

Butterfly, spider, and plant communities in different land-use types in Sardinia, Italy

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Abstract. Butterfly, spider, and plant species richness and diversity were investigated in five different land-use types in Sardinia. In 16 one-hectare plots we measured a set of 15 environmental variables to detect the most important factors determining patterns of variation in species richness, particularly endemism. The studied land-use types encompassed homogeneous and heterogeneous shrublands, shrublands with tree-overstorey, *Quercus* forest and agricultural land. A total of 30 butterfly species, among which 10 endemics, and 50 spider (morpho)species, were recorded. Butterfly and spider community composition differed according to land-use type. The main environmental factors determining diversity patterns in butterflies were the presence of flowers and trees. Spiders reacted mainly to habitat heterogeneity and land-use type. Traditional land-use did not have adverse effects on the diversity of butterflies, spiders, or plants. The number of endemic butterfly species per treatment increased with total species richness and altitude. Butterfly and spider richness did not co-vary across the five land-use types. Butterflies were, however, positively associated with plant species richness and elevation, whereas spiders were not. Conclusively, butterflies did not appear to be good indicators for spider diversity and species richness at the studied sites.

Introduction

Endemic species are often found on islands, as isolation is conducive to speciation (Grant 1998). Consequently, the search for the causes of global patterns of endemism implicitly regards the origin of species diversity, still one of the most challenging and least understood issues we are presently dealing with is biological science. Contrary to general belief, endemic species and patterns of endemism are insufficiently known, even in well-studied Western Europe (Deharveng 1996; Jansson 2003). This also holds true for well understood taxa like mammals; only last year a new endemic bat species was described from Sardinia (Muccedda et al. 2002).

Endemism and extinction are closely coupled (IUCN 2001): the more endemic species occur in an area, the more vulnerable this particular area is, as extinctions

cannot be compensated from elsewhere. Reports since 1600 show that a majority of extinctions in various groups of organisms, from invertebrates to mammals, and plants, were insular taxa (Frankham 1997). The major cause of species' extinctions on islands in the past 50 000 years were human activities (Olson 1989). In our study region Sardinia, which is among the European hotspots of biodiversity and endemism (Médail and Quézal 1999), human activities brought about the extinction of most of the autochthonous mammalian fauna and the gradual introduction of more than 25 mammal species, which constitute the present wild and domestic fauna. Such a turnover has also been recorded on other Mediterranean islands (Vigne 1992). These extinctions include the endemic rabbit *Prolagus sardus* (Lagomorpha, Leporidae), known from subfossil remains found on Corsica, Sardinia, and adjacent small islands, a number of mice-like, insectivorous mammals (e.g., *Nesiotites*, *Tyrrhenicola*, *Rhagamys*), and the giant deer, *Megaceros* (see Vigne 1992). *Prolagus* was an important part of neolithic human's diet, as testified by the great amount of skeletons found in human-inhabited caves, such as the Grotta di Corbeddu near Oliena, and is an early example of human induced extinction of an island species.

Today, however, human induced threats are of a very different kind. Sardinia has become a popular tourist destination, entailing an increased exploitation of the coastal areas. Afforestation programmes and frequent large fires are threatening the natural diversity of the island's interior (Grill et al. 2002); the introduction of fish has been reported to seriously threaten endemic amphibians (Lecis and Norris 2003). The island is not only known for its high proportion of endemic species, for example, 300 out of 2500 plant species are endemics (P. Casula, personal communication), and 14 out of 56 butterfly species are endemics (Grill et al. 2002). Sardinia is also one of Europe's last reserves of virgin evergreen oak forests, *Quercus ilex*, and dense Mediterranean shrublands. These Mediterranean shrub-communities with little or no tree overstorey form a unique vegetation type (Arroyo and Marañón 1990) and have recently been proposed to be included in EU and IUCN conservation policies (Andrés and Ojeda 2002). Their uniqueness consists in their species richness and high levels of endemism (Ojeda et al. 2000). In Sardinia, for example, the majority of the endemic butterfly species occurring on the island rely on shrub communities (Grill et al. 2002). These communities are usually associated with cultural landscapes (Webb 1998), and have developed as the result of forest clearance followed by centuries of traditional land-use (such as burning, cutting, and livestock grazing) (Pungetti 1995). Our era's increased human induced pressure could, however, damage them severely. In order to plan sustainable land-use, it is necessary to understand why a species occurs in a particular habitat and not in another. If we understand the niche characteristics associated with the occurrence and abundance of a species in an area, we might have a key to understand better the reasons why species go extinct, when these niche characteristics change.

In this paper, we investigate the habitat ecology of Sardinian butterflies, with the aim of extending the knowledge on the habitat association of endemic species. To compare butterflies' habitat associations to a group with potentially different habitat requirements, spiders are used as a predatory, non-flying counterpart to the plant-

eating, flying butterflies. The diversity of both groups is analysed in relation to plant diversity, with the general aim of detecting environmental variables that determine patterns of variation in species richness, particularly endemism.

The following three questions are addressed: (i) Which are the main environmental factors that determine the structure and composition of the butterfly and spider communities? (ii) How are butterfly, spider, and plant diversity associated? (iii) Do different land-use practices influence species richness and the presence of endemics?

Methods

Study area

The study sites are situated in South-East and Central Sardinia, Italy (Figure 1). They are dominated by Mediterranean shrubland, with patches of dense shrub and trees, similar to the type of communities described in Andrés and Ojeda (2002). Common plant species are: *Cistus salvifolius*, *Cistus monspeliensis*, *Arbutus unedo*, *Euphorbia dendroidea*, *Asphodelus aestivus*, *Rubus* spp., *Erica arborea*, *Phillyrea latifolia*, *Olea europea*, *Q. coccifera*, *Q. ilex*, and *Q. suber*. Altitudes of the study sites range from 80 to 950 m a.s.l. The climate is Mediterranean with an arid hot summer season, cool winters, and little rainfall.

Plot design and sampling

Butterfly and spider species richness and community composition, were related to plant diversity, and 15 environmental variables. These were measured in 16, 100 m × 100 m plots that were selected to be situated in five different land-use types: three types of extensively grazed shrubland: low shrub (LS), grassland with low shrub (GS), and high shrubs with grass and trees (ST), protected *Q. ilex*-forest (QU), and agricultural land (AG) with *Eucalyptus* spec. stands (Table 1). Plots were assigned to the categories 'homogeneous' and 'heterogeneous' according to their apparent structural plant diversity. Each plot was georeferenced with a handheld GPS device (Garmin 12XL). All field-sampling was conducted in May–June 2001.

Each of the 16 large plots was divided into subplots of 20 m × 20 m size (Figure 1). In each such subplot, the following 15 environmental variables were measured in 12 non-adjacent, systematically selected subplots: (1) altitude, (2) slope (measured with a clinometer), cover of: (3) herb, (4) moss, (5) fern, (6) grass, (7) rock, (8) bare-ground, (9) trees < 10 m, (10) trees > 10 m, (11) shrubs < 2.5 m, and (12) shrubs < 0.5 m (visually estimated as the percentage of the plot surface), (13) count of flowerheads (from classes with <10, >10, >20, or >50), (14) moisture (xeric, mesic), (15) %-cover of most common plant species.

For butterfly sampling, 10 observation hours were spent in each plot, during daytime. The plot was crossed repeatedly on foot from one end to the other at a steady pace, which was only interrupted to note down butterflies. Butterflies were mostly

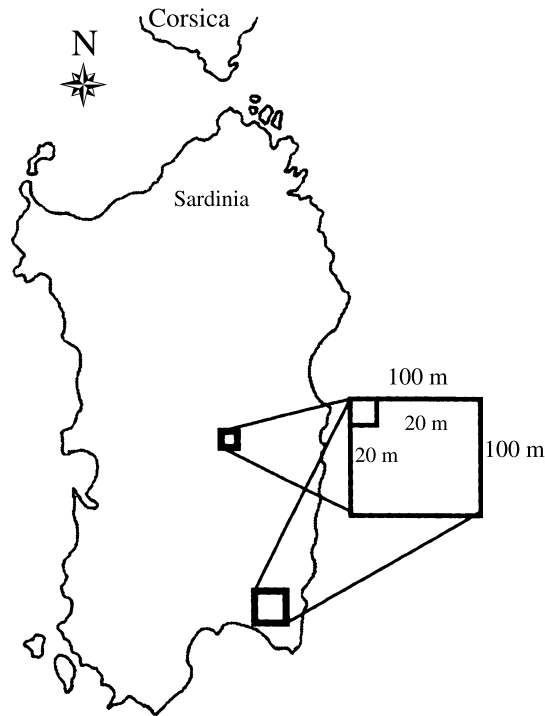


Figure 1. Location of the study sites, and structure and size of the plots.

identified on the wing, or caught with a hand held net and released immediately after identification.

Spiders were sampled with a sweep-net (diameter: 38 cm), taking 3×20 sweeps at each plot. As a consequence, our sampling method detected only spiders sitting in the vegetation at an easily-reachable height; tree-canopies and ground-dwelling species were probably not exhaustively sampled. A number of spider species were only present as juveniles in this period of the year, and could not be identified further than to genus or family level. Such individuals were included as morpho-species. In butterflies, a few early, or very late flying species could have been missed, as sampling time was restricted to a particular time of year.

Analyses

Butterfly and spider diversity were estimated in terms of species richness (S) and Shannon diversity index (H). The Shannon diversity index (Spellerberg and Fedor 2003) is:

$$H = - \sum_{i=1}^n p_i \ln p_i$$

Table 1. The 16 plots used for butterfly, spider and plant sampling. Given are land-use type, vegetation structure, management, geographical position, and altitude (m a.s.l.).

Land-use type	Abbreviation	Heterogeneity	Management	Easting	Northing	Altitude (m)
Low shrub	LS	Homogenous	Extensive grazing	32S 0533538	UTM 4345151	755
Low shrub	LS	Homogenous	Extensive grazing	32S 0534074	UTM 4344994	739
Low shrub	LS	Homogenous	Extensive grazing	32S 0534873	UTM 4345313	791
Low shrub	LS	Homogenous	Extensive grazing	32S 0534101	UTM 4347359	674
Grass + low shrub	GS	Heterogenous	Extensive grazing	32S 0534026	UTM 4344758	731
Grass + low shrub	GS	Heterogenous	Extensive grazing	32S 0535108	UTM 4345390	810
Grass + low shrub	GS	Heterogenous	Extensive grazing	32S 0534464	UTM 4346463	670
Grass + low shrub	GS	Heterogenous	Extensive grazing	32S 0534046	UTM 4344433	722
Grass + high shrub + trees	ST	Heterogenous	Extensive grazing	32S 0535551	UTM 4346011	924
Grass + high shrub + trees	ST	Heterogenous	Extensive grazing	32T 0533134	UTM 4431692	941
Grass + high shrub + trees	ST	Heterogenous	Extensive grazing	32S 0534042	UTM 4344398	724
Grass + high shrub + trees	ST	Heterogenous	Extensive grazing	32S 0534188	UTM 4344709	737
Grass + high shrub + trees	ST	Heterogenous	Extensive grazing	32S 0536098	UTM 4346388	689
<i>Q. ilex</i> forest	QU	Homogenous	Protected area	32S 0536292	UTM 4346785	681
<i>Q. ilex</i> forest	QU	Homogenous	Protected area	32S 0535447	UTM 4347014	686
Agricultural land	AG	Heterogenous	Abandoned	32S 0526643	UTM 4346633	82

where p_i is the proportion of individuals that the i th species contributes to the total in the sample. This simple measure to characterise a community depends on both species richness and the evenness (equitability) with which individuals are distributed among the species.

In order to assess the main environmental factors that determine butterfly and spider species diversity and community composition, we used the Canonical Correspondence Analysis (CCA) option from the program CANOCO (Ter Braak 1986; Ter Braak and Smilauer 1998). CCA extracts the major gradients in the data that can be accounted for by the measured variables. The position of a species in the resulting plot indicates the characteristics of the ecological optima for this species; its abundance or probability of occurrence will decrease with distance from its species point (McGarigal et al. 2000). In the end, this allows to classify the landscape into probability or abundance surfaces for each species. Samples with sample size $n < 4$ were not included in the CCA analysis because the presence of rare species in any given plot is often dictated by chance (Lesica and Cooper 1998). All species abundances were $\log_{10}(x + 1)$ transformed. A forward selection procedure using a Monte-Carlo permutation test with 1000 iterations was used to select the most significant ($p < 0.05$) environmental variables that explained variation in community structure.

The associations between plant, butterfly, and spider species richness were tested with Pearson correlations (two-tailed), as was the association between species richness and the elevation (m a.s.l.) of a sampling site. The significance of differences between the sites was assayed with Student's t -tests.

As many spider species had to be omitted from the CCA analysis due to small numbers of individuals, for spiders, we also present an unconstrained ordination analysis called Principal Coordinate Analysis (PCA). The ecological structure of the spider community was analysed by (1) Jaccard's similarity index (Sokal and Sneath 1963) for all pairs of individuals based on the habitat they were found in, (2) the resulting similarity matrix was factored and ordinated by PCA using the program NTSYS 1.80 (Rohlf 1993).

Results

At the 16 sites sampled, we recorded a total of 30 butterfly species belonging to four different families (Table 2), and 50 (morpho) species of spiders (24 identified to species level) from 13 families (Table 3). Ten butterfly species were endemics. All, except two of these also occur on Corsica, and 20 (i.e., all non-endemics) occur on Sicily (Higgins and Riley 1970). No endemic spider species were found at any of our study sites. Fifteen of the 24 spider species identified to species-level are on the species list of Sicily (Pesarini 1994; Platnick 2003), and 17 are on the Corsican list (Canard 1989). Several spider species are distributionally restricted to southern Europe, namely, *Micrommata ligurina*, *Monaeses paradoxus*, *Tmarus piochardi*, and *Cyclosa insulana*.

Table 2. Butterfly species observed in different land-use types in Sardinia from May to June 2001. Species present on the neighbouring islands, Sicily and Corsica are indicated as well as the type of larval food plant each species uses according to Carter and Heagreaves (1987). G = grasses, H = herbs, S = shrubs, T = trees, LS = low shrub, QU = *Quercus* forest, GS = grass + shrubland, ST = shrubland + trees, AG = agricultural land.

Lepidoptera	Land-use type					Sicily	Corsica	Food-plant
	LS	QU	GS	ST	AG			
Nymphalidae								
<i>Aglais urticae ichnusa</i> Hübner 1824		x	x	x			x	H
<i>Argynnis paphia</i> L. 1758		x				x	x	H
<i>Lasiommata megera paramegera</i> Hübner 1824			x	x			x	G
<i>Nymphalis polychlorus</i> L. 1758	x	x	x			x	x	T
<i>Papilio hospiton</i> Gén� 1839			x	x			x	H
<i>Pararge aegeria</i> L. 1758		x	x	x		x	x	G
<i>Polygonum c-album</i> L. 1758			x			x	x	H + T
<i>Vanessa atalanta</i> L. 1758		x	x			x	x	H
<i>Vanessa cardui</i> L. 1758	x		x	x	x	x	x	H
<i>Charaxes jasius</i> L. 1766		x	x	x		x	x	T
<i>Coenonympha corinna</i> Hübner 1804	x				x		x	G
<i>Hipparchia aristaeus aristaeus</i> Bonelli 1826				x			x	G
<i>Hipparchia neomiris</i> Godart 1824			x				x	G
<i>Hipparchia</i> spp.		x						G
<i>Maniola jurtina</i> L. 1758		x	x	x	x	x	x	G
<i>Maniola nurag</i> Ghiliani 1852		x	x	x				G
<i>Pyronia cecilia</i> Valantin 1894	x		x	x	x	x	x	G
Lycaenidae								
<i>Aricia agestis</i> Schifferm�ller 1775		x	x		x	x	x	H
<i>Callophrys rubi</i> L. 1758						x	x	S
<i>Celastrina argiolus</i> L. 1758		x	x	x	x	x	x	H + T + S
<i>Lampides boeticus</i> L. 1767				x		x	x	H
<i>Lycaena phleas</i> L. 1761			x	x	x	x	x	H
<i>Polyommatus icarus</i> Rottemburg 1775		x	x	x		x	x	H
<i>Pseudophilotes barbagiae</i> De Prins and Van der Poorten 1982				x				H
Pieridae								
<i>Artogeia rapae</i> L. 1758	x	x	x	x	x	x	x	H
<i>Colias crocea</i> Fourcroy 1785	x		x	x	x	x	x	H
<i>Gonepteryx cleopatra</i> L. 1767	x		x			x	x	S
<i>Gonepteryx rhamni</i> L. 1758		x	x		x	x	x	S
<i>Euchloe insularis</i> Staudinger 1861			x	x	x		x	H
<i>Pieris brassicae</i> L. 1758	x		x	x	x	x	x	H
Hesperiidae								
<i>Spialia sertorius therapne</i> Hoffmannsegg 1804			x				x	H
Total number of species	8	14	24	19	12	20	28	
Total number of endemics	0	1	7	7	2			

Table 3. Spider species observed in different land-use types in Sardinia from May to June 2001. Species present on the lists of the neighbouring islands, Sicily and Corsica are indicated according to Pesarini (1994) and Canard (1989). G = grasses, H = herbs, S = shrubs, T = trees, LS = low shrub, QU = *Quercus* forest, GS = grass + shrubland, ST = shrubland + trees, AG = agricultural land.

Arachnida (morpho) species list	Land-use type					Sicily	Corsica
	LS	QU	GS	ST	AG		
Araneidae							
<i>Araniella</i> spp.			x				
<i>Araniella cucurbitina</i> (Clerck 1757)	x		x	x		x	x
<i>Argiope lobata</i> (Pallas 1772)					x	x	x
<i>Cyclosa insulana</i> (Costa 1834)					x	x	x
<i>Mangora acalypha</i> (Walckenaer 1802)			x	x	x	x	x
<i>Mangora</i> spec.	x						
<i>Neoscona adianta</i> (Walckenaer 1802)	x		x			x	x
<i>Zilla diodia</i> (Walckenaer 1802)	x					x	x
<i>Zygiella</i> spp.					x		
Clubionidae							
Clubionidae spp.					x		
<i>Cheiracanthium</i> spp.	x			x			
<i>Cheiracanthium striolatum</i> Simon 1878				x			
Corinnidae							
<i>Trachelas</i> spp.					x		
Dictynidae spp.							
					x		
Sparassidae							
<i>Micrommata</i> spec.					x		
<i>Micrommata ligurina</i> (C.L. Koch 1845)			x				x
Linyphiidae							
Erigoninae spp.			x				
Linyphiidae spp.	x		x		x		
<i>Lepthyphantes mengei</i> Kulczynski 1887	x					x	
<i>Meioneta</i> spp.	x						
Lycosidae spp.							
					x		
Oxyopidae							
<i>Oxyopes</i> spp.			x		x		
<i>Oxyopes</i> cf. <i>nigripalpis</i> Kulczynski 1891			x	x	x	x	
<i>Oxyopes heterophthalmus</i> Latreille 1804	x			x	x		x
Philodromidae							
<i>Philodromus</i> spp. (<i>aureolus</i> – group)	x		x	x			
<i>Philodromus</i> spp.	x		x	x	x		
<i>Philodromus lividus</i> Simon 1875	x		x	x		x	x
<i>Thanatus</i> spp.			x		x		
<i>Tibellus</i> spp.			x				
Salticidae							
<i>Saltididae</i> spp.	x				x		
<i>Euophrys</i> spp.		x	x				
<i>Evarcha jucunda</i> (Lucas 1846)				x		x	x
<i>Heliophanus kochii</i> Simon 1868			x	x			

Table 3. (continued)

Arachnida (morpho) species list	Land-use type					Sicily	Corsica
	LS	QU	GS	ST	AG		
<i>Heliophanus</i> spp.				x			
<i>Salticus</i> cf. <i>propinquus</i> Lucas 1846	x					x	
<i>Thyene imperialis</i> (Rossi 1846)					x	x	x
Theridiidae							
<i>Anelosimus aulicus</i> (C.L. Koch 1838)				x	x	x	x
<i>Dipoena</i> spp.					x		
<i>Simitidion simile</i> (C.L. Koch 1836)	x			x	x		x
<i>Theridion</i> spp.	x						
Thomisidae							
Thomisidae spp.	x		x	x	x		
<i>Monaeses paradoxus</i> (Lucas 1846)					x		
<i>Runcinia grammica</i> (C.L. Koch 1836)				x	x		x
<i>Synema</i> spp.	x	x		x	x		
<i>Synema</i> cf. <i>plorator</i> (O.P. – Cambridge 1872)	x						
<i>Synema globosum</i> (Fabricius 1775)	x		x	x		x	x
<i>Thomisius onustus</i> (Walckenaer 1806)				x		x	x
<i>Tmarus</i> spp.					x		
<i>Tmarus piochardi</i> (Simon 1866)				x			x
<i>Xysticus</i> spp.	x			x	x		
Total	21	2	18	21	26	15	17

Diversity

Butterfly species diversity was highest in the ‘GS’-sites as indicated by a Shannon’s diversity index value of $H=2.97$, and lowest in the ‘LS’-sites ($H=1.92$); spider species richness was highest in the agricultural-land ($H=3.08$), and lowest in the forest ($H=0.69$). For both animal groups, species diversity was similarly high in the ‘ST’-sites (butterflies: $H=2.76$; spiders: $H=2.67$) (Figure 2). Butterfly species richness increased across the five land-use types as follows: low shrub < agricultural land < *Quercus*-forest < shrubland with trees < shrubland with grass. The number of endemic species per land-use type increased with total species richness (Table 2, Figure 2(B)). For spiders, species-richness increased across land-use types in the following order: *Quercus*-forest < shrubland-with-grass < low shrub < shrubland-with-trees < agricultural-land. Mean species richness did not differ significantly between the different land-use types for any of the three groups (Figure 3).

Habitat association

Flowerhead-abundance and %-tree-cover appeared as the first two axes of a CCA analysis, and explained 55% of the variation in butterfly abundance (Figure 4(A)). Axis 1 (41%) was determined by the abundance of flower heads, Axis 2 (14%) by tree

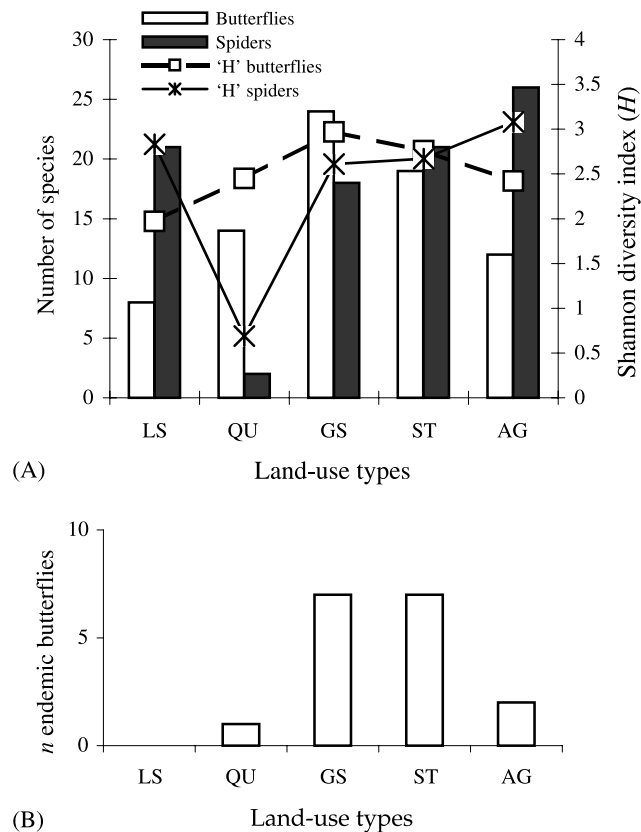


Figure 2. (A) Total number of butterfly and spider species recorded per land-use type, and Shannon diversity index (H). (B) Total number of endemic butterfly species recorded in each land-use type. LS = low shrub, QU = *Quercus* forest, GS = grass + shrubland, ST = shrubland + trees, AG = agricultural land.

abundance. Three of the four endemic species included in the CCA analysis, namely, *Maniola nurag*, *Aglais urticae ichnusa*, and *Lasiommata megera paramegera*, were positively associated with the presence of flower-heads. Another flower-associated species was the lycaenid *Lycaena phleas*. Lycaenids are known to fly preferably in rather open habitats, such as flowery and grassy meadows. This preference was also shown for *Lycaena ottomana* in Greece (Grill and Cleary 2003). *Lasiommata megera paramegera* is usually found in diverse, sometimes grassy, sometimes woody habitats, but appeared here at the extreme end of the flower axis. The two nymphalids *Maniola jurtina* and *Pararge aegeria* were placed on the extreme end of the tree-axis.

The endemic *Maniola nurag* was more associated with the presence of flowers than *M. jurtina*, but less so with trees. *Celastrina argiolus* is similarly associated with trees as *M. jurtina*. Next on the flower-axis was *Aglais urticae ichnusa*. *Charaxes jasius*, *Pieris brassicae*, *Colias crocea*, *Artogeia rapae*, and *Polyommatus icarus* were placed in the centre, and had a moderate association with both axes.

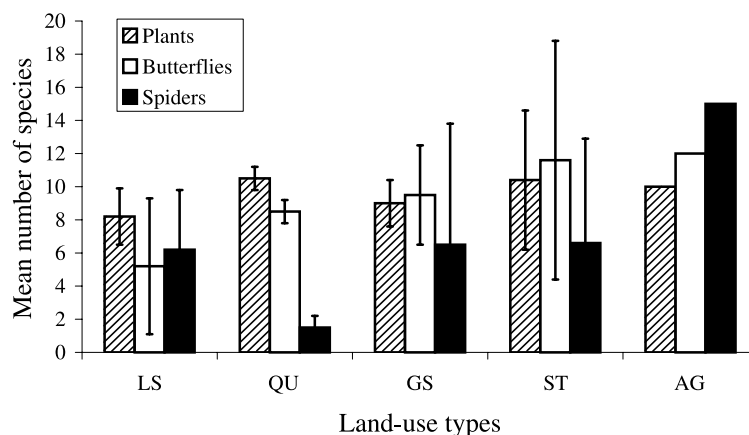


Figure 3. Mean species richness in plants, butterflies and spiders in five different land-use types. LS = low shrub, QU = *Quercus* forest, GS = grass + shrubland, ST = shrubland + trees, AG = agricultural land.

Gonepteryx cleopatra, *Coenonympha corinna*, and *Pyronia cecilia* were at the far end of the flower axis and showed no particular association with either flowers or trees. Subsequent axes were related to topographical variability, and included range in elevation and the proportion of rock-cover. The slope of a site did not result as a determinant factor for butterfly species composition.

For spiders, the first two axes of a CCA analysis were determined by moss-cover (25%) and herb-cover (12%), and explained 37% of the variation in spider abundance. Ground dwelling spiders of the families Salticidae (e.g., *Heliophanus* spp.), Thomisidae, and Philodromidae were less associated with herbaceous vegetation than web-building spiders from Araneidae (e.g., *Neoscona adianta*), Linyphiidae and Oxyopidae (Figure 4(B)).

Spider communities were ordinated into three main groups by the first two axes of the PCA (Figure 5). The first axis (20%) showed land-use as an important factor influencing the community composition of spiders, the second axis (14%) reflected the influence of habitat structure on spider communities and went from homogeneous to heterogeneous habitats. The spider communities in shrubland sites were clearly set apart, as well as the agricultural-communities, with in the centre species that occurred in several different habitats, without any clear association to one or another habitat type (Figure 5). Some species' only occurred at the agricultural site (e.g., *Thyene imperialis*), others only at low shrub sites (e.g., *Salticus* cf. *propinquus*), or high shrub sites (e.g., *Cheiracanthium striolatum*). None of the spider species was restricted to grass-shrub or forest sites.

These same two gradients, habitat heterogeneity and land-use, were also reflected in the number of endemic butterflies per land-use type: the 'GS'-sites and the 'ST'-sites contained most of the observed endemic butterflies (GS = 7, ST = 7; see Table 2), whereas the less heterogeneous and more human influenced 'LS'- and 'AG'-sites contained much fewer endemic butterfly species (LS = 0, QU = 1, AG = 2).

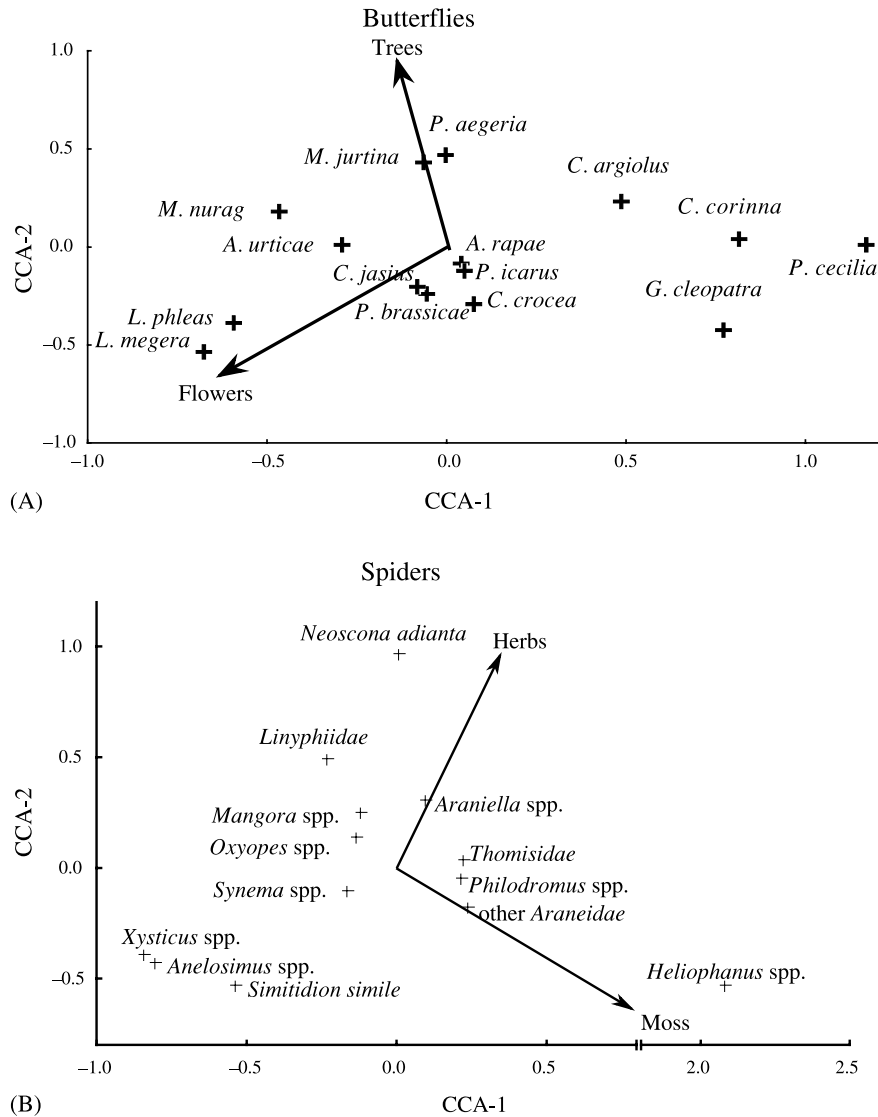


Figure 4. CCA analysis of the composition of butterfly communities at different sites. The two main axes indicate the flower-head abundance ('flowers') and percentage of tree-cover ('trees') as the main factors determining butterfly communities at our sampling sites.

Species richness was significantly, negatively correlated with the elevation of a sampling site for spiders ($r = -0.519$, $P = 0.039$) (Figure 6), and positively, though not significantly correlated for butterflies ($r = 0.409$, $P = 0.118$), but not correlated for plants ($r = 0.175$, $P = 0.516$).

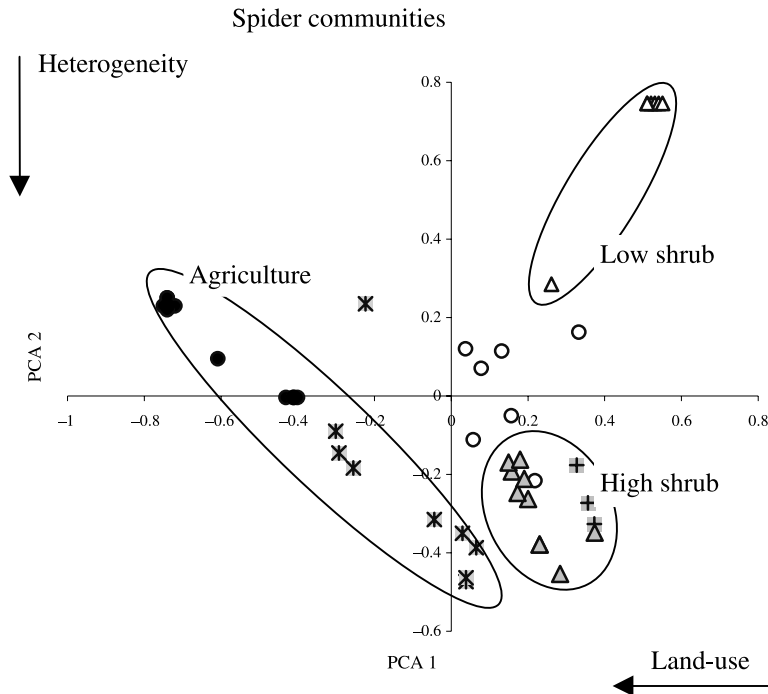


Figure 5. PCA analysis of composition of spider communities. The two first axes indicate the impact of land-use and habitat heterogeneity on the spider communities. Full dots = species limited to the agricultural site; white triangles = species restricted to low shrub sites; crosses = species restricted to high shrub sites; empty dots = species occurring at forest sites and at other land-use types; filled triangles = species occurring at high and low shrubland sites; and asterisks = species occurring at the agricultural site and at least one other habitat type.

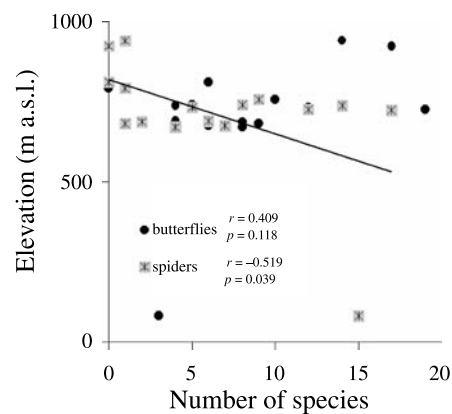


Figure 6. Relationships between butterfly, spider, and plant species richness. n = number of species. (A) Butterflies versus plants, (B) spiders versus plants, (C) butterflies versus spiders.

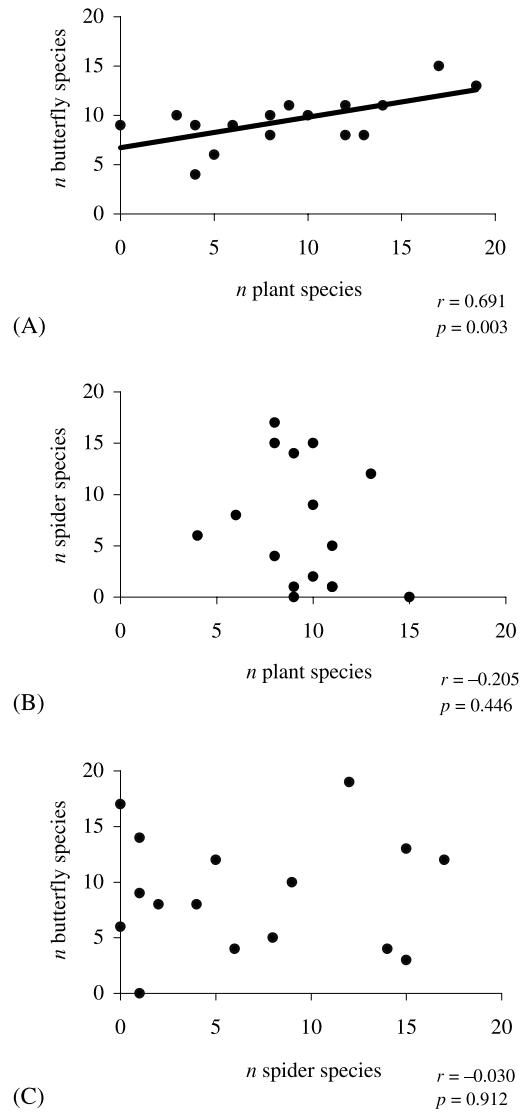


Figure 7. The relationship between butterfly and spider species richness and elevation. Significances were established with Pearson correlations.

Association between butterflies, spiders and plants

Pearson correlations between butterfly, spider, and plant species richness indicated that among these three groups only butterflies and plants are significantly, positively associated, and co-vary across the five land-use types that were investigated

($r = 0.691$, $P = 0.003$) (Figure 7). Spider species richness was not related to plant richness ($r = -0.205$, $P = 0.446$) or butterfly richness ($r = -0.030$, $P = 0.912$).

Discussion

(1) Environmental factors shaping butterfly and spider communities

Butterfly diversity is determined mainly by vegetation composition and structure, and to a lesser extent by topography. Firstly, there is a highly significant, positive relationship between butterfly and plant species richness, and secondly, flower-head-abundance and tree-cover are the two principal environmental variables explaining variation in butterfly species composition. These first two axes of the CCA do not only reflect the butterflies' association with nectar sources ('flower-heads') and shade ('trees'), but also represent a structural gradient from sites with only a single vegetational layer (=shrubs) and no over- or under-storey, through sites with two layers (=grass and shrubs), to sites with three layers (=grass, shrubs, and trees). In the Mediterranean, butterflies often seek shelter in the shade of bushes or trees during the hottest part of the day, a behaviour, that we particularly observed in the satyrids *M. jurtina*, *M. nurag*, and *P. aegeria*. The two ecological gradients represented by the two axes could reflect the differing requirements between larvae and adults. CCA-1 seems related to the adults' ecological requirements, that is, nectar sources, whereas the second axis, CCA-2 appears related to larval requirements, that is, food plants. Seventeen of the butterfly species we analysed feed on herbs (50%), nine on grass (26%), four on shrubs (12%), and another four on trees (12%). These numbers include two polyphagous species whose larvae feed on herbs, shrubs, and trees, namely, *Polygonum c-album* and *Celastrina argiolus* (Table 2). The endemics are either grass- or herb-eating species.

The complexity of plant architecture, that is, vegetation heterogeneity and height, has been reported as an important factor determining Lepidoptera diversity (Haysom and Coulson 1998). We indeed found butterfly diversity to increase with the heterogeneity of a site, an association that is strongest for endemics.

Spider diversity is determined mainly by humidity and vegetation structure. The first two axes of the CCA represent firstly, an ecological gradient from moist to dry habitats, and secondly, a structural gradient from predominantly moss-covered, rocky habitats to herbaceous habitats. Moss-cover is generally indicative for moisture. These two gradients reflect the differing hunting strategies of ground-dwelling and web-building spiders. Web-building spiders usually attach their web on the vegetation. The Linyphiidae for example, make a sheet net and await their prey hanging upside down below their web. Consequently, they appear associated with herbaceous vegetation, where they can attach the web within a certain distance from the ground. Ground-dwelling spiders which do not build webs, like the Thomisidae, Salticidae, and Philodromidae appear less associated with herbs, but are more associated with moisture. Although belonging to the web-builders, the two species of Theridiidae that were included in the analysis, *Anelosimus* spp. and

Simitidion simile, showed no particular association to any of the two axis. The reason for this may be that they build their tangled webs under stones, against trees, fences or walls, and are therefore rather independent of vegetation as fixation points for their webs.

Elevation was also found to be positively related to species richness, but correlations were not significant. Considering, that seven of the nine endemic butterfly species were restricted to mountainous areas (>500 m) (Grill et al. 2003), we expected to find a stronger correlation. Possibly, the lack of significance is due to small sample sizes. Differences in elevation have been shown to be related to diversity in a wide range of taxa (Hawkins and Porter 2003 and references therein, Sutherland 2003), including papilionid butterflies in North America (Kerr et al. 1998), and butterflies and birds in Czech Republic (Storch et al. 2003). Rosenzweig (1995) proposed, that the association between species diversity and elevation reflects a relationship between topographic variation and the number of habitats in an area which is also known to be positively correlated with species richness. However, recent evidence from Californian butterflies suggests that range in elevation is more than just a surrogate for plant diversity and habitat heterogeneity, as the number of habitat types found in an area, was not significantly associated with butterfly richness (Hawkins and Porter 2003).

One of the factors that is often proposed as determining distributional patterns in butterflies, is temperature (Bryant et al. 2002 and references therein). As heliophilous ectothermous organisms they are strongly associated with warmer climate in northern Europe (Bourn and Thomas 2002). In Sardinia, temperature differences between lowland and mountainous areas are possibly responsible for a large part of the differences in endemism richness we find between different areas. On a larger scale, the amplitude of temperature oscillations a given region experienced since the last glacial maximum (Milankovitch oscillations) seems to be a good predictor of endemism in mammals, birds, reptiles, and vascular plants (Jansson 2003). Studies in other parts of the Mediterranean have shown, that endemic species are concentrated in mountainous areas (Balletto 1995). Although we have some evidence that in Sardinia endemism increases with elevation (Grill et al. 2003), much additional work is required to understand the relationship between endemism richness and elevation.

(2) Association of butterfly and spider diversity

Spider species richness does not appear to be associated with butterfly or plant species richness. In two of the five land-use types (low-shrub and agricultural-land) spider diversity was inversely related to butterfly diversity. An inverse relationship to butterflies also appeared in the relationship with elevation, which was significantly negative for spiders, but positive for butterflies (Figure 6). The reason for these inverse relationships could lie in the distinct ecology of the two groups: predatory spiders do not directly rely on plants as food-resources, but only indirectly, that is, if they prey on plant-eating organisms. For the spiders we sampled,

butterflies do not appear to be important prey organisms. Another major difference between these two taxonomic groups is that butterflies have changing habitat requirements in different developmental stages, while spiders rely on similar resources regardless if they are juveniles or adults. An important conclusion here is, that for the areas studied, butterflies are rather bad indicators for the diversity of the spider guild investigated, and vice versa.

Habitat heterogeneity and land-use type seem to have a different effect on spider diversity than they have on butterfly diversity. An explanation for this could be that what is experienced as homogeneous by butterflies and humans is not necessarily homogeneous for spiders. Consequently, spiders might experience human induced disturbance at a different spatial scale than butterflies, and therefore be more resistant to it. Nevertheless, spiders cluster into distinct groups of species that seem determined by gradients of land-use type and habitat heterogeneity. These two factors were also important in shaping the butterfly communities of the different study sites, as discussed above.

(3) Do different land-use practices influence species richness and the presence of endemics?

The Sardinian fauna of spiders encompasses at least 27–29 endemics (Wunderlich 1995). The absence of endemic spider species in our samples, is probably due to methodological restrictions of the sampling method, and does not imply that the land-use types we studied, are unsuitable for endemic spiders. While sweep-nets were used for the present study, pitfall traps have been shown to be a quantitatively more efficient collection method (Zingerle 1999), and might have provided samples with higher numbers of individuals, increasing the chance to detect rare endemic species.

Endemic butterflies occurred primarily in heterogeneous land-use types. The homogeneous low shrubland did not contain a single endemic butterfly species. The two land-use types, where we observed most of the endemics, were shrublands ('GS'- and 'ST'-sites). These types of mountain shrub- and grasslands are known to hold the largest amount of butterfly diversity in Mediterranean landscapes (Munguira 1995). In Sardinia, these shrublands resulted from transformation of former oak forests, such as *Q. ilex* and *Q. pubescens*, through long-term low-level anthropogenic influence (Pungetti 1995). Long-term continuation of traditional land-use is therefore essentially enhancing butterfly diversity in that it prevents shrub- and grasslands from reverting into secondary forests (Grill et al. 2002). Pine- or eucalypt-afforestation sites were not within the scope of this study, and the issue of afforestation has only been touched marginally. Yet, from the observations at the agricultural site, which was partly situated in an *Eucalyptus* plantation, we anticipate that afforestation will have negative effects on species diversity and endemism in Sardinia. Detailed studies on the effects of reforestation in other regions of the Western Mediterranean have documented that pine plantations result in a loss of the local fauna (Díaz et al. 1998; Romero-Alcaraz and Ávila 2000) and flora

(Chiarucci and Decominicis 1995). What was planted in order to make the heathlands profitable, protect the soil from erosion, and ‘improve’ the physiognomy of the landscape, turned out to have adverse effects on the diversity of plants and animals (Andrés and Ojeda 2002). Similar effects have been reported for the South African ‘fynbos’ (Richardson 1998). Paradoxically, in Sardinia, *Eucalyptus* plantations have been reported as the sites with the highest soil erosion (Vacca et al. 2000).

Positive effects of traditional land-use have been reported specifically for the endemic butterfly *P. hospiton* (Aubert et al. 1996). The importance of grazing to maintain diversity is not restricted to butterflies, and has recently been found for Orthoptera in Greece (Kati et al. 2004), and for Auchenorrhyncha, Heteroptera, Coleoptera, and Hymenoptera in Germany (Kruess and Tscharntke 2002). The data we present from Sardinia show congruent results for Arachnida: spider diversity was comparably high in the ungrazed agricultural-land and in the extensively grazed high- and low shrubland, but much lower at the ungrazed forest sites. Obviously, overgrazing will negatively affect insect abundance, but cessation of grazing is also not desirable (compare also Munguira et al. 1997; Kruess and Tscharntke 2002).

Among the 10 endemic butterfly species recorded in this study, one, namely *Papilio hospiton*, is on Appendix II of the European Habitat Directive (Anonymous 1992), and on the Red List of the IUCN (IUCN 2002); another endemic butterfly, *Pseudophilotes barbagiae*, has recently been classified as ‘Vulnerable’ and proposed to be included into the Habitat Directive and the Red List of the IUCN; two more species, *M. nurag*, and *Spialia sertorius therapne* have recently been assigned the status ‘Near threatened’ according to the IUCN threat criteria (Grill et al. 2002). *Pseudophilotes barbagiae* and *M. nurag* are entirely limited to Sardinia, while the other endemic butterfly species also occur on Corsica and a few other islands of the Tyrrhenian archipelago. Like the majority of the endemics, they are restricted to mountain areas.

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