Leontodon iegens; Tolpis succulenta; Ilex perado*; *Myrsine retusa; Rubus ulmifolius; Laurus azorica; Erica scoparia azorica; Hedera azorica; Piconia azorica; Vaccinium cylindraceum,* etc.) some invasive or native (e.g. *Caluna vulgaris; Cryptomeria japónica; Hedychium gardnerianum; Duchsenia indica; Leycesteria formosa; Erigeron karvinskianus; Ulex europaeus; Cyathea cooperi;* etc.).

Exotic Forest

Code: #2.1

Location: Estrada Velha da Ribeira Grande

Coordinates: 624572 N and 4182150 W

Altitude: 216 m

Main Vegetation: *Lantana camara; Persea indica; Laurus azorica; Phytolacca americana; Conyza canadensis; Erigeron karvinskianus; Ageratina adenophora; Solanum mauritianum; Acacia melanoxylon; Eucalyptus globulus; Hedychium gardnerianum; Pittosporum undulatum;* etc.

Code: #2.2

Location: Pinhal da Paz

Coordinates: 619891 N and 4183000 W

Altitude: 276 m

Main Vegetation: *Myrica faya; Camellia japonica; Ginkgo biloba; Pinus pinaster; Platanus sp.; Persea indica; Laurus azorica; Ligustrum henry; Conyza canadensis; Erigeron karvinskianus; Ageratina adenophora; Solanum mauritianum; Acacia* *melanoxylon;; Eucalyptus globulus; Hedychium gardnerianum; Pittosporum undulatum; Tradescantia fluminensis, Lantana camara, Schinus terebinthifolius*, etc.

Code: #2.3

Location: Mata da Abelheira

Coordinates: 620266 N and 4180943 W

Altitude: 135 m

Main Vegetation: *Persea indica; Laurus azorica; Phytolacca americana; Conyza canadensis; Ageratina adenophora; Solanum mauritianum; Acacia melanoxylon; Eucalyptus globulus; Hedychium gardnerianum; Pittosporum undulatum; Tradescantia fluminensis, Lantana camara*, *Rubus ulmifolius, Zantedeschia aethiopica*; *Eugenia myrtifolia*; etc.

Pastures

Code: #3.1

Location: Cerrado dos Bezerros

Coordinates: 644150 N and 4178645 W

Altitude: 476 m

Main Vegetation: Grass (e.g. *Ranunculus trilobus; Rumex crispus; Lolium multiflorum; Bellis perennis; Potentilla angelica; Trifolium glomeratum*) and edges made of *Ilex perado; Laurus azorica; Hydrangea macrophylla, Rubus ulmifolius,* etc.

Code: #3.2

Location: Chã da Macela

Coordinates: 628459 N and 4180078 W

Altitude: 236 m

Main Vegetation: Grass (e.g. *Cyperus esculentus; Rumex crispus; Lolium multiflorum; Potentilla angelica; Partulaca oleracea; Trifolium glomeratum; Amochareis radicata;*

Ranunculus trilobus) and edges made of *Cryptomeria japonica; Pittosporum undulatum; Hedychium gardnerianum; Hydrangea macrophylla, Rubus ulmifolius, Sambucus nigra,* etc.

Code: #3.3

Location: Relva

Coordinates: 612387 N and 4179768 W

Altitude: 140 m

Main Vegetation: Grass (e.g. *Hypochaeris radicata; Rumex crispus; Lolium multiflorum; Ranunculus trilobus; Cyperus esculentus; Partulaca oleracea*) and edges made of *Arundo donax, Hibiscus rosa-sinensis; Rubus ulmifolius, Sambucus nigra,* etc.

Crops

Code: #4.1

Location: Malaca

Coordinates: 625751 N and 4180305 W

Altitude: 130 m

Main Vegetation: Several crops, tomatoes; parsley; turnip; sweet potato; cabbage; watercress; cabbage; corn; onions; fava beans; spinach and French garlic, on a rotating basis.

Code: #4.2

Location: Cabouco

Coordinates: 626735 N and 4180692 W

Altitude: 183 m

Main Vegetation: Several crops, green beans, French garlic, turnip, lettuce, cilantro, arugula, cabbage, parsley, cabbage, potatoes, coriander and cress, on a rotating basis.

Code: #4.3

Location: Cabo da Vila

Coordinates: 627041 N and 4178144 W

Altitude: 94 m

Main Vegetation: Several crops, corn, garlic French; cabbage, potatoes, onions and squash in a rotating system.

Gardens

Code: #5.1

Location: Jardim da Universidade

Coordinates: 617720 N and 4178368 W

Altitude: 40 m

Main Vegetation: Several ornamental plants: *Robinia pseudoacacia; Pittosporum undulatum; Camellia japonica; Azalea indica; Castanospermum australe; Hibiscus rosa-sinensis; Phoenix reclinata; Agapanthus africanus; Rhododendro indicum; Ochna serrulata; Phyllostachys aurea,* etc.

Code: #5.2

Location: Jardim António Borges

Coordinates: 616725 N and 4178122 W

Altitude: 28 m

Main Vegetation: Several ornamental plants: *Agapantus africanus; Araucaria heterophylla; Azalea indica; Camellia japonica; Eugenia myrtifolia; Ginkgo biloba; Hibisco rosa-sinensis; Metrosideros excelsa; Phoenix reclinata; Phyllostachys virides ; Phyllostachys aurea; Phyllostachys bambusoides; Robinia pseudoacacia; Rhododendro indicum; Washingtonia robusta; Ochna serrulata; Podocarpus* sp.; *Syzygium jambos; Callistemon citrinus;* etc.

Code: #5.3

Location: Miradouro Ponta da Madrugada

Coordinates: 663175 N and 4185086 W

Altitude: 308 m

Main Vegetation: Several ornamental flowering plants:

Orchards

Code: #6.1

Location: Rabo de Peixe

Coordinates: 625362 N and 4184972 W

Altitude: 101 m

Main Vegetation: Fruit trees (e.g. avocado trees; *Psidium littorale; Citrus x sinensis; Citrus reticulata; Citrus x limon; Psidium guajava; Anona coriasea; Prunus persica; Prunus japonica*) ans hedges (e.g. *Banksia integrifolia; Myrica faya; Pittosporum undulatum; Metrosideros excelsa; Elaeagnus umbellate*)

Code: #6.2

Location: Lagoa

Coordinates: 625633 N and 4179753 W

Altitude: 102 m

Main Vegetation: Fruit trees (e.g. avocado trees; *Psidium littorale*; *Citrus x sinensis; Citrus reticulata; Citrus x limon*; *Psidium guajava; Anona coriasea; Prunus persica*; *Mangifera indica; Juglans regia; Castanea sativa; Prunus japonica)* and hedges *(*e.g. *Banksia integrifolia; Myrica faya; Pittosporum undulatum*).

Code: #6.3

Location: Fajã de Baixo

Coordinates: 619911 N and 4180133 W

Altitude: 68 m

Main Vegetation: Fruit trees (e.g. avocado trees; *Psidium littorale; Citrus x sinensis; Citrus reticulata; Citrus x limon; Psidium guajava; Anona coriasea; Prunus persica; Prunus japonica; Mangifera indica)* and hedges *(e.g. Banksia integrifolia; Myrica faya; Pittosporum undulatum; hibiscus rosa-sinensis; Camelia japonica*).

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