CHAPTER 1 GENERAL INTRODUCTION

1.1 INTRODUCTION

One of the major problems facing ecologists today is the process of habitat fragmentation. The consequences of this phenomenon have been outlined by Shafer (1990) who states that fragmentation is the principle cause of biodiversity reduction and accelerated extinction rates on both a local and global scale. Although an increasingly worldwide problem, the effects of fragmentary disturbance is especially apparent in Mediterranean-type landscapes where the land has been extensively modified by both natural and anthropogenic disturbance regimes over the last few thousand years (Farina, 1998; Rundel, 1998).

In Portugal and the U.K., two types of disturbance effects are currently being observed. Firstly, extensive activities such as agriculture, fire and afforestation have reduced the remnants of primitive native forests to scattered patches (Blonden & Aronson, 1999). In recent history, land that was previously continuous forest has been transformed into a mosaic-like patchwork in which intensively cultivated areas are separated by variably sized tree stands, which are themselves exposed to different management regimes. The effects of reducing the size and quality of these ancient forests may have profound effects on plant and animal communities, and cause significant disruption to predator-prey relationships (Hunter, 1999). Secondly, with the ever-increasing need for timber, intensive forestry regimes have been implemented to cope with the demand. In Portugal, the widespread use of Eucalyptus plantations at the expense of natural mixed-species stands is probably having a significant, although largely unknown, impact on biodiversity. The disturbance effect in such systems will also be greatly enhanced by temporal factors such as succession.

Since the formation of the Forestry Commission in 1919, around 1 million hectares of forest have been planted in the United Kingdom (Forestry Commission, 1994). Accounting for approximately 11% of mainland Britain, the managed forest is a distinct land-use type generally found in the sub-montane zones of upland Scotland, England and Wales. Represented predominantly by coniferous plantations, around two thirds of the total woodland consists of Sitka spruce *Picea sitchensis* Bong. (Petty & Avery, 1990). As with Eucalyptus in Portugal, Sitka spruce can yield viable timber over a short period of time, and is successfully harvested from areas of relatively poor soil. Although conifer plantations may show greater diversity when compared to the original unproductive habitats (Moss, Taylor & Easterbee, 1979; Newton, 1986;

Ratcliffe 1986; Young, 1986) some argue that such plantations will favour forest species of lower conservation value at the expense of rare moorland species (Thompson, Stroud & Pienkowski, 1988). Although the second rotation of conifers is now underway in the United Kingdom, there are growing concerns as to the damaging effects that plantation forestry may have on soil quality. Clear-felling has long been documented to cause nutrient depletion (Anderson 1985), while conifers are linked to changes in decomposition rates (Butterfield, 1999), soil pH and podsolization (Gee & Stoner, 1988).

The preservation of community structure is inherently bound to the conservation of its biological diversity. To quote Myers (1986):

> *"If a keystone mutualist is eliminated as a result of human disturbance of forest ecosystems, the extinction of several other species will follow, inevitably. Still more to the point, these additional losses may, in certain circumstances, trigger a cascade of linked extinctions. Eventually a series of forest food webs can become unravelled, with shatter effects throughout their ecosystems"* (Myers 1986).

Realistically, the financial scope of most studies on disturbance effects cannot extend to the measurement of the diversity of all the species found within the entire community. Given that some disturbed ecosystems have been found to possess a higher degree of taxonomic richness compared to when they were first undisturbed (Moss, Taylor & Easterbee, 1979), such studies, according to Rapport *et al.* (1985), should aim to identify 'sensitive' species or assemblages that can be used as ecological indicators, responding to a variety of ecological stresses in the community.

Studies on the implications for biodiversity of landscape changes in Mediterranean areas are scarce and mostly restricted to vertebrates in agricultural areas (e.g. Farina, 1997; Preiss *et al.* 1997). Although most conservation efforts have aimed to study and preserve one or more vertebrate species (especially if they are of some economic importance), it is debatable as to whether vertebrates are indeed ideal indicators of overall habitat disturbance in a natural community as they are found in rather small numbers, have a long time span between generations and possess relatively large geographical ranges (Murphy & Wilcox, 1986). This lessens sampling efficiency, along with how quickly one can detect any response by the population to a given stress. In addition, such groups may be less responsive to local or selective habitat loss, a factor that may be of prime importance to other groups of ecological interest.

1.2 CHOOSING TERRESTRIAL ARTHROPODS AS INDICATOR GROUPS

Constituting between 79% and 90% of total global diversity (Pimm *et al.*, 1995), terrestrial arthropods play a significant role in virtually all ecosystems (Kim, 1993). Ideally suited to conservation studies, they are found in numerical abundance, and exploit a wide variety of microhabitats, showing functional niches at virtually all temporal and spatial scales. Possessing the role of pollinator, decomposer, predator, parasite and consumer, terrestrial arthropods have been shown to respond to changing environmental conditions under fragmentary distress (Kremen *et al.*, 1993). For a monitoring technique to be successful, one must be able to identify a terrestrial arthropod assemblage that is limited enough to enable rapid and quantitative assessments, and diverse enough to respond to a variety of anthropogenic disturbances. Recent studies have shown that when the aim is to maintain biodiversity, indicator *assemblages* are preferable to indicator *species*. Following the examination of the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures (HEP), Fry *et al.* (1986) found that using more species to classify a habitat type resulted in less error when predicting the presence of a target species. Indicator assemblages can also be used to monitor other forms of environmental change such as the invasion of pest species, eco-toxicological damage and climate change effects that will in essence, broaden the scope of many baseline studies (Kremen 1992, 1993; Block *et al.*, 1986). Brown (1991) lists the characteristics that are desirable in indicator groups (Table 1):

Table 1: Characteristics deemed desirable of indicator assemblages (Brown, 1991)

Usefulness	***Ease of Analysis***	***Group Characteristics***
Responsive to disturbance	Abundant	Taxonomically diverse
Correlated with other groups and resources	Easy to find	Ecologically diverse
Functionally important to ecosystem	Taxonomically well known	Relatively sedentary
Exhibits damped fluctuations	Easily identifiable/well studied	Endemic or
(No stochastic fluctuations)	Easy to obtain large, random samples	well differentiated

1.3 THE USE OF SPIDERS AS ECOLOGICAL INDICATORS

In the present work the target biological group that will be assessed as a potential biodiversity indicator will be Araneae (spiders). Spiders are found in abundant numbers and are well-known predators that exploit the majority of terrestrial ecosystems. They are found in particularly high numbers in areas of rich vegetation (Foelix, 1996), are generalist feeders and possess a wide array of behavioural adaptations for habitat utilisation and foraging (Wise, 1993). In Portugal, spiders are represented by a diverse range of species, many of which are not yet taxonomically described. Since the works of Bacelar (e.g. 1927a, b, 1928, 1933, 1935, 1936, 1940) and Machado (e.g. 1937, 1941, 1949) in the early 20th century, little attention has been paid to the arachnofauna of Portugal. Fortunately research in this Order has increased in the past decade or so, and at present the current number of species of spiders reported in Portugal stands at 750 (Alderweireldt & Bosmans, 2001; Bosmans, 1993; Cardoso, unpublished; Ferrandez, 1985, 1990, Telfer *et al.*, 2003), a figure that is thought to be a severe underestimation of the true checklist for this semi-tropical country. In the United Kingdom, the spider data and geographical mapping of fauna is very well founded, in part due to the amateur recording scheme set up and run by the British Arachnological Society. At present, the number of species recorded from mainland Britain is 645, with an additional 11 species found in the Channel Islands (Merrett & Murphy, 2000).

The vast majority of spiders can easily be collected using simple pitfall traps. According to the criteria as outlined in Table 1, the Order Araneae is a potentially good candidate for an indicator assemblage, fitting 11 of the 13 criteria as outlined by Brown (1991). Major advantages are found when working with this group. Firstly, classification to family, genus, species or even "morphospecies" level is relatively easy (especially if up-to-date taxonomic keys are available), and as a consequence, non-specialists can be trained quickly to collect and sort spiders (*sensu* Oliver & Beattie, 1993). Grouping in this way reduces taxonomic uncertainties, and allows quick and cheap ecological assessments. Secondly, spiders can be divided into guilds according to the method of how they capture prey (for example web builders, ground foragers and cryptic hunters) thus allowing the analysis of the assemblage composition and exploitation of habitat within the study area.

Unfortunately, spiders have remained outside the normal scope of mainstream conservation studies. Although the taxonomy of spiders has received particular attention in the past, little has been paid to the ecology of forest dwelling populations. This is surprising considering they are dominant predators of woodland arthropods, and play an important functional role in ecosystems. Being highly mobile and having a short life span, spiders could be used as an effective biological tool to assess the effect of disturbance regimes in forest ecosystems. As both microclimate and physical structure of the habitat are two major factors determining microhabitat selection in many invertebrates (e.g. Butterfield *et al.*, 1997; 1999, Samways, 1993), the effects of fragmentation and succession in different types of woodland could play a significant role on species richness and assemblage structure of spider communities.

This project aims to assess the main impacts of disturbance on spider distribution and diversity in a variety of land use types in both Portugal and in the United Kingdom. It is hoped the current work will contribute to a better understanding of the implications of implementing specific forest management practices for biodiversity, in particular in the largely humanized and fragmented landscapes of coastal Portugal.

1.4 OBJECTIVES

To explore the relationship between forested landscape composition and spider diversity in two distinct areas, firstly within two coastal watersheds (ca. 10,000 ha.) of Central-Western Portugal and secondly in Hamsterley Forest, England, U.K., it is intended to:

(i) *Describe the species richness and diversity of spider assemblages associated with the different types of forested areas (including Shrubland) in the study area.* Forested areas in the region include a few remnants of Oak and Pine forests, Shrubland (that is, an area of dry earth of low quality covered primarily with short trees and bushes), and patches of Eucalyptus plantations. Each of these land-use types will be characterized to assess their importance on spider diversity at a landscape scale;

(ii) *Evaluate the edge effect across a Eucalyptus-grassland ecotone.* Four replicate sites containing an area of Eucalyptus bordered next to grassland will be examined to see how epigeal species richness is affected across the boundary ecotone;

(iii) *Compare the effects of succession on ground-dwelling spiders diversity and assemblage structure between blocks of differently aged Sitka spruce plantations and Oak forests in Hamsterley Forest, England, U.K.* Different aged stands of Sitka spruce and Oak woodland will be assessed to determine the influence of vegetation density and canopy closure on the pattern of distribution and diversity of spiders.

(iv) *To examine and compare patterns of succession, or the effect of plantation forestry on habitat complexity and spider assemblage structure between Portugal and England.*

CHAPTER 2 STATISTICAL METHODS, CLASSIFICATION AND REFERENCE COLLECTION

2.1 NOMENCLATURE, REFERENCE COLLECTION AND GUILDS

To date, no key exists for the identification of Iberian species. Several publications helped to identify specimens to genus, however a heavy dependence was placed on a number of arachnologists such as Robert Bosmans (Belgium), Antonio Melic (Spain), Carmen Urones (Spain), J.A. Barrientos (Spain) and M. Fernandez (Spain) to confirm species identities. The following literature was also particularly helpful: Simone (1868-1881), Roberts (1985-1993), Locket & Millidge (1951-1953) and Heimer & Nentwig (1991). The reference material is deposited in the collections of Gillian Telfer, CEABN, Instituto Superior de Agronomia, Tapada da Ajuda, Lisbon, Portugal, Robert Bosmans, Laboratorium voor Ecologie, Ledeganckstraat 35, 9000 Gent, Belgium and Antonio Melic, Avenida Radio Juventud, 37, 50012 Zaragoza, Spain. Classification is as in Platnick (2003).

Spiders are generalist feeders that successfully live in most habitat niches. Although all spiders spin silk, not all build webs. The method by which silk is used can reflect differences in patterns of habitat utilization and foraging behaviour (Wise, 1993). Such groups, or foraging “guilds” are represented by a variety of web spinners, cursorial hunters, jumping spiders, trapdoor spiders and cryptic specialized hunters. Table 2 lists family representatives from each guild along with their mode of prey capture. The classification of spiders according to foraging guild, which can be an effective method of assessing assemblage composition, habitat exploitation and the role of competition in spider communities, will be used in the present work.

The four most commonly seen types of webs are orb, sheet, funnel and scattered, which are woven by families such as Araneidae, Linyphiidae and Agelenidae and Theridiidae respectively. Orb weavers spin webs that are, in principal, comprised of a supporting framework to which a central catching spiral is added. Some orb-weavers wait in the middle of the orb structure while others hide in retreats that are connected to the main web by a single signal line (Figure 1).

Figure 1: *Araneus diadematus* (Family: Araneidae) (a) adult and (b) adult on web

Irregular *scattered* webs, woven by members of the family Theridiidae are normally located around shrubs, trees or close to the ground. Once the web is built, the spiders move to a nearby retreat and await prey. Linyphiids build horizontal *sheet webs*, which can be modified to a hammock or flat sheets onto which they hang underneath and await the entanglement of prey in the upper network layer of the web (Figure 2a). *Funnel-web* spiders construct a funnel inside leaves or crevices, and capture insects that land on the outer margins of the web (Figure 2b).

Figure 2: (a) *Linyphia triangularis* (Family: Linyphiidae) and (b) *Agelena labyrinthica* (Family: Agelenidae)

Thomisids, often referred to as crab spiders, are examples of *ambushers* who do not require the presence of a web to collect prey, but wait for prey in leaves, on tree trunks and on flowers (Figure 3a). *Jumping spiders* on the other hand are extremely active diurnal hunters, and use remarkably developed binocular eyesight and saltatory skills to forage (Figure 3b). *Cursorial hunters* such as the Lycosidae (wolf spiders) are active diurnal ground hunters, the females of which are easily recognized in the field in the summertime carrying egg sacs attached to their abdomen (Figure 3c). Gnaphosids are nocturnal ground hunters and are generally dark, and unicoloured (Figure 3d). Clubionids normally spend the day in a silken retreat and hunt during the night. Primarily ground hunters, this family can also be found in higher vegetation and in trees. In Portugal there is evidence this group uses the nests of the Pine processionary moth for brood care (Branco *et al.*, unpublished). Finally, *trap-door* species, represented for example by the mygalomorphs Atypidae and Nemesiidae hunt from ground burrows, and use subterranean sheets or tubular shaped webs to capture prey.

Figure 3: (a) *Misumena vatia* (Family: Thomisidae); (b) *Salticus scenicus* (Family: Salticidae); (c) *Pardosa amentata* (Family: Lycosidae) and (d) *Zelotes* sp. (Family: Gnaphosidae)

Table 2: Family representatives of spider foraging guilds

Guild	***Examples of Families represented***	***Foraging guild***
Diurnal running spiders	Lycosidae	Cursorial hunters
Nocturnal running spiders	Clubionidae, Gnaphosidae	Cursorial hunters
Jumping spiders	Salticidae	Jumping
Cryptic hunters (crab)	Thomisidae	Cryptic ambushers
Funnel web spiders	Agelenidae	Web-builders
Scattered line weavers	Theridiidae	Web-builders
Sheet web weavers	Linyphiidae	Web-builders
Orb weavers	Araneidae, Tetragnathidae, Uloboridae	Web-builders
Trap-door spiders	Atypidae, Nemesiidae	Hunt from subterranean burrows or use subterranean sheet or tubular shaped webs

2.2 STATISTICAL TESTS OF HYPOTHESES

For analyses of mean values the Levene's test of homogeneity was applied to each dataset, and the Kruskal-Wallis test was used in place of a one-way ANOVA to test significance when the variances were deemed to be unequal. Kruskal-Wallis is generally accepted to be the non-parametric equivalent of one-way ANOVA, and is based on the null hypothesis that all the samples derive from populations with the same median. Unlike the one-way ANOVA it does not make any assumption on the homogeneity of variances in the data or whether the data is of a normal distribution. Described as being a 'rank' test, Kruskal-Wallis converts raw data into ranks before the test is applied, thereby excluding any extreme data that would normally bias parametric test results. In doing so, this reduces the chance of type 1 error (that is, a false negative of a null hypothesis). The disadvantage of using Kruskal-Wallis is that although significance can be shown, no *post hoc* tests exist that can determine which group(s) give(s) the significant result. To compare mean rank values, significance can be identified by carrying out pair-wise Mann-Whitney U tests (Dytham, 2003).

In the present work, we will compare spider richness and assemblage structure between Shrub and Forest landscapes, across a Plantation-Grassland ecotone and along a successional gradient. Both α and β diversity will be calculated: that is, diversity within a particular ecosystem usually expressed as species richness (α diversity), and change in species diversity between ecosystems using similarity indices (β diversity).

2.3 ALPHA-DIVERSITY

2.3.1 SPECIES RICHNESS ESTIMATES

The accurate measurement of total species richness requires an unrealistic amount of sampling effort. The use of the number of observed species in a given sample will always be fraught with errors, and be linked to factors such as sampler bias, phenology and stochasticity. In order to compensate for this, and to give a more realistic measure of total species richness, we applied a variety of non–parametric species richness estimators to the observed data using the software programme EstimateS (Colwell, 1997). Accumulation curves were plotted showing cumulative species richness against number of samples to assess whether the curve approached an asymptote in richness values with increased sampling effort. Estimated richness was thereafter calculated by extrapolating the curve to an asymptote value as calculated for each level of sampling effort. One hundred randomizations of the samples were applied to remove any effect of sampling order bias. The following non-parametric estimators, which rely either on the abundance or incidence of rare species collected in each site, were applied to give an estimated value of species richness: *Chao 1* (Chao, 1984), *Chao 2* (Chao 1987), *ACE* (Chao *et al.*, 1993), *ICE* (Lee and Chao, 1994), *Jacknife 1* and *Bootstrap* (Burnham and Overton, 1978; Burnham and Overton, 1979; Heltsche and Forrester, 1983; Smith and van Belle, 1984). With the exception of the abundance-based *Chao 1* and *ACE*, all the aforementioned estimators use the incidence of rare species to produce an estimate. A brief description of each estimator follows:

Variables used in EstimateS:

S_x = the estimated species richness by estimator x,

S_{obs} = the number of species observed in the sample,

S_{comm} = number of "common" species in the sample, each represented by more than 10 individuals,

S_{rare} = number of "rare" species in the sample, each represented by 10 or fewer individuals,

$S_{comm} + S_{rare} = S_{obs}$

S_{frec} = number of frequent species, each found in more than 10 samples

$S_{inf\ r}$ = number of infrequent species, each found in 10 or fewer samples

$S_{frec} + S_{inf\ r} = S_{obs,}$

F_i = number of species represented by *i* specimens, F_i is number of singletons and F_2 is the number of doubletons,

Q_i = number of species that occur in exactly i subsamples, Q_1 is the number of uniques and Q_2 is the number of duplicates,

m = number of subsamples,

$m_{\inf r}$ = number of samples with at least one infrequent species,

f_i = number of samples containing 1 unique species,

p_i = proportion of samples that contain species *i*,

p_j = proportion of species j in total sample.

2.3.1.1 ABUNDANCE-BASED SPECIES RICHNESS ESTIMATORS

Chao 1 (Chao, 1984) is an abundance based estimator, based on F_1, (the number of singletons), and F_2 (number of doubletons). Using this estimator, the larger the number of singletons there are in a sample, for a given number of doubletons, the greater the difference will be between the observed and true species richness calculated for the assemblage sampled.

$$S_{Chao1} = S_{obs} + \frac{F_1^2}{2F_2},$$

variance:

$$\operatorname{var}(S_{Chao1}) = F_2\left[\frac{G^4}{4} + G^3 + \frac{G^2}{2}\right],$$

where:

$$G = \frac{F_1}{F_2}.$$

Abundance Coverage Estimator (ACE) (Colwell, 1997: modified from Chao & Lee, 1992; Chao *et al.*, 1993) is based on species with less than, or equal to, 10 individuals in the sample.

$$S_{ACE} = S_{comm} + \frac{S_{\inf r}}{C_{ACE}} + \frac{F_1}{C_{ACE}}\gamma_{ACE}^2,$$

where C_{ACE} is the sample abundance coverage estimator:

$$C_{ACE} = 1 - \frac{F_1}{N_{rare}},$$

and N_{rare} is the total number of incidences of infrequent species

$$N_{rare} = \sum_{i=1}^{10} iF_i,$$

γ^2_{ACE} is the coefficient of variation of F_i:

$$\gamma^2_{ACE} = \max\left\{ \frac{S_{rare}\sum_{i=1}^{10} i(i-1)F_i}{C_{ACE}(N_{rare})(N_{rare}-1)} - 1 \right\}.$$

2.3.1.2 INCIDENCE-BASED SPECIES RICHNESS ESTIMATORS

The *Chao 2* (Chao, 1987) estimator relies on Q_1 (the number of uniques, that is, species found only in one quadrat), and Q_2 (the number of duplicates, or species found in exactly two quadrats).

$$S_{Chao2} = S_{obs} + \frac{Q_1^2}{2Q_2},$$

variance:

$$\operatorname{var}(S_{Chao2}) = F_2\left[\frac{G^4}{4} + G^3 + \frac{G^2}{2}\right],$$

where:

$$G = \frac{Q_1}{Q_2}.$$

Incidence Coverage Estimator (ICE) (Colwell, 1997, modified from Lee & Chao, 1994) is based on species found in less than or equal to 10 sampling units.

$$S_{ICE} = S_{frec} + \frac{S_{\inf r}}{C_{ICE}} + \frac{Q_1}{C_{ICE}}\gamma^2_{ICE},$$

where C_{ICE} is the sample incidence coverage estimator

$$C_{ICE} = 1 - Q_1 / N_{\inf r},$$

where $N_{inf\,r}$ is the total number of incidences of infrequent species

$$N_{\inf r} = \sum_{i=1}^{10} iQ_i,$$

γ^2_{ICE} = estimated coefficient of variation of Q_i for infrequent species

$$\gamma_{ICE}^{2} = \max\left\{ \frac{S_{\inf r}}{C_{ICE}} \frac{m_{\inf r}}{(m_{\inf r} - 1)} \frac{\sum_{j=1}^{10} j(j-1)Q_j}{(N_{\inf r})^2} - 1 \right\}.$$

Jacknife 1 (Burnham & Overton, 1978; Burnham & Overton, 1979; Heltshe & Forrester, 1983): is based on the number of uniques in the sample, and also includes the number of quadrats sampled.

$$S_{JACK1} = S + \left(\frac{m-1}{m} \right) Q_1 ,$$

variance:

$$S_{JACK1} \pm t_{\alpha} \sqrt{\mathrm{var}(s)} ,$$

where t_{α} = Student's t value for n-1 degrees of freedom for the appropriate value of α (Krebs, 1989)

Let us define var(ŝ) = variance of var ŝ

$$\mathrm{var}(s) = \left(\frac{m-1}{m} \right) \left[\sum\nolimits_{j=1}^{s} (j^2 f_j) - \frac{k^2}{m} \right],$$

where j = 1, 2, 3..., s.

Bootstrap (Smith & van Belle, 1984): requires presence/absence data and is based on the proportion of quadrats containing each species sampled

$$B(S_{BOOT}) = S_{obs} + \sum_{i=1}^{S_{obs}} (1 - p_j)^n .$$

2.3.2 SPECIES DIVERSITY INDICES

In a given community, there are essentially two components to species diversity: (i) the number of species and (ii) the structure of the community itself, i.e. the relative abundance of individual species (Clapham, 1983). Reporting and comparing sites according to the simplest measure of diversity, that is, the number of species present, should be used with caution as it neither makes a distinction between habitual, transient, common and rare species nor heterogeneity or equitability between the numbers of each species. This is especially relevant when species have been obtained using pitfall trapping. Consequently this had led to the development of a variety of species abundance models, where natural variations in common, medium and rare species between different communities are categorized by simple mathematical descriptions (such as log-normal, gamma, broken-stick, log-series and geometric model). A review of the aforementioned models can be found in Magurran (1988). When dealing with "real data" however, sometimes the data can fit several models simultaneously (or indeed none at all), and goodness-of-fit methods can be of limited statistical power when working with communities of relatively low numbers of species of say, less than 100 species (Engen, 1978; Tokeshi, 1993).

The relationship between number of species and species abundance has been reviewed by many, and to date, no single index has been wholly embraced by the scientific community. Of the available indices, the following have been previously applied in diversity studies of arachnids in forested landscapes and were considered suitable for the present work: (i) log-series α, (ii) Margalef, (iii) Berger-Parker and (iv) Simpson (see Downie, unpublished and Bentley, unpublished).

Species diversity values were calculated using the indices mentioned above. The reciprocal values of the latter two indices indicated increased richness/dominance in relation to increased index value.

(i) Log series α

The log series α index appears to be the most favoured of the numerous diversity indices used as it is easy to calculate, has good discriminant ability, is unaffected by sample size, and is best applied when species abundance does not fit a log normal distribution (see Kempton, 1979; Magurran, 1988; Southwood, 1978; Taylor 1978).

$$S_T = \alpha \log_e \left(1 + \frac{N}{\alpha}\right),$$

where S_T = the total number of species present at a site, and
N = the total number of individuals at the same time.

(ii) Margalef Index

$$DMg = \frac{(S-1)}{1nN},$$

where S = number of species, and

N = number of individuals.

(iii) Berger-Parker Index

$$d = \frac{N_{\max}}{N},$$

where N_{max} = the number of individuals in the commonest species, and

N = the number of individuals in all species combined.

(iv) Simpson Index

$$C = \sum_{I}^{s} \frac{n_i(n_i - 1)}{N(N-1)},$$

where n_i = number of individuals in the *i*th species, and

N = the total number of individuals,

2.4 BETA-DIVERSITY

2.4.1 SIMILARITY (ß-LEVEL DIVERSITY) INDICES

ß-level ordinal diversity indices such as the Jaccard (C_J), Morisita-Horn (C_{mH}), Sørenson Incidence (C_S) and Sørenson Abundance (C_N) indices were applied to calculate similarity/non-similarity between spider populations collected from two different land-use types.

(i) *Jaccard* $C_J = j/(a+b-j)$ (Magurran, 1988)

(ii) *Sørenson (Incidence)* $C_S = 2j/(a+b)$ (Magurran, 1988)

where j = no. of species found in both sites,

a = no. of species in Site A,

b = no. of species in Site B.

(iii) *Sørenson (Abundance)* $C_N = 2_{jN}/(aN + bN)$ (Magurran, 1988)

where aN = the total no. of individuals in Site A,

bN = the total no. of individuals in Site B,

$_jN$ = the sum of the lower of the two abundances found in both sites.

(iv) *Morisita-Horn Index* $C_{mH} = 2\Sigma(an_i bn_i)/[(da+db)aN.bN)]$ (Magurran, 1988)

where aN = total no. of individuals in Site A,

an_i = no. of individuals in the $_i$th species in A.

$da = \Sigma an_i^2/aN^2$

Complete similarity is shown to equal 1.0 in the case where both sets contain identical sets of species, and for very dissimilar sites, the value would be closest to 0.0.

2.4.2 MULTIVARIATE ANALYSES

2.4.2.1 TWINSPAN

The popular divisive polythetic clustering technique "Twinspan" (**Tw**o **W**ay **IN**dicator **SP**ecies **AN**alysis) (Hill *et al.* 1975) was used to compare and group sites or species using correspondence analysis ordination (CA). In general, an initial ordination is made on the data, and samples are divided into groups that are either "positive" or "negative" (based on their score on the 1st CA axis). Groups identified from the first division are split again in a similar manner, and so on until a final classification is made. Such divisions highlight "preferential" species, that is, those species preferring only one side of the dichotomy. In theory, these individuals can be considered as being "indicator" species, and linked to a particular set of environmental conditions. Species represented by less than five individuals were omitted from the Twinspan analyses.

2.4.2.2 CANOCO

The major ordination techniques used in the present work were Detrended Correspondence Analysis (DCA) (Hill *et al.*, 1975) and Canonical Correspondence Analysis (CCA) (ter Braak, 1988), as run in the Multivariate Analysis Programme CANOCO (ter Braak, 1998). DCA is based on the reciprocal averaging techniques as found in CA and is an indirect gradient analysis, while CCA is a Direct or Constrained ordination technique. Such methods produce plots that show samples and/or species mapped in ordination space. DCA analysis is run using species data to extract the axes of maximum variation in species composition (Lepš & Šmilauer, 2003), while the more powerful CCA is used to map the distribution of both samples and species along the ordination axes to show, by the use of vectors, the direction and influence of the measured environmental variables. This ordination method is extremely useful in community ecology projects where the relationship of environmental variables on species composition and distribution is under study.

Chapter 3 – Comparison of spider assemblage structure and diversity in different land-use types in a highly fragmented landscape (Mafra, Portugal)

3.1 Introduction

The progressive fragmentation and modification of natural landscapes as a result of anthropogenic activities has increased dramatically in recent history (Johnson *et al.*, 1981). In Portugal, the land has undergone a major transformation in the last half of the twentieth century, resulting from the replacement of forest stands of Oak and Pine with faster growing, more "economically viable" exotic plantations. The widespread use of monoculture plantations of species such as *Eucalyptus globulus* Labill., at the expense of natural mixed-species stands is probably having a significant, although largely unknown, impact on biodiversity and overall environmental health and sustainability. The presence of such exotic plantations has been shown to impose significant implications on general habitat quality that is linked to increased deep soil disturbance, loss of endemic vegetation following planting and clearing, depletion of soil organic matter (Madeira *et al.*, 1989) along with water holding capacity (Fabião *et al.*, 2002). Furthermore, the natural re-growth of the understory vegetation may be significantly affected, particularly following coppicing and removal of slash after harvesting (Alves *et al.*, 1990, Smith *et al.*, 1997). Removal of the vegetation can lead to an increase in soil erosion in young plantations whose canopy has not yet closed (Fabião *et al.*, 2002) along with other negative effects such as loss of soil aggregation (Tisdall and Oades, 1982) and increased exposure of seedlings to extreme environmental conditions (Smith *et al.*, 1997). It is argued that by regularly removing the vegetation understory from heavily managed forests, such areas will not be able to sustain a high level of biological richness in the long-term (Bengtsson *et al.*, 2000).

First introduced to Portugal in 1829, Eucalyptus plantations have steadily increased in popularity with those seeking a short-term type of forest production. Eucalyptus is an attractive species for timber production as it grows rapidly in a tall and slender fashion. Since 1957 the planting of Eucalyptus stands has increased dramatically and currently, this tree type constitutes approximately 740 thousand hectares of Portuguese woodland. Although 121 species of Eucalyptus are found in Portugal, by far the most popular species is *E. globulus*, which occupies approximately 95% of the total amount of planted Eucalyptus. Currently this tree type represents approximately one fourth of Portugal's forested areas (Figure 4 shows the location of nationwide plantations).

The demand for a higher rate of production of paper has resulted in the planting of Eucalyptus stands outside designated production zones, which ultimately has increased the stress in areas that are either not entirely suited to the growth of this tree, or whose presence has a negative influence on the growth of other species in the surrounding area (Araujo, 1995). In Monchique, where Eucalyptus now represents 60% of the forest area, the Monchique Oak is severely threatened. In this region, eucalypt plantations are blamed for the lowering of water tables, which has negatively impacted on soil quality and local wildlife levels (Araujo, 1995). In addition, such plantations have been linked to increased rates of fire and loss of semi-natural forests, homes and lives. National parks such as Sintra-Cascais, Serra da Estrela and Tapada de Mafra[1] have been severely affected, and in 2003 a state of emergency was called for by the Portuguese Government as fire, thought to have originated from continuous Eucalyptus and Pine plantations, raged throughout the country.

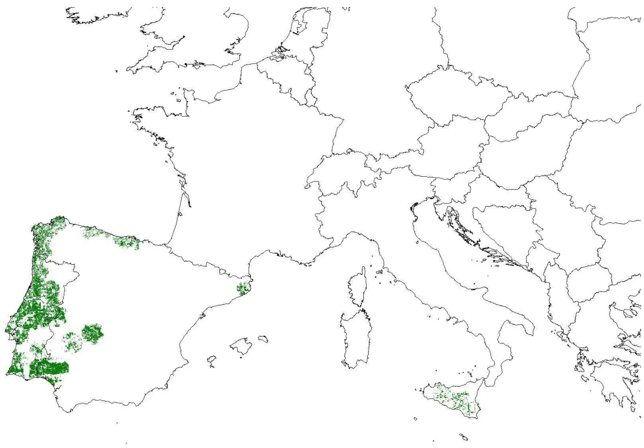


Figure 4: Location of Eucalyptus in Continental Portugal (DGF, 1995)

Although many have debated the negative impacts of Eucalyptus on biodiversity in Portugal, few can ignore this industry accounts for almost half of the total national exports of forest products (Goes, 1991) and is thus an important economic commodity for the country. The use of eucalypt pulp in the production of paper has resulted in Portugal being ranked in the top seven exporters of pulp worldwide (Palma-Ferreira, 1995).

Unfortunately little research has been carried out in the Mediterranean area comparing biodiversity in natural and artificial forests. The majority of comparisons made between

[1] In 2003, after the present work was carried out.

unmanaged forests and plantations concur that richness is generally lower in monocultures (see reviews in Moore and Allen, 1999; Palik and Engstrom, 1999). In the review by Moore and Allen (1999) three observations were made: firstly, diversity is generally lower in plantations when compared to natural forests; secondly, the planting of exotic species is usually lower in forests containing native species and finally, with proper management, species-poor monocultures can be transformed into more species-rich environments. Studying the effects of land-use on Collembola diversity patterns in Portugal, a decrease in abundance, diversity and species richness was linked to an increase in soil-use stress (Sousa *et al.*, 2002: Integrated into the EU funded BIOASSESS project). More recently, Portugal played a major role in the BEAR project which aimed to identify key indicators to help evaluate and monitor forest biodiversity at different landscape scales throughout Europe (http://www.algonet.se/~bear/Bear1.pdf).

In the present work, the role played by habitat structure in relation to spider abundance and community structure in a variety of forest and Shrubland areas within the Council of Mafra, Estremadura region of Portugal will be examined and compared. In particular, the influence of landscape structure on spider diversity will be explored and focus placed on spider richness and assemblage structure in four main land-use groups comprising of Shrubland, established Oak woodland, mixed Pine forest and exotic, monoculture Eucalyptus plantations. Such groups, each comprising of five replicate sites, give a representation of four land-use types experiencing differing degrees of anthropogenic stress.

3.2 DESCRIPTION OF THE STUDY AREA

Using a military map (Carta Militar de Portugal, Série M, No. 388) and from general observation, land use types in Mafra were classified according to whether they were: (1) Shrubland, (2) Oak woodland, (3) Pine forest and (4) Eucalyptus plantations. Five sites in each of the four types were randomly selected for study. The sample areas encompassed the Parque Nacional Tapada de Mafra, a state owned and managed park, and areas to the north, east and west of the park. Figure 5 gives an indication of the location of the study sites.

In the following site descriptions, percentage cover of land with all vegetation other than the crop was measured over an area of $100m^2$, while mean percentage of vegetation of two height classes (0-50cm and $\geq$ 50cm) was calculated from 10-point measurements taken 1m along the pitfall transect. Assessments were also made on the age of the stand, history of fire, vegetation clearance and branch cutting.

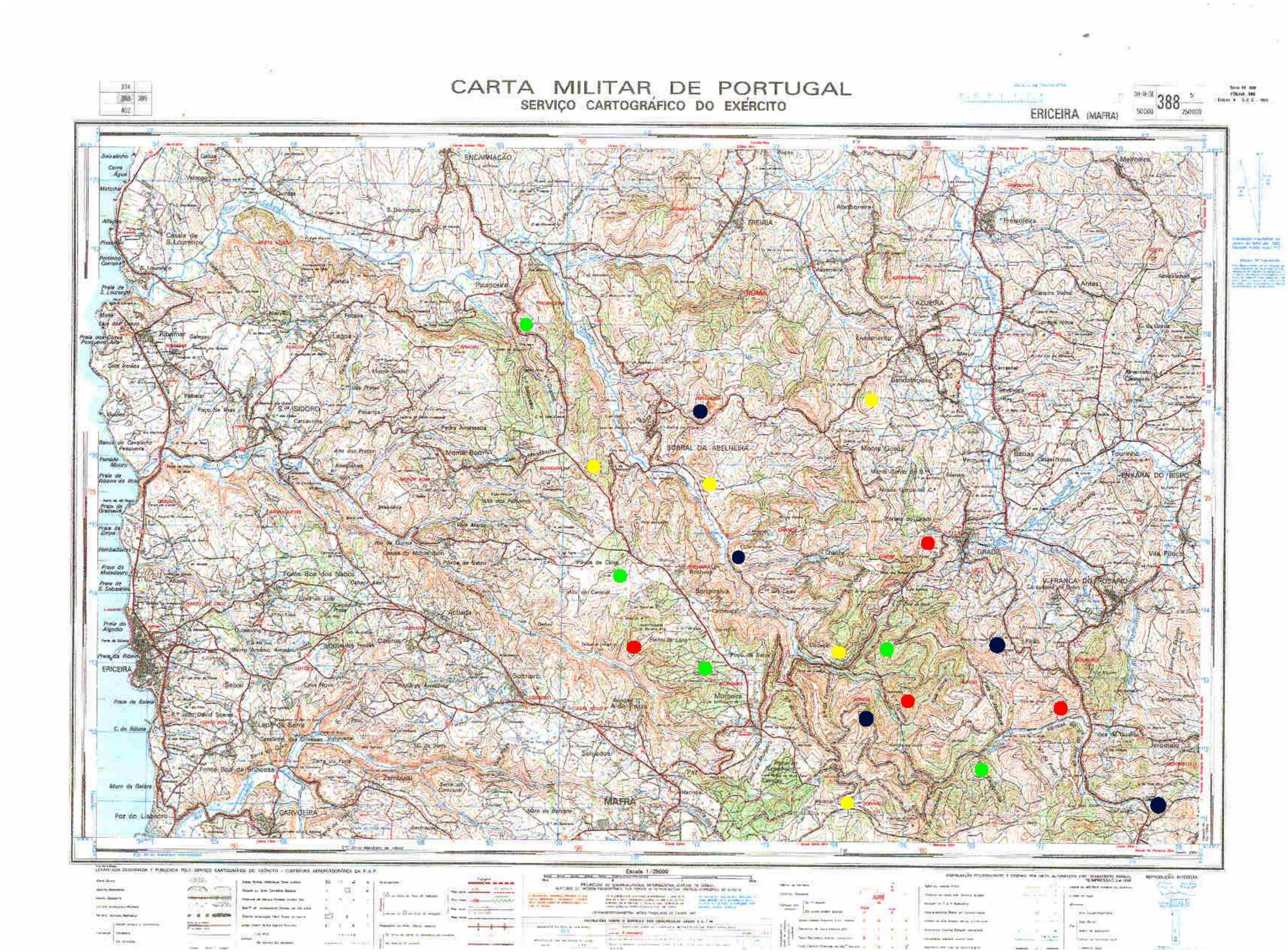


Figure 5 - General location of sites sampled in Mafra during 2001. The coloured circles represent the following land-use types: Yellow = Eucalyptus; Green = Pine; Red = Oak and Blue = Shrubland.

Samples of soil were collected in each site using a trowel and placed in a mixing tray. All stones and large debris were removed, and thoroughly mixed. The samples were transferred to an air-tight bag and the date and location of each were recorded. All samples were sent to the Instituto Nacional de Investigação Agrária, (located within the grounds of Instituto Superior de Agronomia, Tapada da Ajuda, Lisbon) for analysis. The physical characteristics of the soil sampled from each site are shown in Table 3. To assess the effects of habitat on spider diversity and assemblage structure, the following measurements were taken in each site from an area of $10m^2$ (which was thought to give a fair representation of the physical characteristics found in each land use type);

(i) Trunk diameter
(ii) Tree height
(iii) Distance to nearest tree
(iv) North-south crown radius
(v) East-west crown radius
(vi) Crown height

Due to the high density of trees and presence of trees from different rotational periods in some of the Eucalyptus plantations, trunk diameter measurements were taken of all the trees found within the designated $10m^2$ survey area. Diameters were assigned to four different size classes (diameter (i) ≤ 75mm, (ii) 76-124mm, (iii) 125-174mm and (iv) ≥ 175mm. Each tree was assigned a number, and ten trees were randomly chosen for measurement. Mean values were calculated from all the classes to give an estimate of the plantation characteristics.

Eucalyptus Site 1: Tapada de Mafra

Located on the slope of a steep hill (21° descending north-westwards), this 7 years old plantation comprised of first-rotation *E. globulus*, and showed signs of natural regeneration of Eucalyptus and history of clearing. There was no evidence of either cutting (that is, evidence of thinning) or fire. Percentage of bare ground: 0%, with mass of eucalypt leaves on forest floor. Litter depth: 8cm. Percentage cover of land with vegetation: 40% (30% shrubs, 10% herbs). Vegetation comprised of common fern and *Erica lusitanica*, *Erica scoparia*, *Rubus ulmifolius* Schott, *Daphne* sp., *Brachypodium* sp. and *Euphorbia* sp. Mean percentage of quadrant with vegetation with height of 0-50cm: 33%, percentage of vegetation ≥ 50cm: 48%.

Table 3: Physical characteristics of the soil sampled from 20 sites in Mafra in 2001.

Site	***Tree species***	***Soil ph***	***Phosphorus***	***Potassium***	***Magnesium***	***$CaCO_3$ t/ha***	***Soil organic matter***
Ec1	E. globulus	5.8	21 low	>200 very high	>125 very high	0	>6 very high
Ec2	E. globulus	5.2	123 high	121 high	68 medium	5	2.05 medium
Ec3	E. globulus	6	48 low-medium	>200 very high	>125 very high	0	>6 very high
Ec4	E. globulus	5.9	16 very low	135 high	>125 very high	0	5.1 high
Ec5	E. globulus	4.4	21 very low	137 high	>125 very high	16	>6 very high
Oak 1	Q. suber	7.9	44 low	>200 very high	>125 very high	0	4.4 high
Oak 2	Q. suber / Q. faginea	6.3	17 very low	>200 very high	>125 very high	0	6.4 very high
Oak 3	Q. suber / Q. faginea	6.2	42 low	>200 very high	>125 very high	0	5.55 high-very high
Oak 4	Q. suber	6.3	65 medium	157 high	>125 very high	0	>6 very high
Oak 5	Q. suber	8.1	11 very low	98 medium-high	105 high	0	5.1 high
Pine 1	P. bravo	5.6	14 very low	117 high	>125 very high	6	5.45 high-very high
Pine 2	P. pinea	6.2	11 very low	>200 very high	>125 very high	0	5.55 high-very high
Pine 3	P. bravo	4.6	13 very low	96 medium-high	>125 very high	12	>6 very high
Pine 4	P. bravo	5	17 very low	106 medium-high	>125 very high	12	>6 very high
Pine 5	P. bravo	5.6	16 very low	133 high	>125 very high	6	>6 very high
Shrub 1	N/A	8.1	12 low	163 high	>125 very high	0	3.3 medium
Shrub 2	N/A	5.6	8 very low	153 high	112 high	5	4.05 high
Shrub 3	N/A	8.1	36 low	131 high	>125 very high	0	3 medium
Shrub 4	N/A	6.6	12 very low	157 high	>125 very high	0	>6 very high
Shrub 5	N/A	6.3	28 very low-low	155 high	>125 very high	0	4.2 high

Eucalyptus Site 2: Serra do Chipre

This relatively young *E. globulus* plantation was located on the slope of a valley, facing 17° north-east, and was almost completely cleared of vegetation and showed signs of cutting and fire. There was a small amount of natural regeneration of *Eucalyptus* species. Bare ground: 5%, with the majority of the plantation floor covered in leaves. Litter depth: 3cm. Percentage coverage of land with vegetation: less than 5% (comprising principally of shrubs, scattered throughout). Of the minimal vegetation in this site species included *Ulex* sp., *Rubus ulmifolius* Schott, *Pistacia lentiscus* L., and naturally regenerated *Crataegus monogyna* Jacq. Mean percentage of quadrant with vegetation with height of 0-50cm: <5%, percentage of vegetation ≥ 50cm: 0%.

Eucalyptus Site 3: Bandalhoeira

Located 150m from a small village, and on a hill with a slope of 19°, this *E. globulus* plantation was in its fourth rotation, contained a small amount of deadwood, and had complete coverage of ground with eucalypt leaves. There was a considerable amount of litter, broken glass and household items strewn throughout the plantation. There were signs of natural regeneration of *Quercus suber*, and no obvious history of clearing, cutting or fire. Litter depth: 17cm. Percentage cover of land with vegetation: 60% (40% shrubs, 20% herbs). Vegetation was represented by *Ulex* sp., *Erica* sp., *Brachypodium* sp., *Rosmarinus officinalis* L., *Pistacia lentiscus* L. In some areas the gorse and heather had grown in excess of 1.5 metres. Mean percentage of quadrant with vegetation with height of 0-50cm: 52%, percentage of vegetation ≥ 50cm: 42%.

Eucalyptus Site 4: Sobral da Abelheira

On top of a small hill with a slope of 7°, and 200m from a collection of four small dwelling houses, this *E. globulus* plantation was in its fifth rotation. The area showed natural regeneration of Eucalyptus and had a very small amount of deadwood. There was evidence of clearing. Percentage of bare ground: 10%, 40% cover of land with vegetation (35% shrubs, 5% herbs). Litter depth: 10cm. Vegetation comprised mainly of *Erica* sp., *Ulex* sp., *Brachypodium* sp., and *Cistus* sp. Mean percentage of quadrant with vegetation with height of 0-50cm: 45%, percentage cover of vegetation with height ≥ 50cm: 51%.

Eucalyptus Site 5: Casais de Ervideira

Sloping 11° south westwards, and located on the slopes of a large valley, this *E. globulus* plantation showed no signs of clearing, cutting or fire. There was natural regeneration of

Eucalyptus and the plantation floor was covered in leaves, rocks and a small amount of deadwood. Approximately 20% of the land was covered with vegetation (18% shrubs, 2% herbs) comprising mainly of *Brachypodium* sp., *Ulex* sp., *Pistacia lentiscus* L. and *Erica* sp. Mean percentage of quadrant with vegetation with height of 0-50cm: 30%, percentage cover of vegetation with height ≥ 50cm: 50%.

Pine Site 1: Tapada de Mafra

Situated on the slope of a valley, sloping 22° south-east, with *Pinheiro bravo* the dominant tree type. The age of the stand was approximately 60-70 years, and showed signs of natural regeneration of *P. bravo*, *Quercus suber* and *Oliveira* sp. There was no apparent history of clearing, cutting or fire, but there was a high level of *Myrtus* grazing. Percentage of bare ground: less than 1%, 85% cover of land with vegetation (75% shrub, 10% herbaceous). Litter depth: 4.5cm. Vegetation comprised mainly of shrubs such as *Erica* sp., *Daphne gnodium, Myrtus* sp., *Ulex* sp. and *Rosmarinus officinalis* and grasses such as *Brachypodium*. Mean percentage of quadrant with vegetation with height of 0-50cm: 35%, percentage cover of vegetation with height ≥ 50cm: 65%.

Pine Site 2: Tapada de Mafra

Located on the slope of a valley (10.5° sloping northwards) the dominant tree type in this plantation was *P. pinea*. The age of the stand was approximately 50-60 years, with a high presence of dead wood and natural regeneration of Eucalyptus. There was a history of clearing and cutting, with no evidence of fire. Percentage of bare ground: less than 1%, cover of land with vegetation: 55% (5% shrub, 50% herbaceous). Litter depth: 2.5cm. Vegetation comprised mainly of shrubs such as *Erica scoparia*, *Daphne* spp., along with ferns and *Brachypodium* sp. Mean percentage cover of quadrant of vegetation with height of 0-50cm: 40%, percentage cover of vegetation with height ≥ 50cm: 20%.

Pine Site 3: Murgeira

Situated on a plateau with a slight slope (4.8° north-east), this 70 years old plantation was dominated by *Pinheiro bravo*, contained deadwood and showed signs of natural regeneration of *Pinheiro* sp., *Q. suber* and *Q. faginea*. There was no apparent history of clearing or fire, however there were some signs of selective cutting. Percentage of bare ground: 0%, cover of land with vegetation: 65% (45% shrubs, 20% herbaceous). Litter depth: 8cm. Vegetation comprised mainly of *Ulex* sp., *Erica* sp., and common fern. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 55%, percentage cover of vegetation with ≥ 50cm: 30%.

Pine Site 4: Povoa de Cima

Situated on a plateau with a slight slope (4.8° north-east), this 70 years old plantation was dominated by *Pinheiro bravo*. There were signs of natural regeneration of *Pinheiro* sp., *Quercus* sp. and *Eucalyptus* sp., no apparent history of clearing, cutting or fire and very little deadwood. No bare ground, and percentage cover of land with vegetation was 80% (70% shrubs, 10% herbaceous). Vegetation was dominated by *Ulex sp.*, *Erica scoparia*, *Brachypodium* sp. and variegated *Daphne* sp. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 31%, percentage cover of vegetation with height ≥ 50cm: 24%.

Pine Site 5: Picanceira

This 70 years old plantation was located on the slope of a valley (5.2° north), and comprised mainly of *Pinheiro bravo*. There were no signs of deadwood, history of clearing or evidence of fire, but signs of natural regeneration of *Quercus* sp. and history of cutting. Percentage of bare ground: 5%, and percentage of land covered with vegetation approximating 90% (80% shrubs, 10% herbs). Litter depth: 10cm. Vegetation comprised of *Erica scoparia*, *Erica lusitanica*, *Mirtus communis* L., *Brachypodium* sp., *Trifolium* sp. (clover) and *Allium* (wild onion). Mean percentage cover of quadrant with vegetation with height of 0-50cm: 23%, percentage cover of vegetation with height ≥ 50cm: 56%.

Oak Site 1: Vila Pouca

Located beside a farm and on a steep slope, this *Quercus suber* woodland had a high presence of natural regeneration of Oak, and a large amount of deadwood. There were no signs of clearing, cutting or fire. Highly overgrown with shrubs, there was approximately 95% coverage of land with vegetation (70% shrub, 25% herbs), represented by species such as *Erica scoparia*, *Daphne* sp., *Rubus ulmifolius* Schott, *Pistacia* sp., *Euphorbia* sp., *Brachypodium* sp. and common fern. Litter depth: 8cm. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 30%, percentage cover of vegetation with height ≥ 50cm: 70%.

Oak Site 2: Tapada de Mafra

Situated on a very slight slope of a valley (2°), this site comprised of a mixed Oak population of *Q. suber* and *Q. faginea*. There was a large amount of dead trees, and no signs of clearing, cutting or fire. No signs of cork removal from trees, and high amount of lichen growth on the north-facing part of the branches. Percentage of bare ground: less than 1%, and percentage of land covered with vegetation approximately 85% (15% shrubs, 75% herbs). Litter depth: 8 cm. Vegetation comprised of *Brachypodium* sp., *Daphne* sp., variegated *Daphne sp.*, *Erica scoparia* and *Allium* sp. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 33%, percentage cover of vegetation with height ≥ 50cm: 11%.

Oak Site 3: Tapada de Mafra

Located on the bottom of a valley (3°, sloping eastwards) and beside a river. This old mixed Oak site of *Q. suber* and *Q. faginea* had a large presence of deadwood and no signs of clearing, cutting or fire. There was a high amount of lichen growth on the trees. Percentage of bare ground: less than 1% (with a large coverage of leaves), with full coverage of the land with vegetation (approximately 30% shrubs, 70% herbs). Litter depth: 7cm. Vegetation comprised of common fern, *Erica scoparia*, *Brachypodium*, *Mirtus communis* L., *Rubus ulmifolius* Schott, *Euphorbia* sp. and *Pistacia* sp. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 33%, percentage cover of vegetation with height ≥ 50cm: 46%.

Oak Site 4: Forte do Picolo

This *Quercus suber* plantation was found on a steep slope of a valley (17°), between two Eucalyptus plantations, and showed signs of natural regeneration of Oak, and history of fire. There were no apparent signs of clearing or cutting. With full coverage of the forest floor comprising mainly of leaves, approximately 40% of this site was covered with vegetation (10% shrubs, 30% herbs) represented by species such as *Ulex* sp., *Brachypodium* sp., *Daphne* sp., *Cistus* sp., *Rubus ulmifolius* Schott and *Ruscus aculeatus* L. Litter depth: 5 cm. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 44.5%, percentage cover of vegetation with height ≥ 50cm: 36.2%.

Oak Site 5: Campo do Mato de Cima

On top of a plateau and sloping 5° south-east, this 50 years old woodland was dominated by *Q. suber*, and located between a mature Eucalyptus plantation on one side, and on the other by a young Eucalyptus stand. There was a large presence of deadwood, and signs of natural regeneration of Oak and Eucalyptus. No evidence of history or fire, but some signs of selective cutting. Percentage of bare ground: less than 5%, with percentage of land covered with vegetation around 95% (80% shrubs, 15% herbs). Litter depth: 3cm. Vegetation comprised of common fern, *Ulex* sp., *Rubus ulmifolius* Schott, *Mirtus communis* L., *Erica lusitanica* and *Erica scoparia*, variegated *Daphne* sp., *Brachypodium* sp., and several species of fungi. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 33%, percentage cover of vegetation with height ≥ 50cm: 64%.

Shrub Site 1: Tapada de Mafra

Located near the top of a plateau, and sloping at an angle of 10°C westwards, this Shrubland area contained neither trees nor deadwood, and did not show any signs of clearing, cutting or fire. With full coverage of the land covered in vegetation (70% shrub, 30% herbs), litter depth was 0cm. There was evidence of grazing, and presence of animal faeces. Of the shrubs present, the following species dominated: *Erica scoparia*, *Erica lusitanica*, *Pistacia lentiscus*, *Ulex* sp., *Daphne gnodium*, while *Brachypodium* sp. represented the majority of the herbaceous vegetation. Mean percentage cover of vegetation with height of 0-50cm: 55%, percentage cover of quadrant with vegetation with height ≥ 50cm: 45%.

Shrub Site 2: Tapada de Mafra

Situated on a fairly steep slope of a valley (descending 14° eastwards), this area did not show any presence of trees, deadwood, signs of natural regeneration, history of clearing, cutting or fire. There was some evidence of wild boar foraging and activity, as indicated by soil disturbance and a high amount of faecal matter. Full coverage of land with vegetation (80% shrubs, 20% herbs). Litter depth: 0cm. Dominant species included *Erica scoparia*, *Erica lusitanica*, *Ulex* sp., *Rubus ulmifolius* Schott, *Daphne* sp., *Mirtus communis* L., *Brachypodium* and ferns. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 22%, percentage cover of vegetation with height ≥ 50cm: 78%.

Shrub Site 3: Abelheira

Located on a steep piece of land (20°) and used primarily as a practice shooting ground and a training area for hunting dogs, this area of Shrubland was represented by species such as *Erica scoparia*, *Erica lusitanica*, *Pistacia lentiscus*, *Ulex* sp., *Daphne gnodium*, *Rubus ulmifolius* Schott, *Mirtus communis L.* and *Brachypodium* sp. Full coverage of land with vegetation (90% shrubs, 10% herbs). Litter depth: 0cm. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 20%, percentage cover of vegetation with height ≥ 50cm: 80%.

Shrub Site 4: Mosqueiro da Cima

This area of Shrubland was situated between two vineyards, sloping 18° and represented by species such as *Erica scoparia, Erica lusitanica*, *Pistacia lentiscus*, *Ulex* sp., *Daphne gnodium, Rubus ulmifolius* Schott, *Ulex sp., Mirtus communis* L., *Brachypodium*. Full coverage of land with vegetation (90% shrubs, 10% herbs). Litter depth: 0cm. Mean percentage cover of with vegetation with height of 0-50cm: 25%, vegetation with height ≥ 50cm: 75%.

Shrub Site 5: Juromelo

Located approximately 500m from the village of Juromelo and on a site with a slope of 15°, the vegetation of this area comprised mainly of *Erica scoparia*, *Erica lusitanica*, *Pistacia lentiscus*, *Ulex* sp., *Daphne gnodium*, *Rubus ulmifolius* Schott, *Mirtus communis* L., and *Brachypodium* sp. There was full coverage of land with vegetation (95% shrubs, 5% herbs). Litter depth: 0cm. Mean percentage cover of quadrant with vegetation with height of 0-50cm: 25%, percentage cover of vegetation with height ≥ 50cm: 75%. Two weeks before the end of the sampling period, this location was completely cleared by fire, which also destroyed several homes and burned a large part of the landscape to the east and south of the site.

3.3 METHODOLOGY AND DATA ANALYSIS

Between 7 April and 1 October 2001, spiders were collected using a variety of trapping techniques in the 20 sample sites. The adopted sampling protocol was a modified version developed by Coddington *et al.* (1991), who used aerial hand collection, ground hand collection, litter extraction with Tullgren funnels, and vegetation beating. Collection of spiders was made both by quantitative and qualitative methods (sweep netting, vegetation beating, hand collection and pitfall trapping). A description of each technique follows:

(1) *Hand collection*: This method employs the hand-collection of spiders below knee height ("looking down" *c.f.* Coddington *et al.*, 1991; 1996) and above knee-height ("looking up" *c.f.* Coddington *et al.*, 1991; 1996) to collect both ground spiders from the leaf litter, shrubs, fallen leaves, dead wood, along with species from tree trunks and tall vegetation. All spiders were collected by a pooter (aspirator) and transferred to a 70% alcohol solution. A timed block of 15 minutes search was made in each site every fortnight (totalling 15 minutes x 12 = 3 hours per site; 20 sites = 3 x 20 = 60 hours total sampling).

(2) *Vegetation beating*: All tall shrubs and vegetation were beaten with a large, robust stick. Spiders were caught on a white cotton collecting-tray, and transferred using a pooter to a 70% alcohol solution. Fifteen minutes of vegetation beating was made in each site every fortnight (totalling 15 minutes x 12 = 3 hours per site; 20 sites = 3 x 20 = 60 hours total sampling).

(3) *Sweep netting*: All shrubs between 0.2m and 2.0m in height above ground level were swept with a sweep net. In order to prevent loss and/or damage of spiders the nets were checked every 3 successive sweeps and specimens were transferred to a 70% alcohol solution using a pooter. A sampling unit of 15 minutes was made in each site every fortnight (totalling 15 minutes x 12 = 3 hours per site; 20 sites = 3 x 20 = 60 hours total sampling).

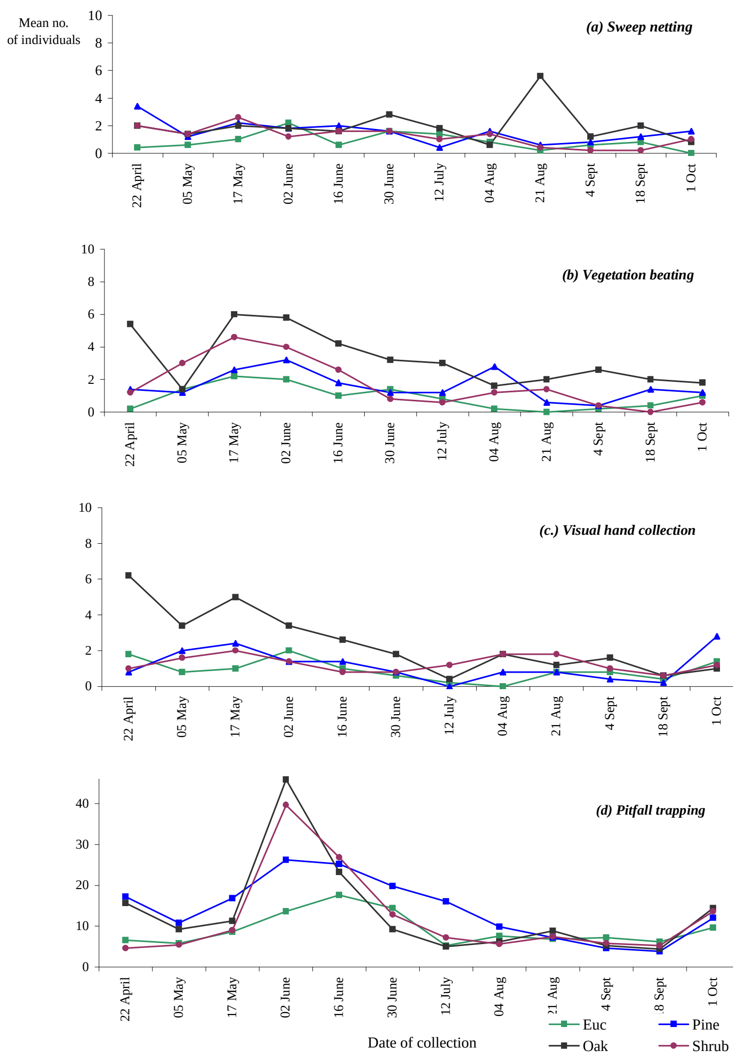
(4) *Pitfall trapping*: Five pitfall traps (diameter 7.5cm) were laid in each of the 20 sites, sunk rim-deep into the soil and 2m apart. To avoid desiccation and cannibalism each trap was filled with 100ml ethylene glycol (anti-freeze). Traps were emptied and re-set every two weeks, with care taken to realign the traps flush with the soil.

All spider samples were kept separate and the dates and locations were recorded. The specimens were grouped into either juveniles or adults, and all adults were identified to species or morphospecies level.

3.4 RESULTS

Between 22 April 2001 and 1 October 2001, a total of 11525 spiders comprising of 4023 adults and 7502 juveniles, representing 30 families and 183 species were caught from twenty sites representing four land-use types in Mafra, western Portugal. One-way Kolmogrov-Smirnov tests indicated adult, juvenile and total catch between sites were normally distributed ($p>0.05$, non.sig., all cases), and consequently no transformations were made on the data. Individual site catch varied considerably ($\chi^2 = 647.8$, d.f. = 19, $p<0.001$), with the highest numbers of spiders (871) collected from Oak Site 1 and the lowest from Eucalyptus Site 2 (199 individuals). When the adult and juvenile data were compared separately, significant differences were found in catch size between sites ($\chi^2 = 547.9$ and 531.3, respectively, d.f. = 19, $p < 0.001$, both cases), with highest number of adults (434) and juveniles (546) collected from Oak Site 1 and Eucalyptus Site 3, respectively. Fewest numbers from both age classes were collected from Eucalyptus Site 2: in this location only 83 adults and 116 juveniles were collected throughout the entire study period. When the data for each land-use type were pooled, highest mean numbers of adults (249.8 ± 48.5) and juveniles (436.4 ± 29.8) were collected from the Oak sites. Eucalyptus gave the lowest mean adult catch (141.0 ± 23.1), while the lowest mean number of juveniles was collected from the Shrub areas (346.6 ± 29.6). When compared separately, a one-way ANOVA showed no significant difference in the numbers of spiders caught from each age class between vegetation type ($F_{3, 19}$ = 2.195 (adults) and 0.807 (juveniles), $p > 0.05$, non sig., in both cases).

Figure 6: Mean capture of adults per sample in each land-use type



Pitfall trapping was by far the most successful collection technique in quantitative terms and accounted for 75% of the adult catch in Eucalyptus, Pine and Shrub groups and 63% in the Oak sites. This finding was not unexpected since pitfall trapping was the only form of continuous form of sampling used in the study. With the exception of vegetation beating and hand collection in the Oak sites (which, when pooled, accounted for 16% and 12% of the catch, respectively), all the three other manual techniques yielded similar proportions (6-9%) in the remaining land-use groups. With the exception of individuals collected by sweep netting, the highest mean numbers were caught mainly between 17 May and 23 June 2001, inclusive (Figure 6). There was a considerable decrease in catch after this point that remained relatively stable, until around 21 August to 4 September 2001 when there was a slight increase in the number of adults caught by sweep netting in the Eucalyptus sites.

Mean figures are shown separately for both age classes and for each collection technique in Figures 7 and 8, while the mean sample catch in each land-use type is shown in Figure 9. When the data for all collection techniques and age classes were pooled, one-way ANOVA showed no significant difference in the mean numbers of adults and juveniles caught per sample in each of the land-use types ($F_{3,19}$ = 2.20 and 0.81, respectively $p > 0.05$, non sig., both cases). However, when each collection technique was analysed separately and compared, the following results were obtained:

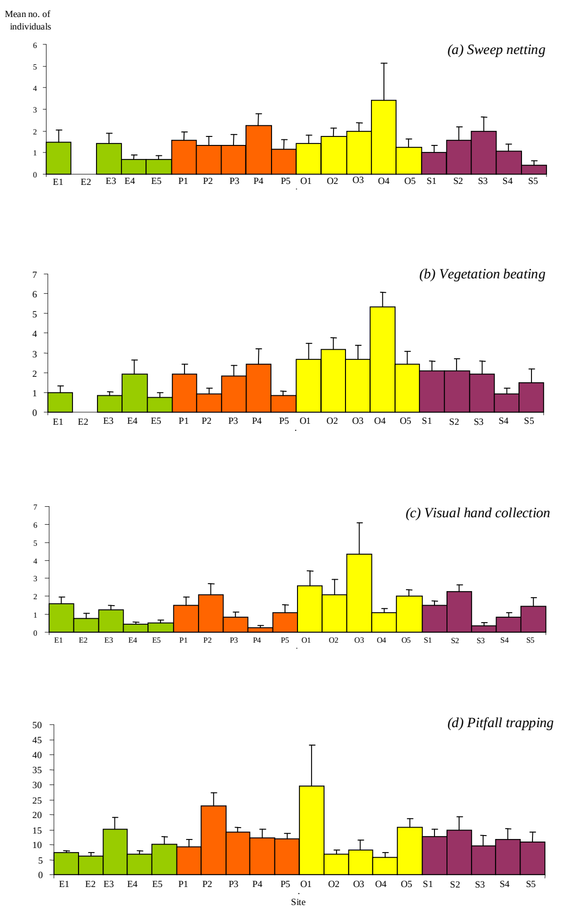
Sweep netting: one-way ANOVA followed by a *post hoc* Scheffe test showed the mean number of adults caught per sample was significantly higher in Oak (1.97, s.e. ± 0.38) compared to Eucalyptus (0.84, s.e. ± 0.17, $F_{3,236} = 3.48$, $p < 0.05$), with either groups not differing significantly in mean sample catch from Pine and Shrub areas. With respect to the immature catch, a one-way ANOVA followed by a Duncan's post hoc test identified the mean number of juveniles to be significantly greater in Shrubland compared to Eucalyptus ($F_{3,236} = 2.67$, $p = 0.05$).

Vegetation Beating: Kruskal-Wallis tests showed significant differences in median adult catch, ($\chi^2_3 = 37.19$, $p < 0.05$) with pair-wise Mann-Whitney tests identifying Oak and Pine to have a significantly higher catch than in Eucalyptus (U = 716.0 and 1304.5, $p < 0.05$ both cases), while the catch in Oak was significantly greater than in Pine and Shrub (U = 1091.5 and 1137.5, $p < 0.05$, all cases). No significant difference was recorded in mean juvenile catch between groups ($F_{3,236} = 2.11$, $p > 0.10$, non. sig.).

Hand collection: Kruskal-Wallis showed significance between groups ($\chi^2_3 = 8.93$, $p < 0.05$), with pair-wise Mann-Whitney tests indicating that Oak had significantly higher adult catch than Eucalyptus and Pine (U = 1321.0 and 1387.5, $p < 0.05$ both cases), with the Oak values not significantly greater than Shrub (U = 1543.0, $p = 0.16$, non sig.). With the juvenile catch, a

Kruskal-Wallis test followed by pair-wise Mann Whitney tests showed the median catch to be significantly greater in Oak compared to Pine and Shrub (U = 1295.0 and 1233.0, $p < 0.05$), with Eucalyptus values considerably higher than Pine and Shrub (U = 1347.0 and 1279.0, $p < 0.05$).

Pitfall Trapping: Kruskal-Wallis showed significance (χ^2_3 = 9.58, $p < 0.05$), with pair-wise Mann-Whitney showing the median adult catch in Pine to be considerably higher than in Eucalyptus, Oak and Shrubland (U = 1215.0, 1345.0 and 1434.5, $p < 0.05$ all cases). No significant difference was recorded in mean juvenile catch between groups ($F_{3,236}$ = 0.38, p = 0.77, non sig.).



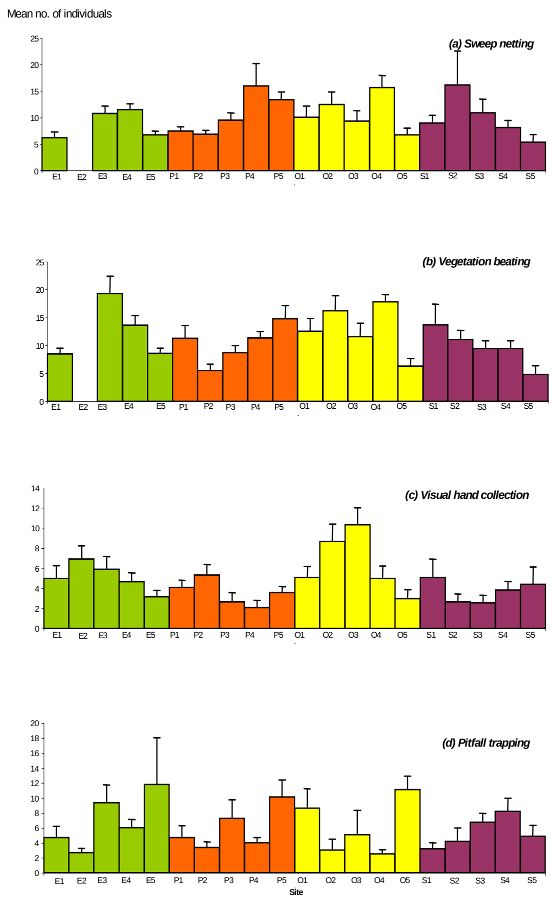


Figure 7: Adults **Figure 8: Juveniles**

Figure 7 and 8: Mean number of adult spiders (Fig. 7) and immatures (Fig. 8) caught either per 15-minute random manual sampling or by 2-weekly continuous sampling. Manual collections are represented by: (a) sweep netting, (b) vegetation beating and (c) hand collection, while continuous sampling is represented by (d) pitfall trapping. E1-5 = Eucalyptus stands, P1-5 = Pine stands, O1-5 = Oak stands, S1-5 = Shrubland.

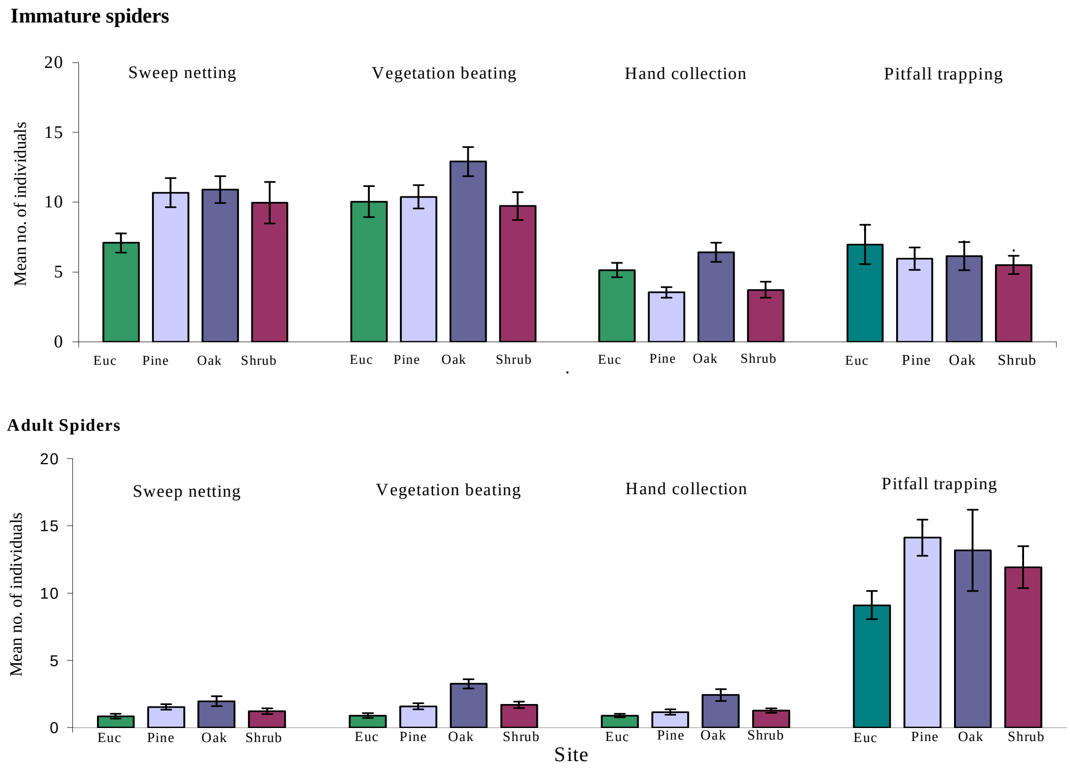


Figure 9: Mean number of immature and adult spiders caught per sample in 20 sites representing 4 land-use types

3.4.1 Distribution of spider guilds

Table 4 shows the number and proportion of the catch in each land-use type when the replicate data were pooled for the ten most common families represented. Table 5 shows the abundance of spiders and their respective proportions for each foraging guild, for all adult data collected. Parametric and non-parametric tests were applied to test the null hypothesis that samples derived from either the same mean (one-way ANOVA followed by Scheffe and Tukey *post-hoc* tests), or the same median (Kruskal-Wallis followed by pairwise Mann-Whitney tests, in the case where the Levene's test deemed the variances to be unequal).

With the exception of Pine sites, of the ten most common families represented, non-web builders dominated the catch when compared to web builders (Table 4). When comparing species representation however, a more balanced proportion between the two main groups was evident.

A one-way ANOVA revealed the mean number of cribellate spiders was significantly higher in Oak than in Eucalyptus ($F_{3,19} = 4.623$, $p<0.05$, Scheffe and Tukey indicating Eucalyptus ≠ Oak = Pine = Shrub). No significant difference in mean catch was found in the following groups, when the data for each group were pooled and compared using one-way ANOVA: Diurnal hunters ($F_{3,19} = 2.009$, $p > 0.05$, non sig.), Jumping spiders ($F_{3,19} = 0.988$, $p > 0.05$, non sig.), Nocturnal hunters ($F_{3,19} = 1.669$, $p > 0.05$, non sig.), Purse-web spiders ($F_{3,19} = 0.333$, $p > 0.05$, non sig.), Scattered line-weavers ($F_{3,19} = 1.734$, $p > 0.05$, non sig.) and Sheet-web builders ($F_{3,19} = 2.535$, $p > 0.05$, non sig.).

Kruskal-Wallis tests followed by Mann-Whitney U tests showed that significantly higher numbers of ambusher spiders (represented by the Families Sparassidae, Thomisidae and sub-Family Philodromidae) were collected in Shrubland (9.3% of catch, Table 5), ($\chi^2_3 = 13.29$, $p<0.05$) when compared to Eucalyptus (1.3%), Pine (1.3%) and Oak (1.9%) sites (U = 0.000, 0.000, 1.000, respectively, $p < 0.05$ all cases). With the exception of the funnel web spiders (Family: Agelenidae), which were collected in significantly higher numbers in Pine (34% of the catch) than in Shrub (4.7%, Table 5), ($\chi^2_3 = 7.97$, U = 1.000, $p < 0.05$ both cases) and to a lesser statistical extent in Oak (7%), (U = 1.00, p = 0.056) no significant differences were found in the median catch of the remaining spider guilds (Irregular web builders, Orb weavers, Pirate spiders and Trapdoor spiders).

Table 4: The ten most common families represented, their web/non-web guild association and percentages of species represented (%S_T) and abundance (%N_T) in each land use group.

		Eucalyptus		***Pine***		***Oak***		***Shrub***	
Family	***Web builders***	**% S_T**	**% N_T**	**% S_T**	**% N_T**	**% S_T**	**% N_T**	**% S_T**	**% N_T**
Agelenidae	Funnel web	9.5	19.4	5.6	34.6	5.9	7.0	5.1	4.7
Araneidae	Orb weaver	4.8	1.6	5.6	2.4	5.9	4.2	6.8	6.6
Linyphiidae	Sheet web	11.9	10.5	14.4	13.4	11.8	13.4	10.3	4.4
Theridiidae	Scattered line weaver	13.1	7.1	13.3	5.7	17.6	6.5	12.8	4.8
	Total	**39.3**	**38.6**	**38.9**	**56.1**	**41.2**	**31.1**	**35.0**	**20.5**

Family	***Non-web builders***	**% S_T**	**% N_T**	**% S_T**	**% N_T**	**% S_T**	**% N_T**	**% S_T**	**% N_T**
Dysderidae	Nocturnal hunter	3.6	7.2	4.4	11.2	3.9	12.2	2.6	3.9
Gnaphosidae	Nocturnal hunter	14.3	10.9	11.1	11.0	8.8	6.1	20.5	18.2
Lycosidae	Diurnal hunter	4.8	2.8	4.4	5.8	4.9	11.0	4.3	3.3
Nemesiidae	Trapdoor Spider	1.2	9.1	1.1	2.7	1.0	4.6	0.9	8.4
Salticidae	Jumping Spider	13.1	10.1	11.1	3.7	11.8	5.8	11.1	6.9
Zodariidae	Diurnal Hunter	1.2	15.9	1.1	3.7	1.0	21.1	0.9	24.8
	Total	**38.2**	**56.0**	**33.2**	**38.1**	**31.4**	**60.8**	**40.3**	**65.5**

Table 5: Total number of individuals and respective proportions when assigned to functional guilds in each land-use type (pooled data from all collection techniques).

	Eucalyptus		***Pine***		***Oak***		***Shrub***	
Web builders	***N***	***% catch***	***N***	***% catch***	***N***	***% catch***	***N***	***% catch***
Cribellate web builder	9	1.3	15	1.4	35	2.8	19	2.0
Funnel web	137	19.4	382	34.6	88	7.0	45	4.7
Irregular space web builder	-	-	1	0.1	-	-	-	-
Orb web weaver	11	1.6	26	2.4	54	4.4	64	6.6
Purse-web	-	-	1	0.1	1	0.1	1	0.1
Scattered line weaver	50	7.1	63	5.7	81	6.5	46	4.8
Sheet/Hammock web weaver	75	10.6	148	13.4	167	13.4	43	4.5
Total	**282**	**40.0**	**636**	**57.6**	**426**	**34.3**	**218**	**22.7**

Non-web builders	***N***	***% catch***	***N***	***% catch***	***N***	***% catch***	***N***	***% catch***
Cryptic Ambusher	9	1.3	14	1.3	24	1.9	90	9.3
Diurnal hunters	142	20.1	129	11.7	414	33.1	329	34.1
Jumping Spider	71	10.1	41	3.7	72	5.8	67	6.9
Nocturnal hunters	135	19.1	251	22.8	255	20.4	181	18.7
Pirate spider	2	0.3	2	0.2	-	-	-	-
Trap-door spider	64	9.1	30	2.7	58	4.6	81	8.4
Total	**423**	**60.0**	**467**	**42.4**	**823**	**65.7**	**748**	**77.3**

3.4.2 SPECIES RICHNESS

The summary values and species richness estimates from all 20 sites are represented in Table 6. The greatest observed richness was from Oak Site 1, with 56 species collected in this site. Lowest number of species was caught from Eucalyptus Site 2, which yielded only 18 species. When data from each of the land groups were pooled, highest observed richness was found in Shrub (123 species), followed by Oak (106), Pine (95) and Eucalyptus (84 species, Table 6). An analysis of variance followed by a Duncan's *post hoc* test showed the mean number of species caught in Eucalyptus (33.8) was significantly lower than in Pine (44.4), Shrub (47.6) and Oak (48.6), ($F_{3,16}$ = 3.93, $p<0.05$, Duncan's test Eucalyptus≠Pine=Oak=Shrub). Overall, sampling intensity (when based on ratio of adults to species) was highest in the Pine and Oak groups (11.6 and 11.8 respectively), and lowest in the Eucalyptus (8.4) and Shrub (7.9) areas. When the intensity was calculated according to ratio of total number of caught individuals (adults and juveniles) to species, similar values were found in the Eucalyptus (29.3), Pine (30.9) Oak (32.4) areas, while Shrub gave the lowest figure of 21.1. Inventory completeness (that is, percentage of non-singleton catch) was highest in Pine and Shrub areas, (72.6% and 66.4% respectively), and almost identical in the Eucalyptus (64.3%) and Oak (64.2%) sites (Table 6). Table 6 also shows the values derived from various species richness estimates applied to the data. A discussion of each estimate is detailed below.

Species Richness Estimates:

(1) Log series α

A wide range of values were obtained, and when ranked in order of richness the four most diverse sites were: Oak Site 2 (28.75), Shrub 1 (23.67), Pine 1 (23.29) and Oak 3 (23.10): all areas found within the protected park, Tapada de Mafra. The least rich site was Eucalyptus Site 2, with an alpha score of 7.08. Surprisingly, Pine Site 2, which comprised of an area within the Tapada containing aged species of *P. pinea* was the second least diverse group, with a value of 9.54. When the data were pooled, Shrub and Oak were the richest land-use types (with values of 36.9 and 27.6 respectively), and Eucalyptus and Pine sites, the least rich (24.9, in both cases).

Table 6: Summary values and species richness estimates from 20 Mafra sites in 2001. Each estimate represents the mean calculated from 100 randomizations of sample order, and was calculated using the software EstimateS. Sampling intensity is the ratio of individuals to number of species collected and inventory completeness represents the proportion of the catch excluding singletons.

	Euc 1	***Euc 2***	***Euc 3***	***Euc 4***	***Euc 5***	***Euc Total***
Observed richness	39	18	40	39	33	84
No. of immatures	294	116	546	432	365	1753 (x = 350.6 ± 71.9)
No. of adults	136	83	222	117	146	704 (x = 141.0 ± 23.1)
No. of singletons	14	8	14	20	12	30
No. of doubletons	11	1	8	5	5	15
Sample intensity:						
based on adult data	3.5	4.6	5.6	3.0	4.4	8.4
based on all data	11.0	11.1	19.2	14.1	15.5	29.3
Inventory completeness	64.1	55.6	65.0	48.7	63.6	64.3
Estimates:						
Log normal α	18.29	7.08	14.24	20.48	13.28	24.87
Margalef	7.74	3.85	7.22	7.98	6.42	12.66
Berger-Parker 1/D	5.44	4.61	2.55	6.50	4.42	6.29
Simpson 1/D	13.74	9.15	5.77	17.3	12.45	16.54
ACE	48.16	28.41	53.59	69.69	43.53	117.00
ICE	60.91	30.37	68.91	76.28	48.00	131.31
Chao 1	46.63 ± 6.2	33.00 ± 39.6	50.20 ± 8.6	70.94 ± 26.1	44.17 ± 11.2	111.25 ± 14.49
Chao 2	54.62 ± 10.9	41.75 ± 59.6	57.36 ± 11.8	85.33 ± 35.7	48.15 ± 13.1	125.70 ± 20.24
Jacknife 1	56.42 ± 3.9	27.17 ± 2.7	58.33 ± 5.3	61.00 ± 5.6	46.75 ± 4.3	117.92 ± 8.82
MM Mean	69.82	31.7	65.0	74.23	52.02	119.19

	Pine 1	***Pine 2***	***Pine 3***	***Pine 4***	***Pine 5***	***Pine Total***
Observed richness	50	34	44	45	49	95
No. of immatures	332	255	340	403	504	183 (x = 366.8 ± 41.6)
No. of adults	176	327	218	202	180	1103 (x = 220.6 ± 27.9)
No. of singletons	17	13	13	20	20	26
No. of doubletons	8	4	7	6	8	16
Sample intensity:						
based on adult data	3.5	9.6	5.0	4.5	3.7	11.6
based on all data	10.2	17.1	12.7	13.4	14.0	30.9
Inventory completeness	66	61.8	74.5	55.6	59.2	72.6
Estimates:						
Log normal α	23.29	9.54	16.62	17.96	22.17	24.92
Margalef	9.48	5.70	7.99	8.29	9.24	13.42
Berger-Parker 1/D	6.52	3.48	12.82	5.05	9.00	7.82
Simpson 1/D	24.02	7.17	27.16	15.03	25.25	22.29
ACE	65.04	52.74	54.24	71.52	70.78	118.52
ICE	62.17	53.38	56.62	77.39	76.50	125.47
Chao 1	65.22 ± 11.7	49.86 ± 16.4	53.85 ± 8.8	72.35 ± 20.1	70.23 ± 15.1	114.16 ± 10.9
Chao 2	60.09 ± 6.8	51.71 ± 16.1	64.22 ± 17.9	66.09 ± 13.8	72.08 ± 14.2	124.23 ± 15.0
Jacknife 1	67.42 ± 5.5	47.75 ± 3.4	58.67 ± 3.1	65.17 ± 4.0	71.00 ± 5.2	124.33 ± 5.8
MM Mean	84.49	47.8	60.45	67.18	95.35	120.81

	Oak 1	***Oak 2***	***Oak 3***	***Oak 4***	***Oak 5***	***Oak Total***
Observed richness	56	55	53	37	42	106
No. of immatures	437	486	438	494	327	2182 (x = 436.4 ± 29.8)
No. of adults	434	166	206	186	257	1249 (x = 249.8 ± 48.5)
No. of singletons	28	28	23	14	14	38
No. of doubletons	4	8	8	7	4	10
Sample intensity:						
based on adult data	7.8	3.0	3.9	5.0	6.1	11.8
based on all data	15.6	11.9	12.2	18.4	13.9	32.4
Inventory completeness	50.0	49.1	56.6	62.2	66.7	64.2
Estimates:						
Log normal α	17.10	28.75	23.10	13.87	14.26	27.66
Margalef	9.06	10.56	9.76	6.89	7.39	14.73
Berger-Parker 1/D	2.19	9.76	4.48	2.74	4.28	4.73
Simpson 1/D	4.38	28.83	12.23	6.56	12.24	14.85
ACE	96.11	93.07	77.95	51.98	56.04	150.51
ICE	99.76	106.3	86.49	68.95	59.85	149.11
Chao 1	132.16 ± 62.2	97.17 ± 26.3	81.25 ± 19.0	48.48 ± 9.9	60.48 ± 18.6	170.07 ± 33.8
Chao 2	114.37 ± 36.7	130.77 ± 49.6	84.6 ± 18.2	56.12 ± 13.9	52.51 ± 7.6	159.89 ± 24.9
Jacknife 1	84.42 ± 7.7	85.25 ± 6.8	78.67 ± 8.4	54.42 ± 4.6	57.58 ± 5.3	144.5 ± 7.2
MM Mean	88.3	96.46	103.53	60.09	61.29	135.77

	Shrub 1	***Shrub 2***	***Shrub 3***	***Shrub 4***	***Shrub 5***	***Shrub Total***
Observed richness	54	52	47	39	46	123
No. of immatures	373	411	357	357	235	1733 (x = 346.6 ± 29.6)
No. of adults	208	249	166	174	171	968 (x = 193.2 ± 15.6)
No. of singletons	23	26	17	17	18	41
No. of doubletons	7	8	13	9	10	10
Sample intensity:						
based on adult data	3.9	4.7	3.5	4.5	3.7	7.9
based on all data	10.8	12.5	11.1	13.6	8.8	21.1
Inventory completeness	57.4	51	63.8	56.4	60.9	66.4
Estimates:						
Log normal α	23.67	20.06	21.84	15.62	20.64	36.93
Margalef	9.93	10.17	9.00	7.37	8.75	17.60
Berger-Parker 1/D	6.30	1.95	3.25	3.70	6.84	4.03
Simpson 1/D	18.51	7.56	9.54	8.10	17.62	13.03
ACE	76.99	91.62	61.48	60.97	65.21	159.13
ICE	80.66	100.10	75.97	56.2	75.04	158.76
Chao 1	85.8 ± 22.1	89.27 ± 23.2	56.76 ± 7.1	52.69 ± 10.3	59.98 ± 10.0	196.71 ± 38.5
Chao 2	79.08 ± 14.7	96.65 ± 25.7	72.19 ± 15.8	50.82 ± 8.3	71.09 ± 15.2	171.85 ± 21.9
Jacknife 1	77.83 ± 6.18	80.5 ± 6.8	69.00 ± 5.9	55.5 ± 3.7	68.92 ± 7.8	162.33 ± 8.3
MM Mean	97.22	91.97	84.2	70.73	91.91	173.84

(2) Margalef Index

Using this index the five most diverse sites were as follows: Oak 2 (10.56), Shrub 2 (10.17), Shrub 1 (9.93), Oak 3 (9.76) and Pine 1 (9.48): again, all areas found within the park Tapada de Mafra. As found with the Log series α index, Pine 2 (with a value of 5.70) and Eucalyptus 2 (3.85) were the least rich sites. As found with the log series alpha calculations, when the data were pooled together, Shrub and Oak were the most species rich (17.60 and 14.73 respectively), and Pine (13.42) and Eucalyptus (12.66) the least diverse (Tables 6).

Dominance Indices:

(3) Reciprocal Berger-Parker Index

Adopting the reciprocal of this index, we can determine the degree of dominance/evenness of the species collected in each site, with increased values equating to increased evenness. The five highest values, indicating greatest degrees of evenness, were calculated as follows: Pine 3 (12.82), Oak 2 (9.76), Pine 5 (9.00), Shrub 5 (6.84) and Pine 1 (6.52). The two lowest values were given for Oak 1 (2.19) and Shrub 2 (1.95), and reflected the lowest degrees of species evenness. Overall, greatest evenness, and therefore lowest dominance, was found in the Pine (7.82) and Eucalyptus (6.29) sites, while the converse was calculated in Oak and Shrub areas (4.73 and 4.03, respectively, Table 6).

(4) Reciprocal Simpson Index

Using this index, the five groups showing greatest evenness were Oak 2 (28.83), Pine 3 (27.16), Pine 5 (25.25), Pine 1 (24.02) and Shrub 1 (18.51). It should be noted that three of these sites were found within Tapada de Mafra. Eucalyptus 3 and Oak 1 sites yielded the lowest values (5.77 and 4.38, respectively) and hence were deemed the least even. Highest values were calculated overall from Pine (22.29) and Eucalyptus (16.54) sites, with lowest values derived from Oak (14.85) and Shrub (13.03) areas (Table 6).

Table 7 shows the results of a Spearman's Rank Correlation coefficient test run to compare individual site rankings. Observed species richness was strongly and positively correlated with the Log series α and Margalef indices ($p < 0.01$, both cases), but not correlated with the reciprocal Berger-Parker and Simpson indices. Correlation was not found with any variables when tested against species abundance. The Log series α was positively linked with all the three indices, in particular with the Margalef and Reciprocal Simpson ($p < 0.01$, both cases), while the Margalef index showed a positive correlation with the Reciprocal Simpson ($p < 0.05$). The strongest positive correlation with the reciprocal Berger-Parker was with the reciprocal Simpson ($p < 0.01$). From these findings, we can therefore determine that the two diversity indices were highly correlated with one another, as were the two dominance/evenness indices, when each were compared at the $p = 0.01$ significance level.

Table 7: Correlation between species richness, abundance and the four diversity indices, using Spearman's Rank Correlation Coefficient, + = $p \leq 0.05$; ++ = $p \leq 0.01$, N.S. = non significance.

Variable	***Abundance***	***Log series α***	***Margalef***	***Reciprocal Berger-Parker***	***Reciprocal Simpson***
Species richness	N.S.	++	++	N.S.	N.S.
Abundance		N.S.	N.S.	N.S.	N.S.
Log series α			++	+	++
Margalef				N.S.	+
Rec. Berger-Parker					++

Figures 10 to 13 show the accumulated richness curves for the observed number of species caught throughout the study period, along with the associated species richness estimates calculated using the following estimators: *ACE*, *Chao 1* & *Chao 2* (bias-corrected) and *Jacknife 1*, using the software EstimateS. Table 6 includes the standard deviations for each value (please note EstimateS does not compute the s.d. for the ACE and ICE estimations). In the individual Eucalyptus sites lowest estimates ranged from 27.17 (s.d. ± 2.65) in Site 2 (*Jacknife 1*), to 85.33 species (s.d. ± 35.7) in Site 4 (*Chao 2*). In the Pine groups, values varied from 47.75 (s.d. ± 3.35) (*Jacknife 1*) in Pine 2 to 77.39 in Pine 4 (*ICE*), while in Shrub values ranged from 50.82 (s.d. ± 8.3) (*Chao 2*) in Shrub 4 to 100.1 (*ICE*) in Shrub 2. From the Oak data, highest individual richness values were obtained from Oak Site 1 with 132.16 species (s.d. ± 62.2) (*Chao 1*), with lowest richness 48.48 (s.d. ± 9.9) calculated from Oak 4 (*Chao 1*).

Figure 14 shows the data for each land-use type when pooled and compared. Using all four indices, overall diversity was lowest in Eucalytpus (111.25, s.d. ± 14.49, *Chao 1*) and highest in Shrubland (196.71 species, s.d. ± 38.5, *Chao 1*). Oak was the second highest in terms of richness (170.07, s.d. ± 33.8, *Chao 1*), followed by Pine (124.23, s.d. ± 15.0, *Chao 2*).

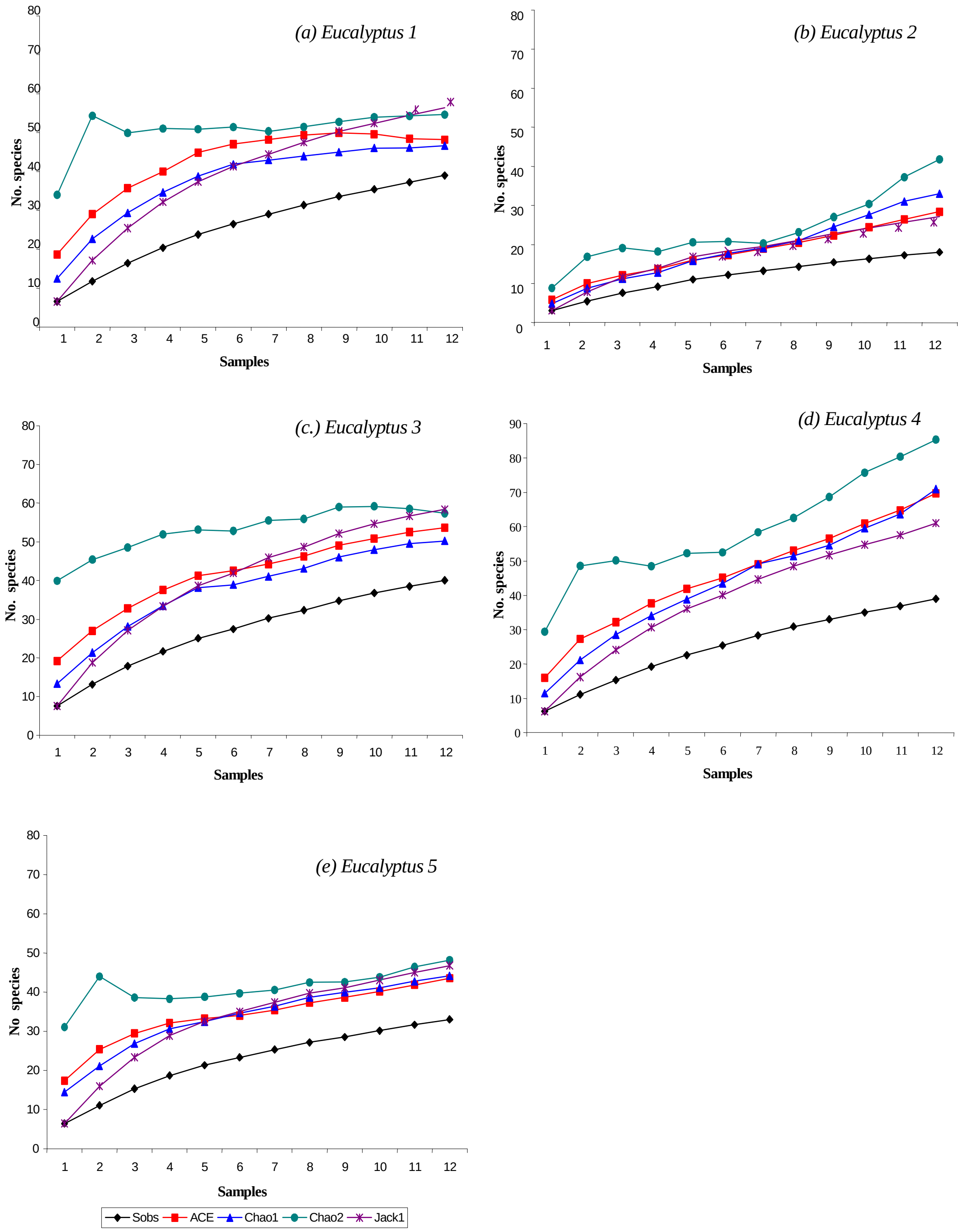


Figure 10: Species richness values calculated from 12 collections taken from 5 Eucalyptus sites in Mafra, 2001.

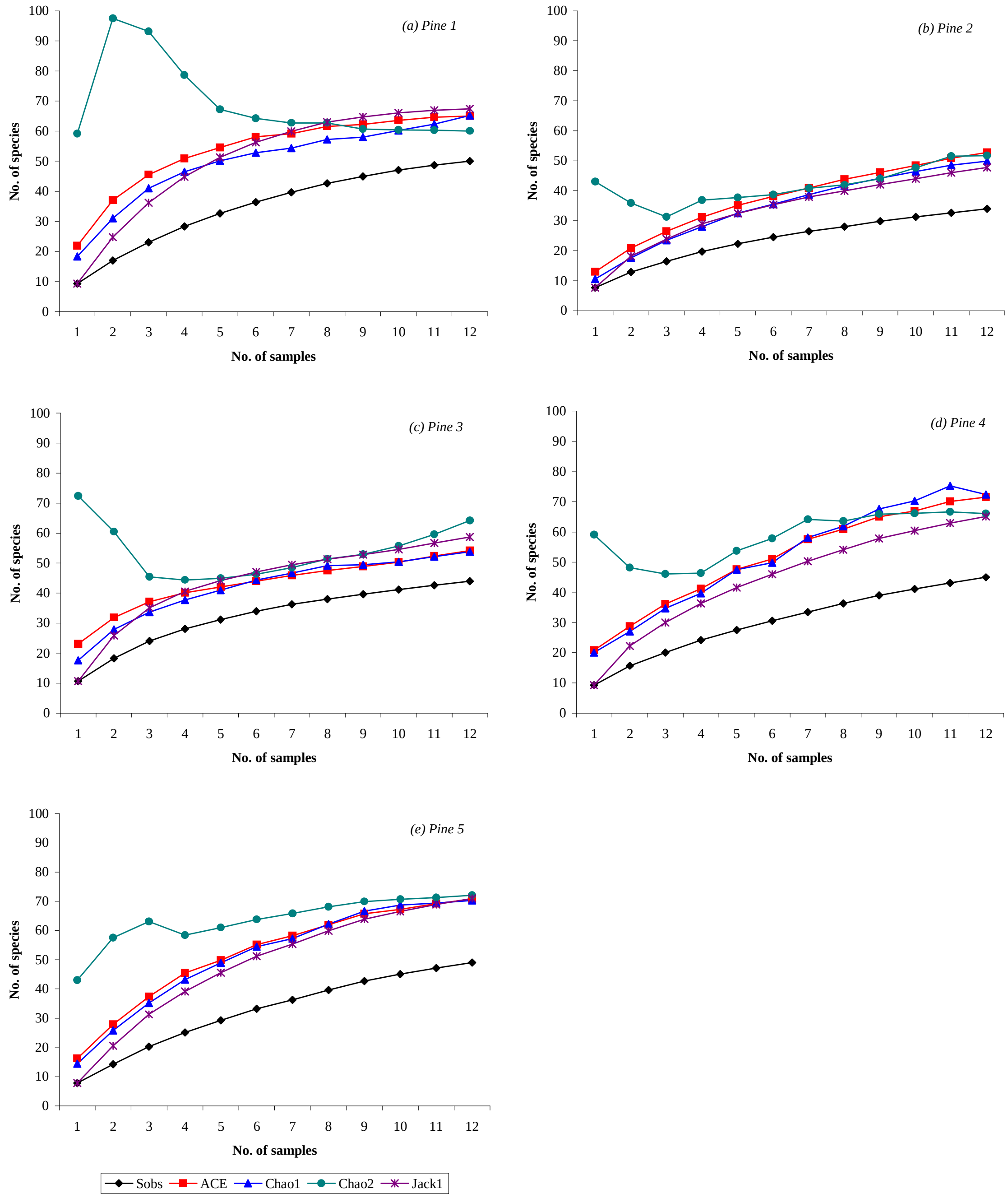


Figure 11: Species richness values calculated from 12 collections taken from 5 Pine sites in Mafra, 2001.

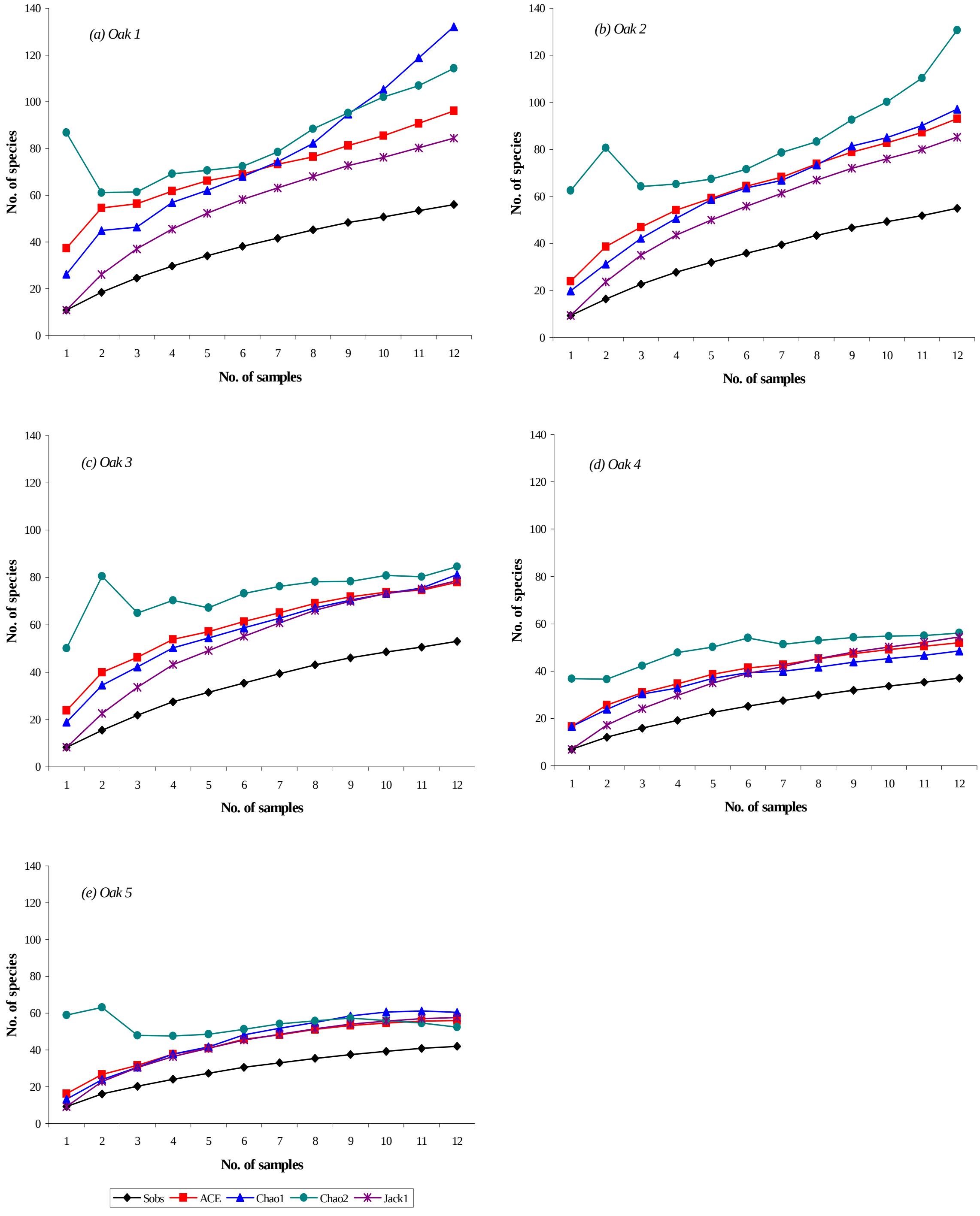


Figure 12: Species richness values calculated from 12 collections taken from 5 Oak sites in Mafra, 2001.

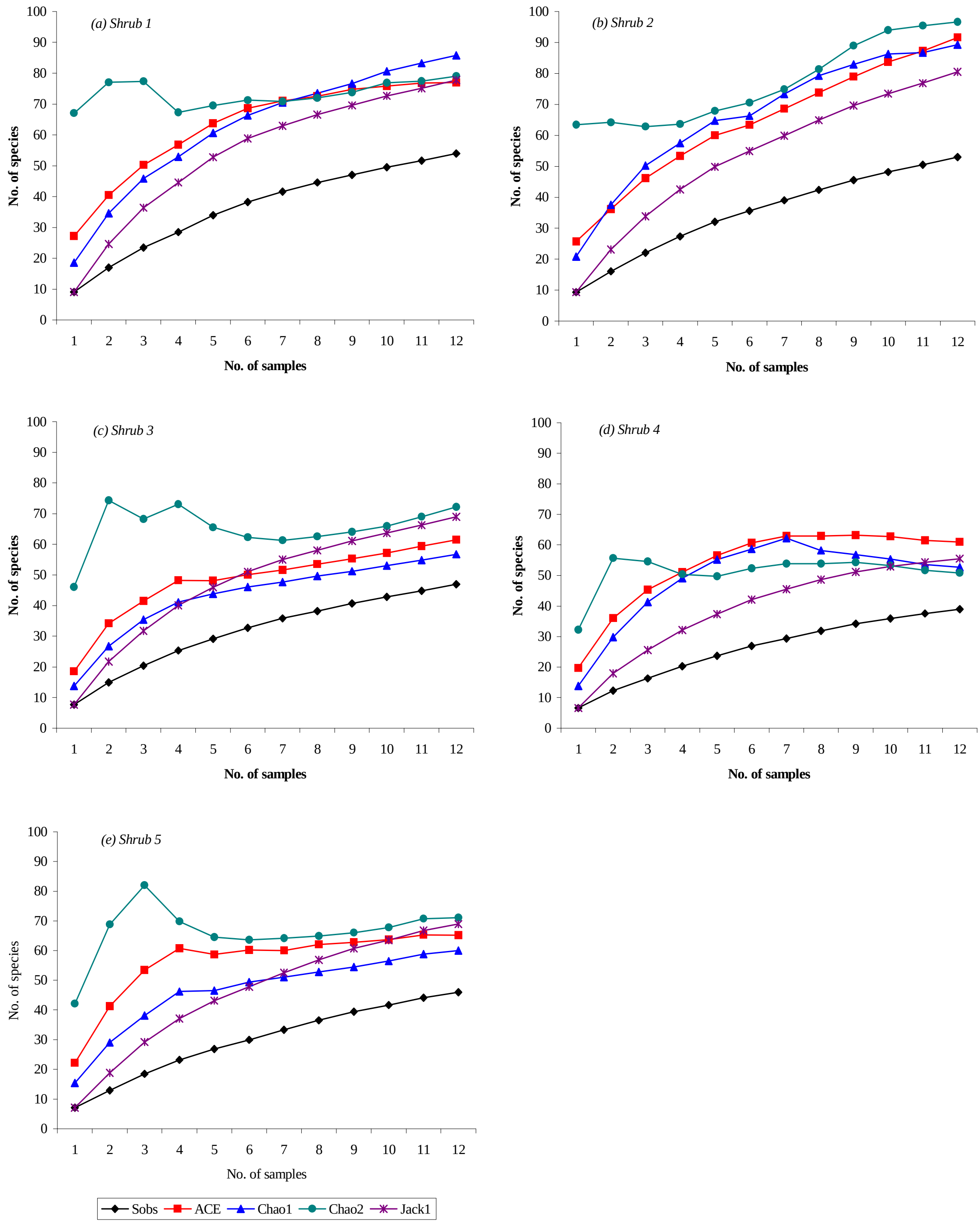
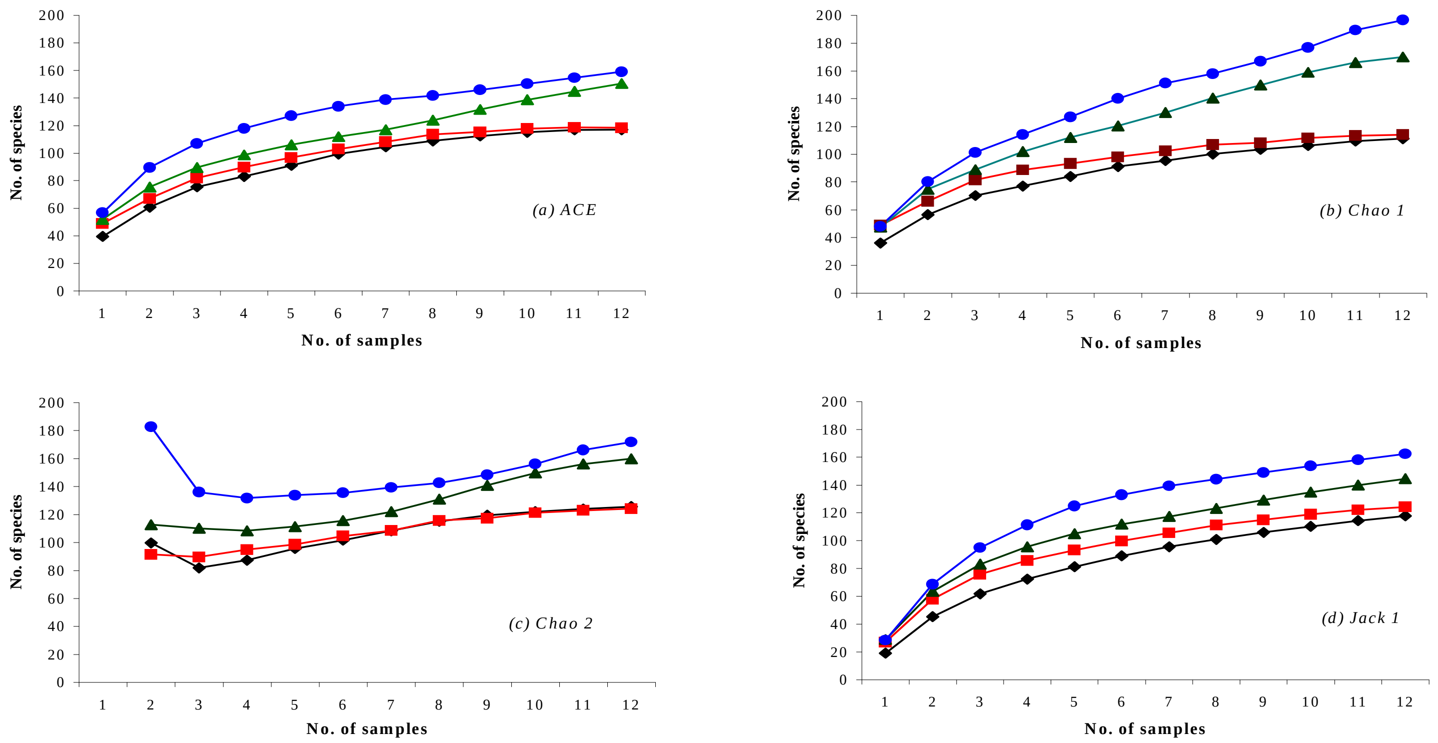


Figure 13: Species richness values calculated from 12 collections taken from 5 Shrub sites in Mafra, 2001.

Figure 14: Species richness values derived from (a) *ACE*; (b) *Chao 1*; (c) *Chao 2* and (d) *Jacknife 1* estimates, using the software EstimateS. Land-use types are designated by the following solid lines and shapes: Eucalyptus - black diamond; Pine - red square; Oak - green triangle; and Shrub – blue circle.



When pooled, highest numbers of exclusive species (34) were caught from Shrubland, and accounted for 18.6% of the catch (Table 8). Oak sites yielded the lowest number of exclusives (9 species, 4.9% of the total adult catch), followed by Eucalyptus (10 species, 5.5%) and Pine (13 species, 7.1%).

Table 8: Number of species and number of exclusive species in each land-use type

	Eucalyptus	Pine	Oak	Shrub
Spiders (S = 183)				
Observed richness	84 (45.9%)	95 (51.9%)	106 (57.9%)	122 (66.7%)
No. of exclusive species	10 (5.5%)	13 (7.1%)	9 (4.9%)	34 (18.6%)

Highest numbers of shared observed species were found between Oak and Shrub groups (73 species), while Eucalyptus and Pine shared the least amount of species (54) (Table 9).

Table 9: Shared observed species between land-use types (pooled data)

	Pine	Oak	Shrub
Eucalyptus	54	61	56
Pine		68	58
Oak			73

Highest similarity was calculated between the Oak and Shrub groups by the Morisita-Horn and Sørenson Abundance indices, while Jaccard and Sørenson Incidence calculated Pine and Oak sites to be the most similar. With the exception of the Jaccard Index, that calculated Eucalyptus and Shrub areas to be highly dissimilar, all the other indices that Pine and Shrub sites were the least similar in terms of number of shared species (Table 10).

Table 10: Similarity matrices calculated for each land-use type (pooled data)

	Euc-Pine	Euc-Oak	Euc-Shrub	Pine-Oak	Pine-Shrub	Oak-Shrub
Jaccard	0.432	0.472	0.375*	0.511†	0.367	0.474
Morisita-Horn	0.657	0.781	0.791	0.437	0.321*	0.861†
Sørenson (Inc.)	0.603	0.642	0.546	0.676†	0.537*	0.643
Sørenson (Abund.)	0.551	0.504	0.500	0.477	0.358*	0.558†

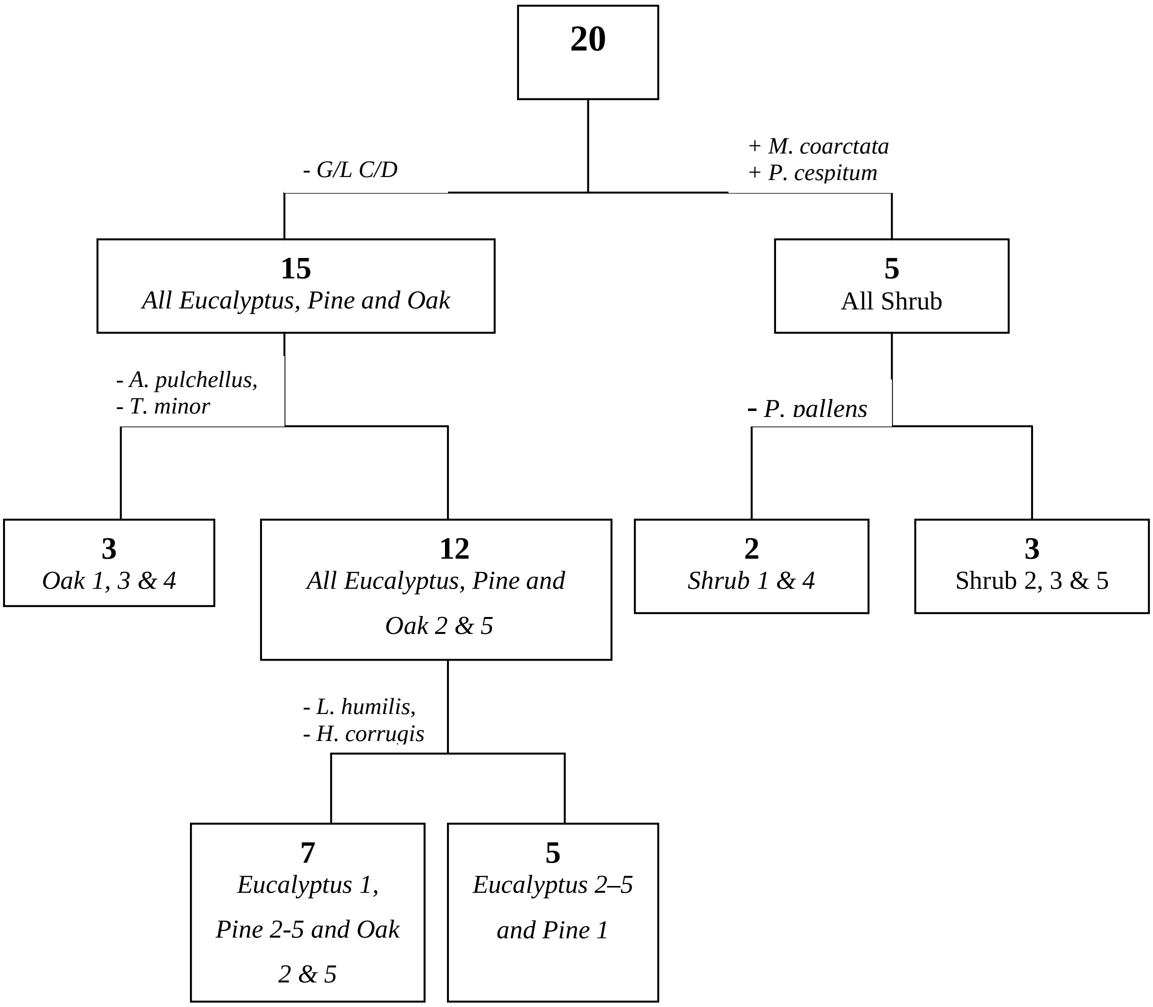
† Highest value of similarity

* Lowest value of similarity

3.4.3 CLASSIFICATION USING SPIDER ASSEMBLAGE STRUCTURE TO GROUP SITES

TWINSPAN was used to group sites using species abundance data of individuals trapped in numbers of 5 and over. Figure 15 shows the breakdown of the ordination and includes the indicator species at each division. The first separation of the data clearly distinguishes the forest areas from Shrubland and is based on the significant presence of the morphospecies "*G/L C/D*" in the former. The philodromid *Philodromus cespitum* and gnaphosid *Micaria coarctata* were found to be highly differential species, with the positive presence of both species in Shrubland.

Figure 15: Twinspan ordination dendrogam based on species caught with 5 or more individuals. Ordination was carried out using pseudospecies cut-off levels 0, 1, 10, 100, 1000 with 1, 2, 2, 2, 2 weighting.

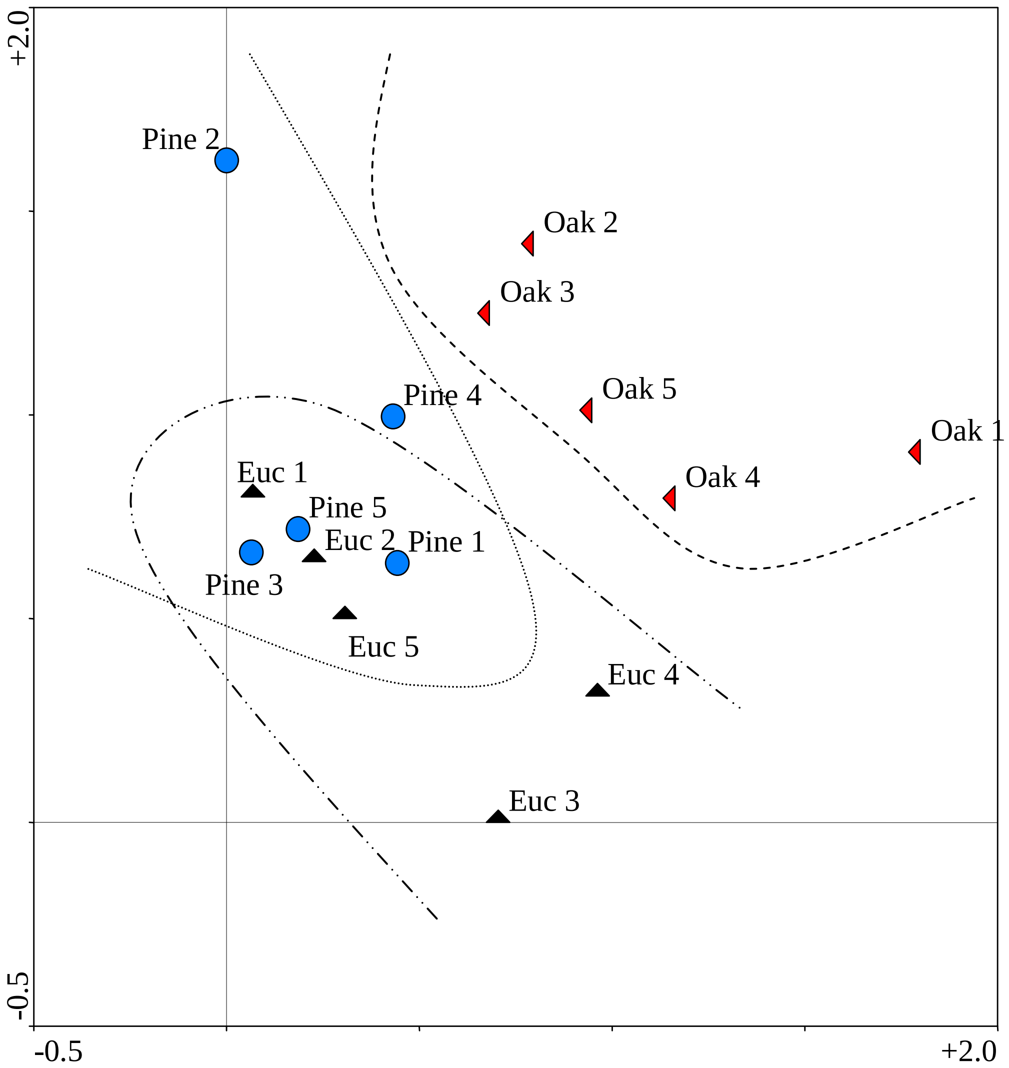


The presence or non-presence of the liocraniid *Trachelas minor* and theriid *Anelosimus pulchellus* accounted for the second division on the negative side of the dichotomy, being positively recorded in Oak sites 1, 3 and 4. A further division, aided by the presence of the dictynid *Lathys humilis* and linyphiid *Hybocoptus corrugis* in Eucalyptus Site 1, Pine Sites 2-5 and Oak Sites 2 & 5 separated the majority of the Pine sites and remaining Oak from the final four Eucalytpus areas.

Twinspan clearly showed the Shrubland sites to be highly distinct from the forest areas, and thus it was decided to omit the Shrub data in the DCA and CCA runs using CANOCO. As the environmental variables measured in these sites were not wholly compatible with those measured in the forest areas (and which would have caused unnecessary distortion when the CCA ordination was carried out), we felt further justified in doing so. In both the DCA and CCA ordinations, only species caught in numbers equal to or exceeding five individuals were included, with the data log-transformed *log (n + 1)*.

Figure 16 shows the distribution of the woodland sites in ordination space using DCA. The eigenvalues associated with the Axis 1-4 were 0.22, 0.12, 0.06 and 0.03, respectively. The omission of the Shrubland data further distinguished the Oak sites from Pine and Eucalyptus, with the former grouped in a large distinct cluster. With the exception of Pine 2 (the sole *P. pinea* site) and Eucalyptus Sites 3 and 4, all the remaining Eucalyptus and Pines sites were clustered together. When the scores on each axis for each site are compared, on axes 1 and 2, the Eucalyptus groups lie between 0.06-0.96 on Axis 1 and between 0-0.8 on Axis 2, while Pine groups lie between 0.07-0.45 on Axis 1 and 0.62-0.99 on Axis 2 (with the exception of Pine Site 2, which lies on 0.0 (Axis 1) and 1.62 (Axis 2)). This differs with the Oak groups, which are plotted between 0.68-1.80 on axis 1 and 0.79-1.42 on Axis 2. From such findings we can therefore intimate that Eucalyptus and Pine are similar in terms of species composition of those species caught in numbers of 5 or over, and contrast markedly with the Oak site fauna.

Figure 16: Ordination diagram of Axis 1 against Axis 2 using Detrended Correspondence Analysis of 15 sites in Mafra, Portugal based on spider abundance data (of individual species trapped 5 times or more) in 2001. Eigenvalues: Axis 1 – 0.22 Axis 2 – 0.12 with log transformation of species *log (n+1).*



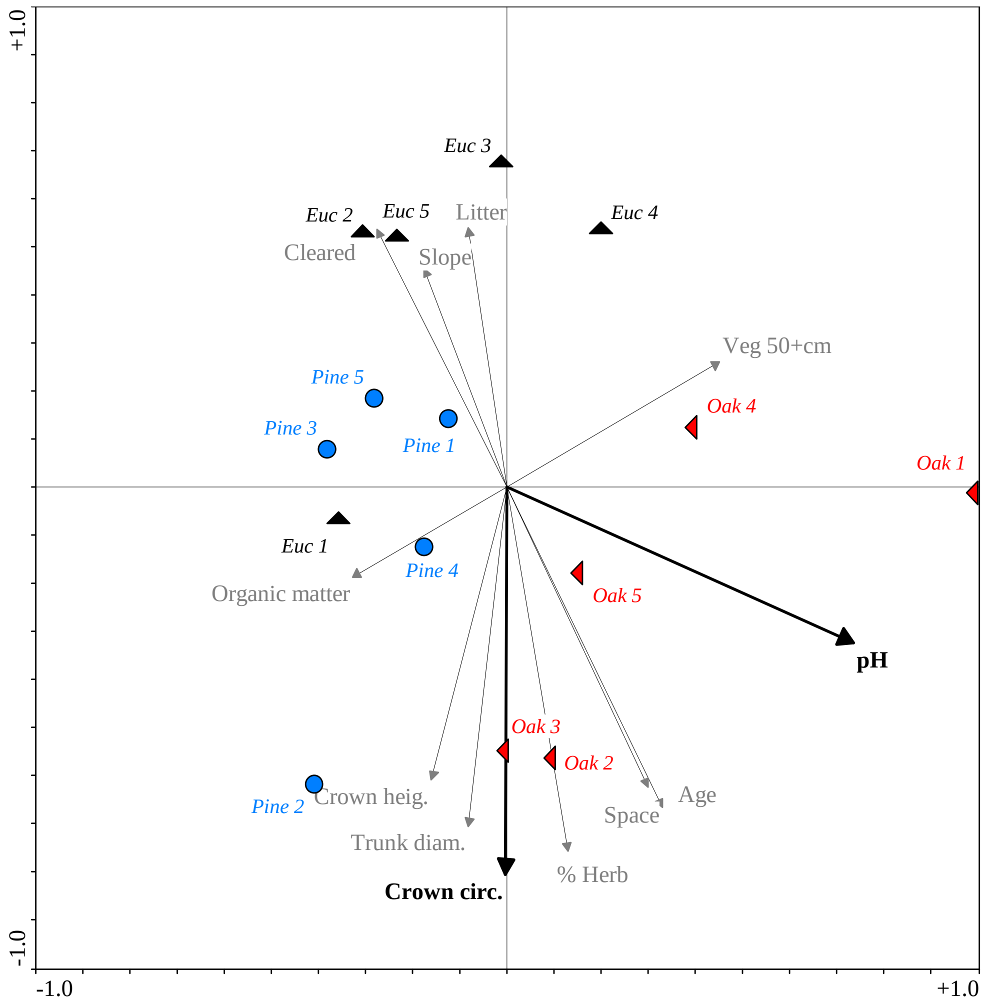
Axes	1	2	3	4	Total inertia
Eigenvalues:	0.223	0.118	0.055	0 .031	1.118
Lengths of gradient:	1.796	1.622	1.072	1.655	
Cumulative % variance					
of species data :	20.0	30.5	35.5	38.2	

Canonical Correspondence Analysis (CCA) (ter Braak, 1986) with automatic forward selection and associated Monte Carlo Permutation tests (involving 199 unrestricted permutations) was used to identify the environmental variables that exerted the most influence on species distribution. Figure 17 shows the CCA ordination diagram of the 20 sites based on their spider population and influence of environmental variables. The eigenvalues obtained for the 4 axes, which can give an indication of the amount of community variation explained by each axis was 0.223, 0.146, 0.129 and 0.107 (for Axes 1 to 4, respectively). Separation of the different land-use types following CCA ordination was more explicit than shown in the Twinspan and DCA calculations, and clearly suggested that the environmental variables have a significant effect on species distribution. This was confirmed following an automatic forward selection with Monte-Carlo Permutation test that indicated both soil pH and crown circumference exerted the most significant influence on the distribution of species (F-ratios 2.19 and 1.67, P-value = 0.005), (Table 11, and highlighted in bold on Figure 17). Table 11 shows the results of the significance tests obtained following stepwise selection and application of the first 12 environmental variables run by the test.

Table 11: Monte-Carlo Permutation Test results on the influence of environmental variables on species distribution in 15 woodland sites in Mafra, 2001.

VARIABLE	F-RATIO	P-VALUE	VARIABLE	F-RATIO	P-VALUE
Soil pH	2.19	0.005*	Litter depth	1.40	0.190
Crown circ.	1.67	0.005*	Organic cont.	1.15	0.380
% herb	1.23	0.165	P	1.33	0.255
K	1.39	0.085	% Veg 50+cm	1.17	0.360
Age	1.37	0.145	Mg	1.23	0.290
Trunk diam.	1.30	0.200	Slope	1.02	0.490

Figure 17: Ordination diagram using Canonical Correspondence Analysis of 15 sites in Mafra, Portugal based on spider abundance data (of species trapped with 5 or more individuals, log transformed *log (n+1)* in 2001.



Axes	1	2	3	4	Total inertia
Eigenvalues:	0.223	0.146	0.129	0.107	1.118
Species-environment correlations:	1.000	1.000	1.000	1.000	
Cumulative % variance					
of species data:	20.0	33.0	44.6	54.1	
of species-environment relation:	20.0	33.0	44.6	54.1	

Figure 18 shows the distribution of sites and species following CCA ordination. All species caught in numbers of 5 or more are shown, with specimens caught between 20-49 and 50+ times identified by number, and listed by corresponding name in Table 12. A high degree of overlap was shown between the specimens collected in all the three woodland types, as shown by the presence of many species plotted in the central point of the 4 axes. Examples include the sheet web weaver *Lepthyphantes tenuis* (Family: Linyphiidae), nocturnal hunters *Dysdera lusitanica*, *Harpactea* sp. 1 and sp. 2 (Family: Dysderidae) and the funnel web builder *Tegenaria bucculenta* (Family: Agelenidae).

Some species are shown to have a particular association with one forest type, as indicated for example in Oak sites by the positive presence of high numbers of species such as the cribellate *Nigma puella* (Family: Dictynidae), diurnal hunter *Pardosa pullata* (Family: Lycosidae), jumping spider *Evarcha jucunda* (Family: Salticidae), nocturnal hunter "*G/L AB*" and the orb weaver *Mangora acalypha* (Family: Araneidae). Species caught in fewer numbers but associated with Oak sites were the cribellates *Cryphoeca citricola* and *Dictyn latens* (Family: Dictynidae), cryptic hunter *Xysticus cristatus* (Family: Thomisidae), jumping spiders *Icius hamatus* and *Salticus confusus* (Family: Salticidae), nocturnal hunter *Agroeca inopina* (Family: Liocranidae), scattered line weavers *Anelosimus pulchellus*, *Theridion simile* and *Theridion varians* (Family: Theridiidae), sheet web builder *Linyphia maura* (Family: Linyphiidae) and nocturnal hunters *Trachelus minor* (Family: Liocranidae) and *Zelotes fulvopilosus* (Family: Gnaphosidae).

Species associated with Pine areas included the diurnal hunters *Alopecosa albofasciata* (Family: Lycosidae) and *Zora spinimana* (Family: Zoridae), nocturnal hunters *Callilepsis concolor*, *Zelotes cf. clivicola* (Zelotes n.sp.), *Zelotes thorelli* (Family: Gnaphosidae) and *Scotina celans* (Family: Liocranidae), scattered line weaver *Episinus truncatus* (Family: Theridiidae), cribellate web builder *Hyptiotes flavidus* (Family: Uloboridae), sheet web builders *Lepthyphantes flavipes* and *Sintula* n.sp. (Family: Linyphiidae), funnel web-builders *Malthonica n.sp.*, *Tegenaria montigena* and *Tetrix pinicola* (Family: Agelenidae), ambusher *Philodromus dispar* (Subfamily: Philodrominae) and jumping spider *Pseudoeuophrys erratica* (Family: Salticidae).

Eucalyptus Site 1, which was located in the protected national park Tapada de Mafra was shown to have an association with the linyphiid sheet web builders *Lepthyphantes zimmermanni* (a relatively common species) and *Lepthyphantes ollivieri* (an extremely rare species). More revealing however, was the fact that no other species collected in numbers of five or over had any association with the remaining Eucalyptus groups.

Fig. 18: CANOCO ordination diagram of Mafra species, based on specimens caught in numbers equal to or exceeding 5 individuals, and highlighting in plain and bold numbers exceeding 20-49 and 50+ individuals, respectively.

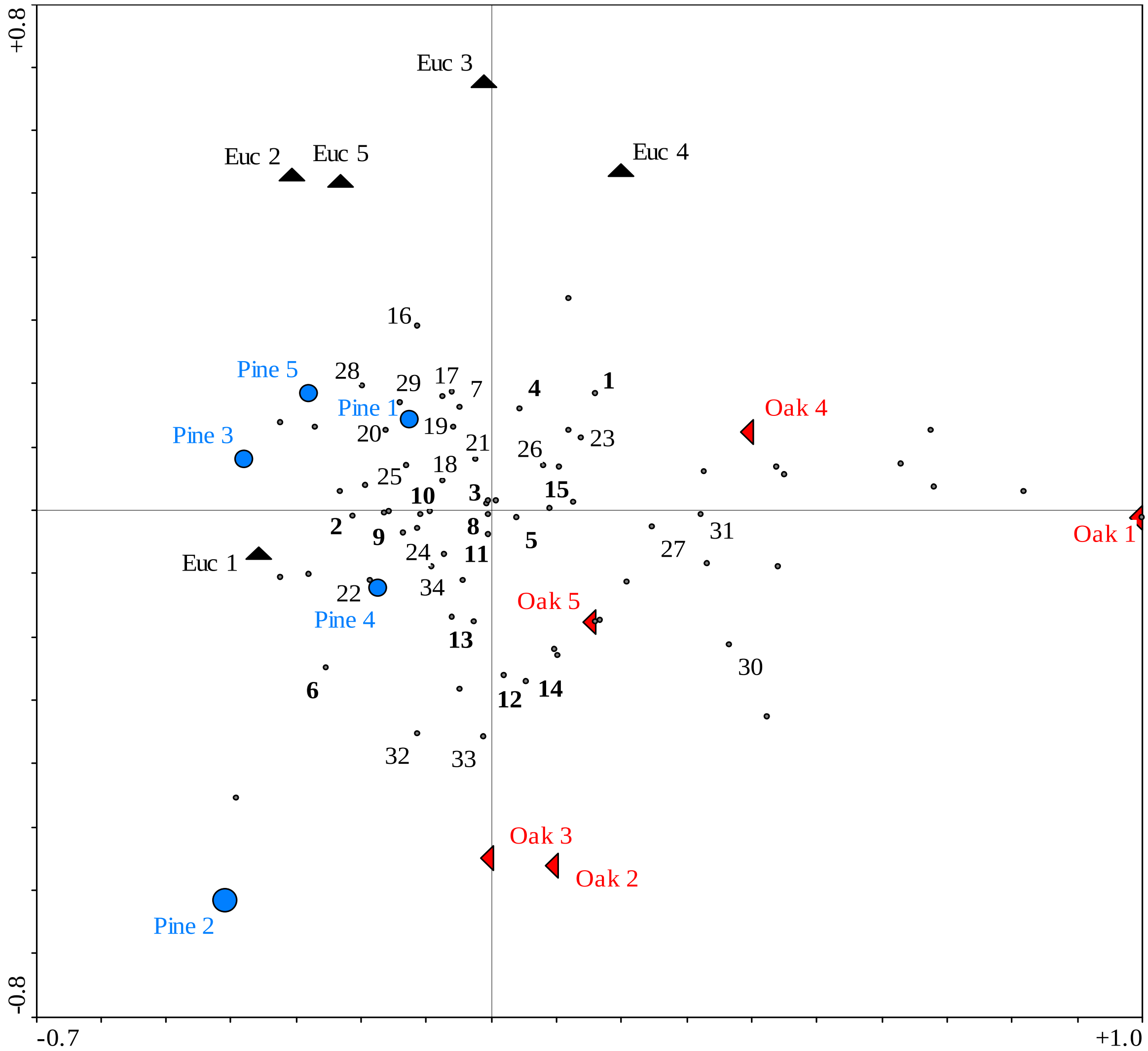


Table 12: Abundance data and respective guild association of species trapped in forest sites in Mafra, as listed in Figure 18. The ten most common species are highlighted according to forest habitat preference (red - Oak, blue - Pine), while non-highlighted entries indicate generalists.

Number	*Guild*	*Species*	*No. of individuals*
1	Diurnal hunter	*Z. machadoi*	417
2	Funnel web	*T. montigena*	236
3	Sheet web weaver	*L. tenuis*	175
4	Trapdoor	*Nemesia sp.*	152
5	Nocturnal hunter	*Harpactea sp. 1*	125
6	Funnel web	*T. pinicola*	125
7	Nocturnal hunter	*Z. reconditus*	120
8	Nocturnal hunter	*D. lusitanica*	95
9	Funnel web	*Malthonica sp.*	91
10	Funnel web	*T. bucculenta*	91

Table 12: Abundance data and respective guild association of species highlighted in Figure 18 (cont.).

Number	***Guild***	***Species***	***No. of individuals***
11	Nocturnal hunter	*Harpactea sp. 2*	86
12	Diurnal hunter	*P. pullata*	82
13	Diurnal hunter	*P. hortensis*	78
14	Funnel web	*M. lusitanica*	60
15	Orb weaver	*M. acalypha*	55
16	Jumping	*E. semiglabrata*	49
17	Diurnal hunter	*A. albofasciata*	48
18	Sheet web weaver	*L. stygius*	47
19	Nocturnal hunter	*Z. medianus*	39
20	Sheet web weaver	*Sintula n. sp.*	37
21	Scattered line weaver	*T. mystaceum*	36
22	Sheet web weaver	*L. flavipes*	33
23	Jumping	*E. erratica*	32
24	Nocturnal hunter	*G/L CD*	30
25	Diurnal hunter	*Z. spinimana*	29
26	Sheet web weaver	*M. elegans*	24
27	Sheet web weaver	*N. puella*	24
28	Jumping	*P. erratica*	24
29	Scattered line weaver	*E. truncatus*	22
30	Jumping	*E. jucunda*	22
31	Nocturnal hunter	*G/L AB*	21
32	Sheet web weaver	*H. corrugis*	21
33	Nocturnal hunter	*D. fuscipes*	20
34	Scattered line weaver	*E. maculipes*	20
			2566

3.5 DISCUSSION

The role played by habitat structure in relation to spider abundance and assemblage structure has been a subject extensively studied in a variety of natural communities (e.g. Duffey, 1966; Riechart, 1976; Hatley & McMahon, 1980; Abraham 1983; Greenstone, 1984; Uetz, 1975; Uetz, 1991; McIver *et al.*, 1992). Little work however has focused on the species composition or communities associated with different forest type stands in the Mediterranean region, in particular in the Iberian Peninsula. Variations in species richness and assemblage structure between land-use types can infer important ecological hypotheses such as community health and function, and can aid subsequent forestry conservation and management (Nichols *et al.* 1998). To explore the influence of landscape structure on spider biodiversity in a number of different vegetation types in central Portugal we focused on spider richness and assemblage composition in four main land-use types comprising of Shrubland, established Oak woodland, mixed-Pine forests and exotic, monoculture eucalypt plantations. Such groups, each comprising of five replicate sites, gave a representation of four land-use types experiencing differing degrees of anthropogenic stress, and ranged from the relatively undisturbed natural vegetation through to the intensively managed plantations.

Specifically, we aimed to examine the role played by structural complexity and vegetation architecture on spider assemblage structure and distribution of species following the application of multivariate statistics. Presence/absence data were used to study associations with land-use type, in order to predict distribution of species across the landscape scale (Scott *et al.*, 2002). Alpha diversity was calculated using a variety of species richness estimators such as the Log series α, Margalef, Reciprocal Berger-Parker and Reciprocal Simpson indices. The use of such indices in ecology has been a focus of much criticism over the years (e.g. Green, 1979; Magurran, 1988) as both species richness and relative abundance of species are combined to give a single value of diversity, with many arguing that such a simplification results in a loss of information (e.g. Green, 1979). However diversity values, especially when combined with simple species rank-abundance plots can provide ecologists with a quick and easy way of comparing different sites. Magurran (1988) has reviewed the advantages and disadvantages of using a number of diversity indices. One criticism of the Log series α index was given by Butterfield & Coulson (1983) who found that this index underestimated diversity in large samples, while overestimating diversity in small samples.

Shrubland and Oak, the two different land-use types exposed to the lowest levels of environmental disturbance, were found to be the most diverse in terms of species richness by both the Log series α and Margalef indices. Using the former index, both Pine and Eucalyptus gave similar diversity values, while the latter identified Pine to be slightly more diverse than Eucalyptus. In terms of dominance/evenness of the species abundance data, very different results were obtained with the reciprocal Berger-Parker and reciprocal Simpson indices: lowest dominance and therefore greatest evenness, were calculated in Pine and Eucalyptus sites, while greatest dominance and lowest evenness were found in Shrub and Oak areas. When compared, high correlation was established between the two richness indices and also between the two dominance indices. This is in general agreement with Goodman (1975) who found that rankings produced by species richness indices were often highly correlated, as were those calculated from dominance indices. When the two types of indices were compared however, the rankings often differed notably (Goodman, 1975). In the present work, the dramatic differences in rankings could be explained from the differential mobility rates, changes in vegetation complexity and subsequent trapping success that resulted in the over-representation of highly active species and under-representation of sedentary spiders. As the Berger-Parker and Simpson indices are not dependent on species richness, but rather on the abundance of common species, a relatively small sample size could introduce bias into the calculation (Magurran, 1988). Consequently, we concur with the findings that evenness measures are best applied in community studies where there is a very large sample size and total species richness is already known (Peet, 1974). As this study was carried out over a comparatively short time and involved the comparison of different land-use type we believe it would be a safer approach to use indices that are based on species richness data, as opposed to those based on community dominance. This was particularly evident from the observation that although pitfall trapping was numerically the most successful technique for catching ground dwelling spiders, manual collection of spiders using sweep netting and vegetation beating accounted for a significant number of web building spiders. Furthermore we feel justified in using such indices for two main reasons: there were no significant differences in sample size between sites and because numbers of adults collected were relatively modest when compared to juvenile data (see Butterfield & Coulson, 1983).

A simple one-way analysis of variance, followed by a Duncan's post-hoc test indicated Pine, Oak and Shrub to be significantly richer in terms of observed species than Eucalyptus. To provide an improved value of richness, we applied non-parametric estimators using the software programme EstimateS. Accumulated species richness curves were plotted, and estimates of species richness were calculated and compared. Clear differences were found in the values obtained by the different estimators, and in most sites an asymptote figure was not reached. Although not perfect, the use of such techniques does provide us with an improved estimate of true species richness when compared to baseline observed richness values. Without exception, in all of the estimators used, overall estimated richness was highest in Shrubland, followed by (in decreasing value) Oak, Pine and Eucalyptus.

ß-level ordinal similarity indices such as the Jaccard (C_J), Morisita-Horn (C_{mH}), Sørenson Incidence (C_S) and Sørenson Abundance (C_N) indices were applied to calculate similarity/non-similarity between spider communities from the different land-use types. Such indices reflect degree of change in species diversity between habitats, and allow us to evaluate and compare the numbers and species found in different communities. Both the Morisita-Horn and Sørenson Abundance Indices indicated Oak and Shrubland groups to share the highest number of species, with species exclusivity highest in Shrubland. Such exclusion was confirmed following an analysis using Twinspan that completely separated Shrubland from the three forest types. In contrast, Oak and Pine sites were found to be the most similar in terms of shared observed species using the Jaccard Index and Sørensen (Incidence) index. In three of the four indices used, Pine and Shrubland were found to be the least similar. When choosing the most appropriate index, we found the Morisita-Horn index to be the most satisfactory. This index has been shown to perform better than either the qualitatively based (binary) Jaccard Index or the Sørensen (Incidence) Index (Smith, 1986; Magurran, 1988) as it is based solely on abundance data and is the least dependent on sample size and species richness compared to other indices (Morisita, 1959).

Ordination techniques were applied to study overall similarity and characterize species association with forest type. The application of such techniques has been used successfully on large, complex ecological datasets to extract patterns of species distribution (Rushton *et al.*, 1989). To investigate the role of structural complexity on spider habitat requirements (see Duffey, 1966) we carried out a Canonical Correspondence Analysis followed by a Monte Carlo Permutation test on the woodland data. This technique allowed us to map both site and species position in ordination space, and test the influence of measured environmental characteristics on species distribution.

A comprehensive review of the proximal factors (such as microclimate, habitat structure, disturbance, availability of prey and territoriality) was carried out by Samu *et al.* (1999) who reported that micro-habitat selection is related to biological need such as web placement opportunities, prey availability, oviposition sites and the avoidance of interspecific encounters or harsh climatic conditions (see also Post & Riechert, 1977). McIver *et al.* (1992) outlined three factors that play a significant role on epigeal spider composition: canopy closure, litter development and availability of prey. The first factor, closure of the canopy, acts to maintain equilibrium of the forest floor microclimate (McIver *et al.*, 1992). Huhta (1971) categorized spiders according to whether they were influenced by light or by levels of moisture, with such variables inextricably linked to canopy closure. Site wetness has also been shown to influence distribution of spiders in heathland (Merrett & Snazell, 1983). Several authors have identified from a variety of manipulation experiments that web-site selection is related in particular to humidity in some species of Araneid, Tetragnathid and Linyphiid spiders (Enders, 1977; Gillespie, 1987; Samu *et al.*, 1996), and to temperature in the funnel web-spider *Agelenopsis aperta* (Riechert, 1985).

The results obtained from our analyses strongly suggest both soil pH and crown circumference were the two major factors influencing spider distribution in the sampled sites, with the spiders showing a preference for sheltered areas of neutral soil pH, as found in both the Oak and Shrubland sites. This was in opposition to low levels of association in Eucalyptus, which was characterized by open areas of acidic soil. As micro-habitat selection is related to micro-climate this result is not entirely surprising, especially in a Mediterranean climate, where daytime temperatures can easily reach, and sustain, temperatures of 35°C (95°F). Of particular concern was the lack of association of spiders with Eucalyptus areas. It should also be noted that of the five Eucalyptus sites randomly chosen in this study, only one site (Eucalyptus Site 2) had been cleared of vegetation. Although site clearance can help lower the chances fire spread, it can have a detrimental effect on spider populations (Nyffeler *et al.*, 1994; Thomas & Jepson, 1997). As site clearance is a common practice in Portugal, we can only conclude that the loss of biological diversity in Eucalyptus forests is critically underestimated. Further studies should ideally focus on comparing different aged stands of Eucalyptus to determine successionary effects and/or keystone vegetation species.

Although physical factors appear to affect species distribution in the three main woodland types, no studies were made on inter-specific competition or prey availability. The present work showed a higher proportion of ambushers, diurnal hunters and orb-weaving spiders were trapped in Oak and Shrubland, while Jumping spiders and Funnel web spiders were represented in higher proportions in Eucalyptus and Pine areas, respectively. Web placement in undisturbed areas can reflect habitat structure requirement for optimum energy expenditure in web building species (Robinson, 1971) and as such help us characterize habitat associations based on a spider's sensory perception and prey capture technique (Uetz, 1991). In addition, web placement is often linked to habitats where prey is abundant (Kirby & Spence 1815; cited by Cherrett, 1964). As residence times are comparatively shorter in micro-habitats where prey is scarce (Gillespie, 1987; Weyman & Jepson, 1994), future studies should also be based on resource partitioning and coexistence of species, with particular emphasis placed on prey preference/abundance and timing of life cycle strategies. Vertical stratification was also clearly found between the numbers of juvenile spiders collected manually when compared to the adult catch. As this separation may be a mechanism whereby cannibalism levels are reduced following reproduction (Samu *et al.*, 1999), further studies should take into account intra-guild predation. Future studies should also include the role of natural enemies such as birds, and in particular, lizards on spider abundance and diversity. Such organisms could have greater influence than previously attributed on spider numbers and would help to give us an insight on the role played by spiders as intermediate representatives in the local food web. In the present work, a number of lizards were only found trapped in pitfalls laid in eucalypt plantations and it would have been interesting to study this further.

Clearly, the inability to collect all of the species present within a locality, no matter the intensity or sampling effort and experience of the collector, must be taken into account when comparing species richness estimates between sites. Care must be given when equating the number of species collected throughout the duration of the sampling period with the actual number of species present in the community. In addition, the disproportionate use of different trapping methods (for example continuous pitfall trapping versus timed blocks of manual collection) will not accurately reflect the true proportion of representatives from different foraging guilds. Pitfall trapping, although strongly reflecting temporal variations and spatial patterns of richness, can only be used to determine site-specific activity of species and should be used with care when comparing communities, as changes in, for example, ground vegetation complexity, trap placement and climatic conditions can lead to differential mobility rates between individuals. (Greenslade, 1964; Southwood, 1978; Turnbull, 1973). For all its criticisms though, pitfall trapping has been shown to be a good estimator of number of epigeal spider species when used in a variety of habitats, including those that do not have a leaf litter (Breymeyer, 1966; Gist & Crossley, 1973; Uetz & Unzicker, 1976), and is a simple, economical and continuous method of trapping. Finally, it should be stressed that sampling over a period of 5-6 months will not accurately reflect yearly temporal variations in species distribution, while manual sampling during daylight hours will ultimately negatively bias estimates of nocturnal foliage dwellers.