

# Leaf beetle communities (Coleoptera: Chrysomelidae) of two mixed forest ecosystems dominated by pine–oak–hawthorn in Isparta province, Turkey

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Chrysomelid beetles inhabiting the herb, shrub and tree layers of two mixed forest ecosystems dominated by pine–oak–hawthorn were studied during April–October in 2005 and 2006 in Isparta province, Turkey. The leaf beetles of both sites were investigated in terms of species composition, dominance structure and vegetation preference. Frequency values and host plants were also provided for some species. A total of 127 Chrysomelidae species belonging to ten subfamilies were collected. Species composition similarity between the herb and tree layers was 3% at both sites, while similarity between the shrub and tree layers was 25% at site I and 44% at site II. In terms of vegetation structure, the herb layers of the two sites shared 60% of their chrysomelid species, the shrub layers shared 44% and the tree layers shared 50%, a result also reflected in a PCA analysis. The herb layer was the most diverse vegetation stratum in terms of leaf beetle diversity, and it appears that vegetation cover is the main factor influencing leaf beetle species composition at both forest stands studied.

## Introduction

The Chrysomelidae constitutes one of the most abundant and diverse families of living organisms (Santiago-Blay 1994). A common feature of this family is its phytophagous feeding habit, which it shares with the Curculionidae, Cerambycidae and Bruchidae (Hsiao 1994). Chrysomelids are mostly oligophagous, though some groups tend to be polyphagous. Adult leaf beetles feed on leaves, flowers, pollen and young shoots and their larvae feed mainly on leaves or roots (Jolivet & Verma 2002). Adults and larvae of

many species are important pests of crops, tree and shrub plantations, medical herbs and animal fodder (Mirzoeva 2001). The diversity and composition of herbivore assemblages was a favored theme of community ecology in the 1970s (Lewinsohn *et al.* 2005) and in recent years some studies have been performed on leaf beetle communities in different forest types (Wagner 1998, Wařowska 2001, Řehounek 2002, Flowers & Hanson 2003, Charles & Basset 2005, Ohsawa & Nagaike 2006).

Studies on leaf beetles in forests in southwestern Turkey are of a faunistic character and

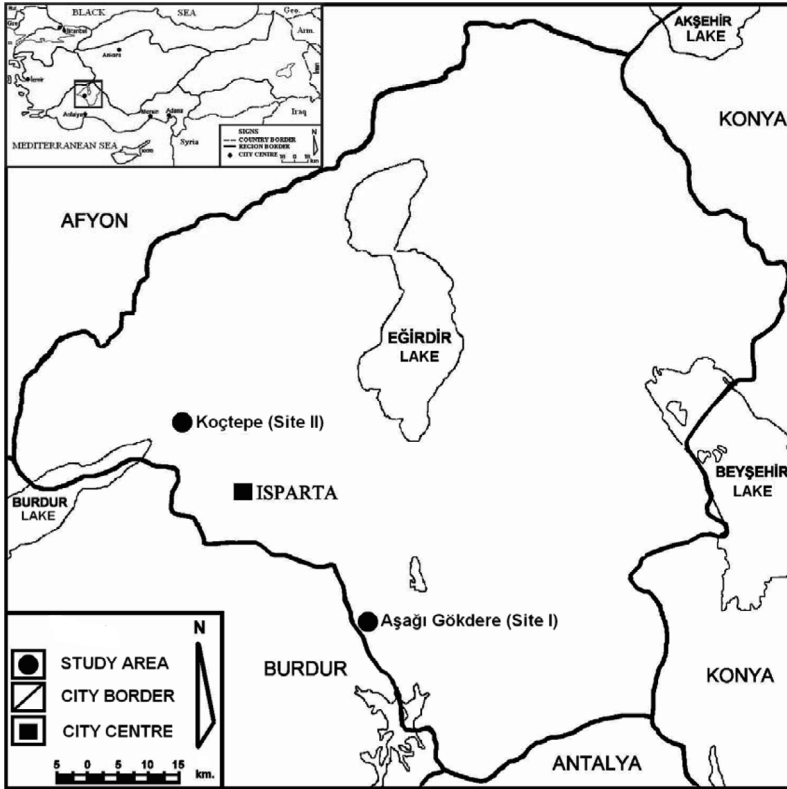


Fig. 1. Location of the forest areas under investigation in Isparta province, Turkey.

provide no detailed quantitative data (Gök & Çilbiroğlu 2003, 2005, Çilbiroğlu & Gök 2004, Aslan & Gök 2006). Therefore, the aims of this study are as follows: (i) to characterize the chrysomelid community (species composition, dominance structure and frequency values) associated with the herb, shrub and tree strata in two mixed forest ecosystems dominated by pine–oak–hawthorn, (ii) to compare the vertical stratification of leaf beetles at each study site, (iii) to compare the spatial distribution of leaf beetles between the two study sites, (iv) to present seasonal variation of leaf beetles at these sampling sites, and (v) to investigate the effects of temperature and altitude of the two sites on leaf beetle species composition.

## Material and methods

### Study sites

The study was carried out during April–October in 2005 and 2006 at two mixed forest ecosys-

tems in Isparta province, which is situated in the western Mediterranean region of Turkey at a mean altitude of 1050 m. Isparta province is a transition area between the Mediterranean and Central Anatolia. Climatic conditions are arid in the north and temperate in the south (Babalık 2002). Because of these variable climatic conditions of Isparta province, one of the study sites was located in the north, while the other was located in the south. Both forest stands are under control of the Official Forestry Management of Isparta and the forests are protected from goat or cattle grazing.

Site I (Aşağı Gökdere) is situated 35 km south of the city of Isparta (30°27'E, 37°52'N, 380 m a.s.l.) (Fig. 1). The tree layer was dominated by *Pinus brutia*, which covered nearly 80% of the area. Other relatively less abundant tree species included *Quercus cerris*, *Q. infectoria*, *Pistacia terebinthus*, *Salix* spp. and *Populus* spp. The shrub layer included *Quercus coccifera*, *Crataegus monogyna*, *Cistus creticus* and *Rubus canescens*. Species included in the herb layer mainly belonged to Lamiaceae, Boraginaceae,

Asteraceae, Scrophulariaceae and Brassicaceae. *Pinus brutia* was planted by the Official Forestry Management of Isparta, while other tree and shrub species were allowed to grow spontaneously in the area. At the time of this study, the age of *Pinus brutia* was 20 years old and the average canopy height was approximately 2.5–3.5 m.

Site II (Koçtepe) is located near the city of Isparta (30°47'E, 37°33'N, 1100 m a.s.l.) (Fig. 1). The tree layer consisted of *Pinus nigra* and *Cedrus libani*, which covered about 80% of the area. This layer also included *Quercus infectoria*, *Q. pubescens*, *Pyrus eleagrifolia*, *Prunus divaricata* and *Amygdalus communis*. The shrub layer was dominated by *Quercus coccifera*, *Crataegus monogyna* and *C. orientalis*. Species belonging to Brassicaceae, Poaceae, Lamiaceae, Asteraceae, Papaveraceae, Euphorbiaceae and Scrophulariaceae dominated the herb layer. *Pinus nigra* and *Cedrus libani*, which were approximately 15–20 years old, were planted by the Official Forestry Management of Isparta, whereas the other tree and shrub species present were allowed to grow spontaneously. At the time of this study, the average canopy height was approximately 2.0–2.5 m.

## Beetle sampling

Sampling was performed every two weeks (one day interval between the two sampling localities) at 2 × 2 km areas selected from both forest stands. Areas of similar characteristics (i.e., cover area of herbs, volume of pine–oak–hawthorn species) were selected from each locality. Leaf beetles were collected from the herb and shrub layers by means of sweep-netting and from the tree layer (up to 2.5 m) by branch clipping over an umbrella. During each sampling visit, six hours were spent (9:00–15:00) walking throughout the study areas and sampling the different vegetation strata, paying equal attention to each vegetation type. Specimens were sorted and pinned. The prepared specimens were identified according to keys in Mohr (1966), Gruev and Tomov (1984, 1986), Lopatin (1984) and Warchałowski (1991, 1993, 1994, 2003). Identified beetles were assigned into vegetation association types according to their current occurrences on the plants. The associa-

tions of some common species are in accordance with the literature (Mohr 1966, Gruev & Tomov 1984, 1986, Jolivet 1988, Warchałowski 1991, 1993, 1994, Jolivet & Hawkeswood 1995, Konstantinov 1998, Sassi & Kısmalı 2000, Jolivet & Verma 2002, Aslan & Gök 2006). For the other collected species, the degree of damage on the vegetation was taken into consideration in the classification.

## Data analyses

Dominance structure and frequency values of each leaf beetle species collected were determined according to Krebs (1994). In order to define the dominance structure of the chrysomelid species collected, the following scale was used: eudominant > 7.6%, dominant 5.1%–7.5%, subdominant 2.6%–5.0%, recedent 1.1%–2.5%, subrecedent 0.0%–1.0%.

Sørensen's index ( $S$ ) (Eq. 1) was used to determine species composition similarity of the Chrysomelidae communities inhabiting the herb, shrub and tree strata and between the two study localities.

$$S = 2C/(A + B) \quad (1)$$

where  $A$  is the number of species in the first community,  $B$  is the number of species in the second community, and  $C$  is the number of species occurring in both communities compared. The index ranges from 0 (no similarity) to 1 (complete similarity) (Logarzo *et al.* 2005).

Shannon's index of total species diversity ( $H'$ ), Simpson's index of dominance ( $D$ ) and Shannon's index of evenness ( $E'$ ) — Eqs. 2, 3 and 4, respectively — were used as diversity indexes (Krebs 1994). Shannon's index of total species diversity is defined as

$$H' = -\sum_{i=1}^s p_i \ln(p_i) \quad (2)$$

Simpson's index is defined as

$$D = \frac{\sum_{i=1}^s n(n-1)}{N(N-1)} \quad (3)$$

and Shannon's evenness index is defined as

$$E' = \frac{H'}{\ln(S)} \quad (4)$$

where *n* is the number of individuals of each species collected, i.e., the abundance of each species, *S* is the number of species, *N* is the total number of all individuals, *p<sub>i</sub>* is the relative abundance of each species calculated as the proportion of individuals of a given species to the total number of individuals in the community: *n/N*.

A Principal Components Analysis (PCA) was used to identify the effects of the three vegetation strata of the two sampling areas on the distribution of the leaf beetles collected. A Canonical Correspondance Analysis (CCA) was used to analyze the response of leaf beetles to a set of environmental variables. The CCA scores were calculated from linear combinations of the species collected from each vegetation stratum (Table 1) and the measured environmental variables (altitude, mean annual precipitation, mean annual temperature, herb cover, shrub cover and tree cover) of each habitat. The geographical positions of the stands were measured using GPS (Garmin etrex). The mean annual temperature and mean annual precipitation of the study areas were taken from the data base of the Turkish State Meteorological Service and the shrub and tree covers from the Official Forestry Management of Isparta. The PCA and CCA were carried out with the MultiVariate Statistical Package (MVSP 3.1) for Windows.

## Results

### Leaf beetle fauna associated with the study sites and vegetation layers

A total of 127 species, representing ten Chrysomelidae subfamilies were collected from both study sites during 2005–2006 (Table 1). At site I (Aşağı Gökdere), 84 species belonging to nine subfamilies were collected in total: 62 species from the herb layer, 10 species from the shrub layer and 8 species from the tree layer. The remaining 4 species were vertically distributed between two different vegetation strata (Fig. 2a). Of these, *Psylliodes anatolicus* was associated with the herb and tree layers while *Labidostomis*

**Table 1.** Leaf beetle species collected from the two mixed forests studied in Isparta province, Turkey (*n* = number of individuals, DG = dominance group, V = vegetation, H = herb, S = shrub, T = tree, Ed = eudominant, D = dominant, Sd = subdominant, R = recedent, Sr = subrecedent).

Subfamily/species	Site I			Site II			Host Plants	V
	<i>n</i>	Dominance (%)		<i>n</i>	Dominance (%)			
		DG	DG		DG	DG		
<b>Orsodacninae</b>								
1 <i>Orsodacne variabilis</i>				436	6.68	D	<i>Pyrus eleagrifolia</i> , <i>Q. coccifera</i>	S-T
<b>Criocerinae</b>								
2 <i>Crioceris bicrucata</i>	18	0.29	Sr				<i>Asparagus</i> spp.	S
<b>Clytrinae</b>								
3 <i>Clytra atraphaxidis</i>	53	0.84	Sr	19	0.29	Sr	<i>Pistacia terebinthus</i>	T
4 <i>Clytra binominata</i>	2	0.03	Sr					S
5 <i>Clytra bodemeyeri</i>	12	0.19	Sr	4	0.06	Sr	<i>Quercus coccifera</i>	S
6 <i>Clytra novempunctata</i>	33	0.52	Sr	23	0.35	Sr	<i>Crataegus monogyna</i>	S
7 <i>Coptocephala unifasciata</i>	26	0.41	Sr	51	0.78	Sr		H
8 <i>Lachnaia sexpunctata</i>				9	0.14	Sr	<i>Q. coccifera</i> , <i>Q. pubescens</i> , <i>Q. infectoria</i>	S-T
9 <i>Labidostomis asiatica</i>				58	0.89	Sr	<i>Crataegus monogyna</i>	S
10 <i>Labidostomis rufa</i>	27	0.43	Sr	53	0.81	Sr	<i>Crataegus monogyna</i>	S

11	<i>Labidostomis karamanica</i>	32	0.51	Sr	31	0.48	Sr	<i>Q. coccifera, Q. pubescens, Q. infectoria</i>	S-T
12	<i>Smaragdina judaica</i>	11	0.17	Sr				<i>Arbutus unedo</i>	S
13	<i>Smaragdina limbata</i>	50	0.79	Sr	75	1.15	R	<i>Q. pubescens, Q. infectoria, Q. coccifera</i>	S-T
14	<i>Smaragdina tibialis</i>	56	0.89	Sr	24	0.37	Sr	<i>Q. infectoria, Q. cerris</i>	T
<b>Cryptocephalinae</b>									
15	<i>Cryptocephalus bipunctatus</i>				26	0.40	Sr	<i>Q. coccifera, C. monogyna</i>	S
16	<i>Cryptocephalus duplicatus</i>	63	1.00	Sr	24	0.37	Sr	<i>Taraxacum</i> spp., <i>Anthemis</i> spp.	H
17	<i>Cryptocephalus moraei</i>	28	0.45	Sr	13	0.20	Sr	<i>Hypericum</i> spp.	H
18	<i>Cryptocephalus octomaculatus</i>				77	1.18	R	<i>Q. pubescens</i>	T
19	<i>Cryptocephalus prusias</i>				1	0.02	Sr	<i>Crataegus monogyna</i>	S
20	<i>Cryptocephalus pygmaeus</i>	8	0.13	Sr					H
21	<i>Cryptocephalus surdus</i>	11	0.17	Sr				<i>Salix caprea</i>	T
22	<i>Cryptocephalus turicus</i>				5	0.08	Sr	<i>Crataegus monogyna</i>	S
23	<i>Cryptocephalus wehnckei</i>				4	0.06	Sr	<i>Q. coccifera, Q. pubescens, Q. infectoria</i>	S-T
24	<i>Cryptocephalus trimaculatus</i>	9	0.14	Sr				<i>C. monogyna, Q. coccifera</i>	S
25	<i>Pachybrachis excisus</i>	34	0.54	Sr	197	3.02	Sd	<i>Q. pubescens</i>	T
26	<i>Pachybrachis limbatus</i>	94	1.49	R	116	1.78	R	<i>Q. coccifera, Q. infectoria</i>	S-T
27	<i>Pachybrachis sinuatus</i>				29	0.44	Sr	<i>Salix caprea</i>	T
28	<i>Pachybrachis tessellatus</i>							<i>Q. coccifera</i>	S
<b>Eumolpinae</b>									
29	<i>Macrocoma rubripes</i>	8	0.13	Sr	11	0.17	Sr		H
30	<i>Pachnophorus villosus</i>	3	0.05	Sr					H
<b>Chrysomelinae</b>									
31	<i>Chrysolina didymata</i>	470	7.47	D				<i>Populus</i> spp.	H
32	<i>Chrysolina marginata</i>				23	0.35	Sr		H
33	<i>Chrysomela populi</i>	33	0.52	Sr					T
34	<i>Colaphus sophiae</i>				56	0.86	Sr		H
35	<i>Entomoscelis adonidis</i>				155	2.38	R	<i>Papaver</i> sp.	H
36	<i>Entomoscelis suturalis</i>				15	0.23	Sr	<i>Papaver</i> sp.	H
37	<i>Gastrophysa polygوني</i>				3	0.05	Sr		H
38	<i>Gonioctena fornicata</i>	25	0.40	Sr	10	0.15	Sr		H
39	<i>Plagidera versicolora</i>	195	3.10	Sd				<i>Salix caprea</i>	T
40	<i>Timarcha tenebricosa</i>				4	0.06	Sr		H
<b>Galerucinae</b>									
41	<i>Calomicrus atrocephalus</i>	670	10.6	Ed	289	4.43	Sd	<i>Pinus brutia, P. nigra, Cedrus libani</i>	T
42	<i>Calomicrus lividus</i>	87	1.38	R					H
43	<i>Calomicrus malkini</i>	451	7.17	D				<i>Pistacia terebinthus, Q. cerris</i>	T
44	<i>Exosoma neglectum</i>	62	0.99	Sr	80	1.23	R	<i>Allium</i> spp.	H
45	<i>Diorhabda elongata</i>	190	3.02	Sd				<i>Tamarix smyrnensis</i>	S
46	<i>Diorhabda fischeri</i>				17	0.26	Sr	<i>Onobrychis hypogrea</i>	H

continued

Table 1. Continued.

Subfamily/species	Site I		Site II		Host Plants	V
	n	Dominance (%)	n	Dominance (%)		
	DG	DG	DG	DG		
47 <i>Galeruca interrupta</i>			10	0.15	Sr	H
48 <i>Galeruca tanacetii</i>			40	0.61	Sr	H
49 <i>Lochmaea limbata</i>			616	9.44	Ed	S
50 <i>Luperus xanthopoda</i>			274	4.20	Sd	S-T
51 <i>Monolepta anatolica</i>			5132	?	?	T
52 <i>Nymphius forcipifer</i>			20	0.31	Sr	S
53 <i>Nymphius lydius</i>			383	5.87	D	S
54 <i>Phyllobrotica elegans</i>			4	0.06	Sr	H
<b>Hispinæ</b>						
55 <i>Dicladispa testacea</i>	334	5.31				S
56 <i>Hispa atra</i>	4	0.06			Sr	H
<b>Cassidinae</b>						
57 <i>Cassida rubiginosa</i>	8	0.13			Sr	H
58 <i>Cassida vibex</i>	11	0.17			Sr	H
<b>Alticinae</b>						
59 <i>Altica lythri</i>	600	9.54			Ed	S
60 <i>Altica oleracea</i>	82	1.30			R	H
61 <i>Altica quercetorum</i>			2	0.03	Sr	H
62 <i>Aphthona atrovirens</i>			3	0.05	Sr	H
63 <i>Aphthona kuntzei</i>	75	1.19			R	H
64 <i>Aphthona nigricutis</i>			42	0.64	Sr	H
65 <i>Aphthona pygmaea</i>	92	1.46			R	H
66 <i>Chaetocnema conducta</i>	2	0.03			Sr	H
67 <i>Chaetocnema coyei</i>	164	2.61			Sd	H
68 <i>Chaetocnema tibialis</i>	7	0.11			Sr	H
69 <i>Dibolia rugulosa</i>			3	0.05	Sr	H
70 <i>Longitarsus aeneicollis</i>	27	0.43			Sr	H
71 <i>Longitarsus affierii</i>	145	2.30			R	H
72 <i>Longitarsus anchusae</i>	80	1.27			R	H
73 <i>Longitarsus aramaicus</i>	19	0.30			Sr	H
74 <i>Longitarsus atricillus</i>	3	0.05			Sr	H
75 <i>Longitarsus australis</i>	5	0.08			Sr	H
76 <i>Longitarsus ballotae</i>	30	0.48			Sr	H
77 <i>Longitarsus corynthius</i>			111	1.70	R	H
78 <i>Longitarsus exoletus</i>	7	0.11			Sr	H



Table 1. Continued.

Subfamily/species	Site I		Site II		Host Plants	V
	n	Dominance (%)	n	Dominance (%)		
	DG	DG	DG	DG		
119 <i>Psylliodes anatolicus</i>	21	0.33	21	0.32	<i>Quercus pubescens</i>	H-T
120 <i>Psylliodes chalcomerus</i>	20	0.32	108	1.66	<i>Carduus pycnocephalus</i>	H
121 <i>Psylliodes chrysocephalus</i>	44	0.70	3	0.05	<i>Sinapis alba</i>	H
122 <i>Psylliodes cupreus</i>	574	9.12	4	0.06	<i>Sinapis alba</i> , <i>Alyssum</i> spp.	H
123 <i>Psylliodes hospes</i>	9	0.14	3	0.05		H
124 <i>Psylliodes instabilis</i>	39	0.62	4	0.06	<i>Sinapis alba</i>	H
125 <i>Psylliodes magnificus</i>	5	0.08	2	0.03		H
126 <i>Psylliodes tricolor</i>			4	0.06		H
127 <i>Psylliodes yalvacensis</i>			6	0.09		H
	6292	100.00	11655	100.00		

*karamanica*, *Smaragdina limbata* and *Pachybrachis limbatus* were collected from both the shrub and tree layers.

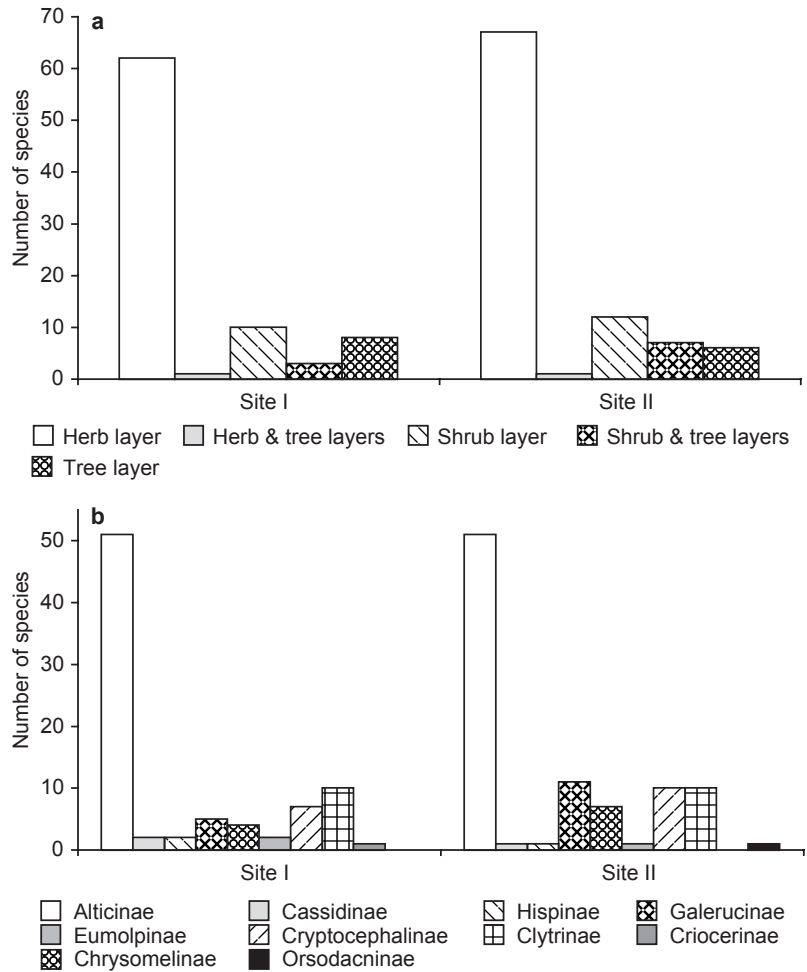
At site II (Koçtepe) the leaf beetle community was made up of 93 species belonging to nine subfamilies (Table 1): 67 species were collected from the herb layer, 12 species from the shrub layer, and 6 species from the tree layer. The remaining 8 species were collected from two different vegetation strata (Fig. 2a). Similarly to site I, *Psylliodes anatolicus* was found in both the herb and tree layers. The other 7 species (*Orsodacne variabilis*, *Lachnaia sexpunctata*, *Labidostomis karamanica*, *Smaragdina limbata*, *Cryptocephalus wehnckeii*, *Pachybrachis limbatus* and *Luperus xanthopoda*) were recorded from the shrub and tree layers; 69 of the 127 species collected belong to the Alticinae (Fig. 2b).

**Frequency, dominance structures and leaf beetle diversity**

The most frequently collected species of sites I and II are shown in Table 2. These leaf beetles were usually categorized as dominant. In the community of site I, the most dominant species were *Psylliodes cupreus* (9.1%), *Chrysolina didymata* (7.5%) and *Longitarsus nigrofasciatus* (3.8%) in the herb layer, *Altica lythri* (9.5%), *Diclidispa testacea* (5.3%) and *Diorhabda elongata* (3.0%) in the shrub layer, and *Calomicrus atrocephalus* (11.0%), *Calomicrus malkini* (7.2%) and *Plagioderia versicolora* (3.1%) in the tree layer. At site II, the most dominant species was *Monolepta anatolica*, which was recorded on its host trees with 5132 individuals. This species was not included in any further calculations as this high number of individuals was nearly equal to all other beetles collected from site II. At site II, the most dominant species were *Phyllotreta variipennis* (8.0%), *Phyllotreta corrugata* (5.5%) and *Phyllotreta cruciferae* (3.5%) in the herb layer, *Lochmaea limbata* (9.4%) and *Nymphius lydius* (5.9%) in the shrub layer, *C. atrocephalus* (4.4%) in the tree layer, and *Luperus xanthopoda* (4.2%) and *Orsodacne variabilis* (6.7%) in both the shrub and tree layers.

At site I, 65 species were classified as sub-recedent, 7 as recedent, 6 as subdominant, 3 as





**Fig. 2.** (a) Numbers of leaf beetle species inhabiting the herb, shrub and tree layers of sites I and II. (b) Numbers of leaf beetle species of the different subfamilies collected.

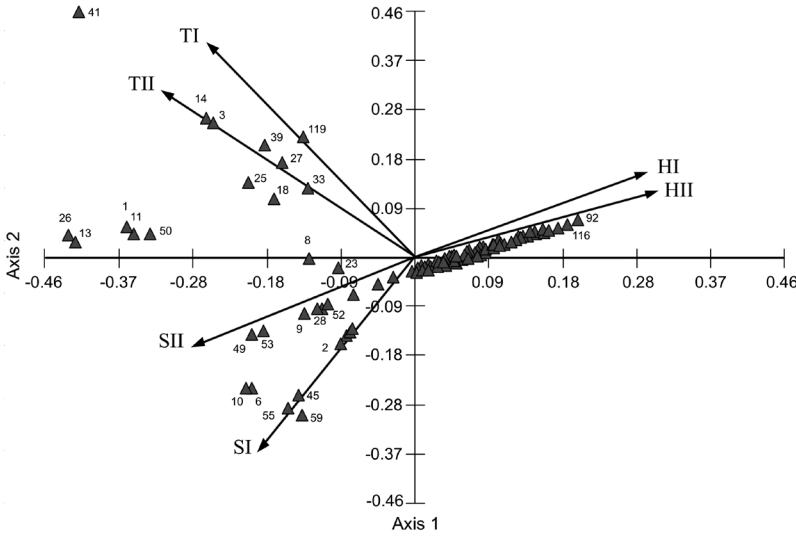
dominant, and 3 as eudominant. At site II, 71 species were classified as subprecedent, 10 as recedent, 5 as subdominant, 4 as dominant, and 2 as eudominant (Table 1).

Shannon's and Simpson's diversity indexes

showed that the herb layer, especially the herb layer of Site II, was more diverse than the other two vegetation strata. The lowest number of species and individuals, hence the lowest diversity, were recorded from the tree layer of Site I.

**Table 2.** Most frequently collected species at sites I and II.

	Species of site I	Frequency (%)	Species of site II	Frequency (%)
Herb layer	<i>Longitarsus nigrofasciatus</i>	100	<i>Phyllotreta variipennis</i>	93
	<i>Longitarsus nanus</i>	93	<i>Phyllotreta nigripes</i>	86
	<i>Chaetocnema coynei</i>	86	<i>Phyllotreta cruciferae</i>	77
Shrub layer	<i>Di cladispa testacea</i>	86	<i>Lochmaea limbata</i>	36
	<i>Altica lythri</i>	64	<i>Pacybrachis limbatus</i>	36
	<i>Diorhabda elongata</i>	57	<i>Smaragdina limbata</i>	36
Tree layer	<i>Calomicrus atrocephalus</i>	43	<i>Calomicrus atrocephalus</i>	43
	<i>Smaragdina limbata</i>	43	<i>Monolepta anatolica</i>	43
	<i>Pachybrachis limbatus</i>	43	<i>Smaragdina limbata</i>	43



**Fig. 3.** Principal Components Analysis (PCA) of leaf beetle species. The abbreviations in the figure; HI = herb layer of site I, HII = herb layer of site II, SI = shrub layer of site I, SII = shrub layer of site II, TI = tree layer of site I, TII = tree layer of site II. Numbers identifying species correspond to those in Table 1.

Overall, leaf beetle diversity was higher at Site II as compared with that at Site I (Table 3). Evenness values were generally high in all vegetation strata, being highest in the herb layers of both sites (Table 3).

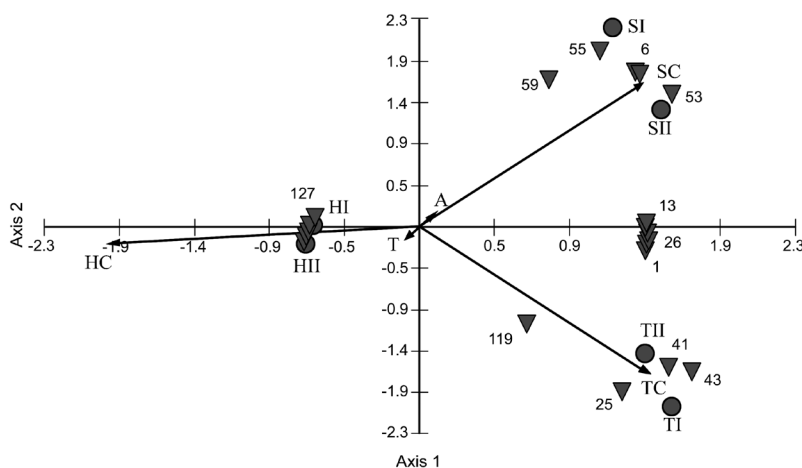
**Vertical stratification**

Only one species, *Psylliodes anatolicus*, was collected from both the herb and tree layers, while three species, *Labidostomis karamanica*, *Smaragdina limbata* and *Pachybrachis limbatus* were collected from the shrub and tree layers at site I. Consequently, similarity of the leaf beetle community was 3% between the herb and tree layers, and 25% between the shrub and tree layers. At site II, *P. anatolicus* was again the only shared species between the herb and tree layers, while seven species, including *Orsodacne variabilis*, *Lachnaia sexpunctata*, *Labidostomis kar-*

*amanica*, *Smaragdina limbata*, *Cryptocephalus wehnckeii*, *Pachybrachis limbatus* and *Luperus xanthopoda* were common to the shrub and tree layers. So, similarity between the herb and tree layers was 3%, and between the shrub and tree layers 44%. In addition, the PCA reveals the scatter of species in accordance with their occurrence in the herb, shrub and tree layers (Fig. 3). Three distinct groups can be identified. The right part of the diagram is characterized by species limited to the herb layer of the two localities, e.g., *Longitarsus nigrofasciatus* and *Phyllotreta variipennis*. The left side of the diagram is characterized by two groups, i.e., a group of species preferring the shrub layer (e.g., *Labidostomis rufa*, *Clytra novempunctata* and *Lochmaea limbata*), and a group preferring the tree layer (e.g., *Calomicrus atrocephalus*, *Smaragdina tibialis* and *Clytra atraphaxidis*). The CCA biplot (Fig. 4) highlights the separation of the leaf beetle community sampled from the herb, shrub and

**Table 3.** Indexes for the three vegetation strata at the two localities. The highest values at each locality are set in boldface.

	Number of species	Shannon's index ( <i>H'</i> )	Shannon evenness ( <i>E'</i> )	Simpson's index ( <i>D</i> )
Herb layer site I	60	<b>3.265</b>	<b>0.797</b>	<b>0.931</b>
Shrub layer site I	12	1.527	0.615	0.694
Tree layer site I	10	1.466	0.637	0.635
Herb layer site II	69	<b>3.371</b>	<b>0.796</b>	<b>0.941</b>
Shrub layer site II	17	1.950	0.688	0.790
Tree layer site II	13	2.001	0.780	0.830



**Fig. 4.** Canonical Correspondence Analysis (CCA) of leaf beetle species and environmental variables. HI = herb layer of site I, HII = herb layer of site II, SI = shrub layer of site I, SII = shrub layer of site II, TI = tree layer of site I, TII = tree layer of site II, HC = percentage herb cover, SC = percentage shrub cover, TC = percentage tree cover, A = altitude of the study site, T = mean annual temperature of the study site. Mean annual precipitation does not appear on the CCA biplot because of the very short length of its arrow. Numbers identifying species correspond to those in Table 1.

tree layers of the two localities. Leaf beetle assemblages of the same vegetation stratum did not separate into distinct groups, while clear differences were found between the three vegetation strata.

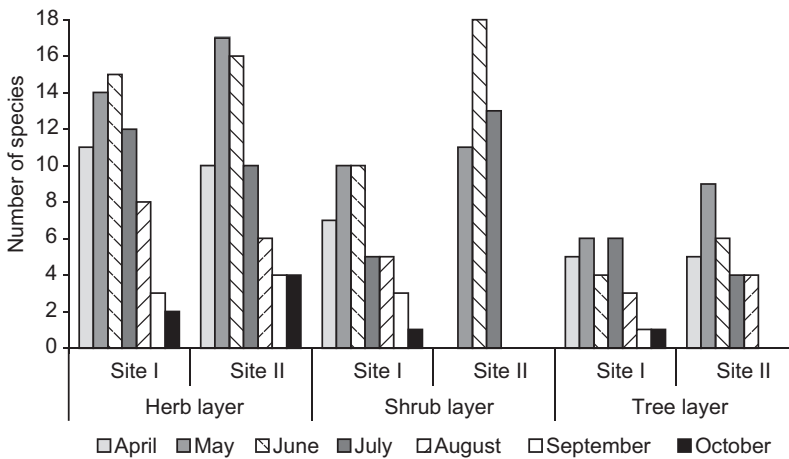
### Spatial variation

The dominant shrub and tree species at the two locations investigated were pine, oak and hawthorn although each study area had some special plant species. Consequently, some leaf beetles specialized to a particular host plants were found only at one study area. *Quercus cerris*, *Pistacia terebinthus*, *Asparagus* spp., *Arbutus unedo*, *Salix caprea*, *Populus* spp., *Tamarix smyrnensis*, *Cistus creticus*, *Salvia potentillifolia*, *Scorpiorus* sp. and *Cynoglossum creticum* occurred only at site I and the leaf beetle species *Crioceris bicruciat*, *Smaragdina judaica*, *Cryptocephalus surdus*, *Pachybrachis sinuatus*, *Plagioder* *versicolora*, *Calomicrus malkini*, *Chrysomela populi*, *Diorhabda elongata*, *Dicladispa testacea*, *Cassida vibex*, *Chaetocnema coyei* and *Longitarsus lateripunctatus*, which feed exclusively on these plants, were only found at site I (Table 1). Similarly, the leaf beetle species *Orsodacne variabilis*, *Cryptocephalus octomaculatus*, *Pachybra-*

*chis excisus*, *Entomoscelis adonidis*, *E. suturalis*, *Diorhabda fischeri*, *Monolepta anatolica*, *Dibolia rugulosa*, *Longitarsus longipennis* and *Phyllotreta procera*, inhabiting *Pyrus eleagrifolia*, *Q. pubescens*, *Papaver* sp., *Onobrychis hypogrea*, *Prunus divaricata*, *Amygdalus communis*, *Phlomis pungens*, *Stachys byzantina*, *Convolvulus arvensis* and *Reseda luteola* were only recorded from site II (Table 1).

In the present study, a total of 93 species were collected from the herb layer, of which 39 were collected from both localities. Sørensen's similarity index value was 60% for leaf beetles inhabiting the herb layer at the two study sites sampled. A total of 25 species were collected from the shrub layer, of which seven species were collected from both localities (Sørensen's similarity = 44%). In the tree layer, six of the 18 species collected from both areas were the same, with a similarity of 50%.

The CCA biplot shows the associations of the leaf beetle species sampled with the environmental variables (Fig. 4). The most distinct separation between species scores was along CCA axis 1, which showed a gradient from the herb layer to the shrub and tree layers. The shrub and tree layers separated out along CCA axis 2. The ordination diagram indicates that the separation of the three vegetation strata can be based on dif-



**Fig. 5.** Leaf beetle species richness in the herb, shrub and tree layers of sites I and II in 2005–2006.

ferences between their leaf beetle assemblages. Temperature (T), altitude (A) and mean annual precipitation did not affect the structure of the leaf beetle assemblages significantly. Environmental variables with long arrows were more strongly correlated with the ordination axes than those with short arrows. Consequently, herb, shrub and tree layer covers were the three main environmental variables determining the leaf beetle species composition (Fig. 4).

### Seasonal variation

Leaf beetle communities showed large seasonal variation for all subfamilies. Leaf beetle abundance and species richness peaked in spring and sharply decreased at the beginning of the summer season (Fig. 5). In spring and in the early summer, dominance and species richness were consistently highest in the shrub and tree layers for all subfamilies, especially for Clytrinae and Cryptocephalinae. In the mid and late summer, leaf beetle dominance and species richness decreased. However, some species, such as *L. nanus*, *L. nigrofasciatus* and *D. testaceae*, were found in large numbers both in spring and in the summer.

### Discussion

Our results showed that the studied mixed forest

ecosystems dominated by pine–oak–hawthorn did not differ much in their leaf beetle community. The results indicate that (i) mixed forest ecosystems dominated by pine–oak–hawthorn were rich in terms of their chrysomelid community and the most diverse vegetation stratum was the herb layer, (ii) in terms of vertical variation, the similarity between the herb and tree layers was low (3% at both sites), while the similarity between the shrub and tree layers was relatively high (25% at site I and 44% at site II), (iii) in terms of vegetation structure, the herb layers of the two sites shared 60% of their chrysomelid species, the shrub layers shared 44% and the tree layers shared 50%, (iv) in terms of seasonal variation, species richness of leaf beetles during the spring season was higher than during the summer season in both forest stands, and (v) temperature and altitude of the two sites were of little importance in shaping the leaf beetle assemblages.

### Vertical variation

Vertical similarity in the composition of leaf beetles was low between the herb and tree layers (3% in both stands) and higher between the shrub and tree layers (25% at site I and 44% at site II). Wąsowska (1994, 1999) carried out similar studies in pine and oak forests in Poland, and showed that the percentage similarity between the herb and tree layers, based on 13 and 19 beetles, were 40% (1994) and 59% (1999) respectively, which

is much higher than that found in our study. However, the 37 beetles of the shrub and tree layers of both study areas were highly similar (65%) in accordance with our results. One possible reason of low vertical similarity between the herb and tree layers stems from the restriction of leaf beetles to one vegetation stratum. The high similarity between the shrub and tree layers is because of the existence of both shrub and tree forms in both layers, which are host plants of leaf beetles. This situation is also supported by our PCA results, which showed that the leaf beetle community of the two stands was composed of three major species groups (Fig. 3).

### Spatial variation

Within stratum similarity, in terms of chrysomelid species composition, was high. This may be due to the similarity in floristic composition within the particular vegetation stratum, and to the close geographical proximity of the stands. However, some differences exist, which may be attributable to unique host plants in the two localities.

Difference of the leaf beetle assemblages inhabiting the herb, shrub and tree layers was mainly related to vegetation cover (Fig. 4). Variation in these environmental factors between vegetation types gave rise to three distinct leaf beetle communities: species associated with the shrub layers (positive values of CCA axes 1 and 2), such as *Labidostomis rufa*, *Dicladispa testacea* and *Clytra novempunctata*, species associated with the tree layers (positive values of CCA axis 1 and negative value of CCA axis 2), such as *Calomicrus atrocephalus*, *C. malkini* and *Pachybrachis excisus*, and species associated with the herb layer (negative values of CCA axis 1), such as *Phyllotreta nigripes*, *Phyllotreta atra* and *Chrysolina didymata*. Mean annual temperature, mean annual precipitation and altitude of the study sites appear to have little effect on the leaf beetle assemblages (Fig. 4). It is possible that these variables influence the host plants of the leaf beetles rather than the beetles themselves. So, they could have indirect affect on the beetle communities of the study sites. This study concurs with similar studies in different habitats

(Řehounek 2002, Wařowska 2006) in terms of the influence of vegetation composition and vegetation cover on Chrysomelidae communities.

The number of phytophagous insect species correlates fairly well with the number of plant species in a community (Takizawa 1994, Murakami *et al.* 2005, Ødegaard 2006). Similarly, mixed forest ecosystems are of great importance for the diversity and dominance of phytophagous insects because of its rich floristic structure. In the present study, the diversity and dominance of leaf beetles were high, as both localities consisted of a mixed forest ecosystem structure, composed of both xeric pines and deciduous shrubs and trees, and a rich herb layer.

The species composition and host specificity of phytophagous beetles may vary considerably between sites because of differences in some determinants of insect species diversity, such as host plant abundance, distribution and species richness (Novotny *et al.* 2004, Ødegaard 2006). Many species, which were frequently found at the study areas, were also the most dominant species. Even if some species were found at both study sites, their dominance level was not the same. It is clear that the density of host plants of the leaf beetles was greatly different at the two localities studied, resulting in differences in the dominance structure and composition of leaf beetles.

### Seasonal variation

A large number of leaf beetles were collected during the spring season, especially in May. Patterns of seasonal occurrence in phytophagous beetles are generally related to species characteristics (i.e. emergence schedule, generation time, voltinism and diapause), availability of resource, and habitat structure (Stork *et al.* 2001, Wagner 2003). In addition, the abundance of phytophagous beetles peaks during leaf-flush periods (Basset 1991, Wagner 1999, Leksono *et al.* 2005a, 2006) because of these beetles' preference for young leaves (Coley & Aide 1991, Novotny *et al.* 2003, Leksono *et al.* 2005b). Moreover, the young leaves are tender and relatively nutritious (Basset & Novotny 1999) but, as the leaves age, they become tougher and less nutritious. These

older leaves can be barriers to phytophagous beetles (Southwood *et al.* 2004). Clytrines and Cryptocephaline adults prefer tender leaves (Jolivet & Verma 2002). The quality of oak leaves undergo considerable spatio-temporal changes, with young oak leaves of higher quality for herbivores than old oak leaves. Summer leaves are tougher, lower in water and nitrogen content and higher in tannin content than spring leaves (Murakami *et al.* 2005). The present study support previous studies (*see above*) in that the number of leaf beetles was high in the spring, particularly in the shrub and tree layers. At these vegetation strata, species belonging to the Clytrinae and Cryptocephalinae subfamilies were collected, which are known to prefer tender leaves (Jolivet & Verma 2002). However, some species, such as *L. nanus*, *L. nigrofasciatus* and *D. testaceae*, were found during almost all field visits, suggesting their ability to utilize host plants during the entire growing season, or their ability to use different host plants.

### Temperature and altitude

The CCA results suggest that differences in altitude and temperature of the studied areas were of little importance in shaping the leaf beetle assemblages. Jolivet *et al.* (1994) and Cloudsley-Thompson (2001) pointed out that species of the genus *Timarcha* live only at high altitudes. Similarly, *Timarcha tenebricosa* seemed to be affected by altitude because it is collected only at the higher study area (site II). In addition, *Entomoscelis suturalis*, *E. adonidis* and *Colaphus sophiae* can also be affected by altitude as *T. tenebricosa*. Although altitude may not directly affect the occurrence of leaf beetles, its indirect effect, i.e., variation in temperature, may cause differences in species richness.

### Conclusion

The Mediterranean region constitutes both a refuge area, and an area that encourages floral exchange and active plant speciation. Two main centers of biodiversity exist in the Mediterranean region: one in the west, including the

Iberian Peninsula (notably with Andalusia) and Morocco (with the Atlas and Rif Mountains), and one in the east, including southern parts of Turkey and Greece (Medail & Quezel 1999). Isparta Province, included in the southern part of Turkey, has great species diversity because of its location in the transition area between the Mediterranean and Irano-Turanian phytogeographic areas. As such, this study is of importance for determining the biodiversity of leaf beetle assemblages in mixed forest ecosystems. In addition, results from the the present study puts forwards four implications; (i) the herb layer is the most diverse stratum in this kind of forest, (ii) the low faunal similarity observed between the herb, shrub and tree layers suggests that different food-webs exist in these three strata, and that leaf beetles prefer specific host plants within these strata, (iii) vegetation cover may influence the vertical stratification and spatio-temporal diversity of leaf beetles, and (iv) there are some chrysomelid species (such as *Calomicrus malkini*, which is endemic to Turkey) unique to the forest ecosystem studied. Chrysomelid beetles may be at risk as a result of grazing, logging and other human activities in these forest ecosystems. Therefore, necessary precautions must be taken in order to protect the biodiversity in these areas.

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