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Ground beetle assemblages and distribution of functional traits in olive orchards and vineyards depend on the agricultural management practice

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Abstract Biodiversity in the Mediterranean is undergoing a decline resulting in reduced ecosystem service provisions. Here we analysed the functional diversity of ground beetles in Mediterranean vineyards and olive orchards using species traits connected to their ecosystem services. Since previous studies showed that habitat type can affect ground beetle trait composition we hypothesized that the proportion of selected traits (body size, feeding preferences, and wing development) would be influenced by integrated pest management (IPM) and organic management (OM), and this would differ from unmanaged habitats. We analysed published data originating from vineyards and olive orchards in several Mediterranean countries with similar agricultural management practices, and for which ground beetles were sampled in a comparable way. We found that significantly more carnivorous species than herbivorous and omnivorous were present from unmanaged habitats compared to OM sites, while there were no significant differences between OM and IPM sites for ground beetles feeding preferences. The proportion of large brachypterous species was highest at unmanaged sites and lowest at IPM sites. Conversely, functional diversities in feeding preferences and size ranges were significantly lower at unmanaged sites. In Croatian sites only, medium-sized macropterous carnivores were the most abundant beetle fauna, with more predatory individuals found in OM sites. Overall, unmanaged habitats supported a higher proportion of carnivorous ground beetle species, while size and wing development were more variable among the sites.

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Introduction

Olive tree (*Olea europaea* L.) and grapevine (*Vitis vinifera* L.) cultivations in the Mediterranean date back to ancient times, and today remain an indispensable economic good as well as providing a significant cultural function in countries that are located in the Mediterranean basin (Kavvadias and Koubouris 2019). Several pest species threaten these cultivations, forcing farmers to rely on various types of pesticides to reduce the damage caused (Picchi et al. 2017). The olive fruit fly (*Bactrocera oleae*) (Rossi, 1790) can cause up to 90% damage in commercial olive groves if left untreated (Ordano et al. 2015). Moths including *Prays oleae* and *Zeuzera pyrina* and several curculio beetles also cause substantial damage to olive cultivation (Ramos et al. 1998). Similarly, in vineyards, pest specieses cause economic levels of damage, with the most important of economic pest species being grapevine moths (*Lobesia botrana*; *Eupoecilia* (syn. *Clysia*) *ambiguella*), grapevine leafhoppers and curculio beetles. In addition, snails and slugs are also frequent pests in vineyards and cause damage by being present on fruit and contaminating the final product or by opening the skin of the fruit and exposing it to fungal infestation.

To improve the control of insect and invertebrate pests, farmers have turned from conventional management (CM) practices to organic (OM) or integrated (IPM) pest management. Both OM and IPM are based on various control methods including: biological control, host-plant resistance breeding, and cultural techniques. Nevertheless, IPM, like CM, still use a range of synthetic chemical pesticides (SCP) targeting different organisms, while SCPs are not used in OM at all (Tshernyshev 1995; Thomas 1999). However, the use of compounds allowed in OM can still damage non-pest and/or native arthropod communities (Iannotta et al. 2007; Scalercio et al. 2009). The Mediterranean basin is a global biodiversity hotspot (Myers et al. 2000) and as such is susceptible to climate change. Climate change coupled with intensive agriculture and the use of SCP may pose an even greater risk of losing still understudied or undescribed biodiversity of the Mediterranean basin.

Ground beetles (Coleoptera: Carabidae) are among the most important groups of beneficial arthropods in agroecosystem food webs since they feed on many plant and insect pests (Kromp 1999; Giglio et al. 2011; Sommaggio et al. 2018). They often dominate numerically within the soil-active arthropods (Lövei and Sunderland 1996) and are capable of consuming to the equivalent of their body mass in food on a daily basis (Thiele 1977). Several studies have recognized them as predators of *B. oleae,* during field (Orsini et al. 2007; Pizzolotto et al. 2018) and laboratory studies (Dinis et al. 2016; Albertini et al. 2018). Maintaining native predatory insect fauna is beneficial for grapevine cultivations (Nicholls et al. 2008).

Ground beetles are recognised as an important insect family found in vineyard agroecosystems (Williamson and Johnson 2005; Franin et al. 2016). Kromp (1999) listed them as effective agents in slug biocontrol, feeding on slug eggs and juveniles (Scaccini 2020), and they have been detected as lepidopteran feeders (e.g. Šerić Jelaska et al. 2014). Ground beetles are of variable sizes, with species ranging from 2 to 60 mm in body length (Homburg et al. 2014). Body size affects their ability to live in certain, environments, migration, and for predatory species, it determines the size range of suitable prey (Šustek 1987; Šerić Jelaska et al. 2014). It is possible to expect changes in ground beetle body size structure and assemblage under the pressure of anthropogenic factors, such as varied land management practices and habitat types (Blake et al. 1994; Šerić Jelaska and Durbešić 2009; Ivanković Tatalović et al. 2020). Blake et al. (1994) noted that if an assemblage of species is typical of a particular habitat type, then similar patterns of body size distributions will appear among similar sites.

Furthermore, different species of ground beetles have different dispersal capabilities, with some species having well-developed hind wings, others being flightless with reduced hind wings present, and some species may develop both types of hind wings (Brandmayr 1991). Habitat can filter ground beetles in relation to their dispersal capabilities and phenology (e.g. Šerić Jelaska and Durbešić 2009; Duflot et al. 2014), which includes the impact that agricultural land use and management may have on the ecological composition of ground beetle assemblages (Cole et al. 2002).

In this study, we analyze the distribution of three ecological and morphological traits of ground beetles (body size, dispersal abilities, and feeding type) among Mediterranean agroecosystems with different management practices. We examine whether Mediterranean habitats with different levels of land management (OM, IPM, and unmanaged sites) will differ in their ground beetle composition and ecological and morphological traits as suggested by Pizzolotto

(2009). Furthermore, we expect that unmanaged sites and sites with OM will support an assemblage consisting of more large, flightless carnivores, due to their stability as a habitat in comparison to sites with IPM. The result can reveal the impact of management practice on ecosystem services of ground beetles on the larger geographical scale and their potential in ecosystem services. In addition, functional diversity of ground beetles and their phenology at our study sites were analysed to obtain the information on functional diversity when the abundance data is used.

Materials and methods

Study sites

To assess the assemblage and the ground beetles' traits composition, we selected published studies with the following criteria: (1) conducted in vineyards and olive orchards within the Mediterranean basin, (2) having samples collected by pitfall traps since they are the most widely used sampling technique for ground beetles (Kromp 1999), and (3) a list of sampled ground beetles identified to species. Based on this criteria, four studies with eight sites were chosen (Table 1).

In our field, study ground beetles were sampled in five sites (Table 1). These sites comprised two vineyards (OM (VYOM1) and IPM (VYIPM1)), two olive orchards (OM (OLOM1) and IPM (OLIPM1)) and one unmanaged site which served as a control (Con1). All sites were located in Zadar County, in Mediterranean Croatia (Table 1). The vineyard and olive orchard sites have been managed for several decades, except for the OLOM1, which was converted from maquis to olive tree plantation 12 years ago. Given the small-medium field size, lack of crop rotation, and stability of the olive orchards (Cirio 1997), we assumed that the time period (> ten years) was substantial to allow beetle fauna to form communities and exhibit stability in species composition, distribution, and abundance (Kromp 1999).

Sites selected based on the published studies experience similar agricultural practice (Table 1) with regular mowing activities. Since data on mowing and mechanical soil preparations were unavailable for all sites, they were not included in further analyses as co-variables. Unmanaged or control sites in Croatia, Italy, and Greece represent typical Mediterranean natural habitats within study areas (Table 1). In total, data on ground beetle species composition from thirteen sites were used in the analyses including our five field sampled study sites. In addition, we separated the selected agricultural sites into two categories: those under the OM and those under the IPM (Table 1). The proportion of traits described in "Data analysis" section was calculated for each site based on presence-absence data for the ground beetle species since data on abundance were unavailable across most of the published studies. Detailed informations about the sample sites featured in this study are given in Table 1.

Ground beetle sampling in Croatian agroecosystems

Sampling of ground beetles took place from April to July and from September to November 2018, so as to cover the entire vegetation season. The month of August was omitted from the sampling period as earlier years indicated draughts and high air temperatures occurred at this time (Croatian Meteorological and Hydrological Service (DHMZ)). In response, ground beetle activity decreased due to aestivation dormancy (Thiele 1977). Specimens were collected in plastic pitfall traps (8 cm ø) with a volume of 300 ml. There were 12 traps per site positioned parallel to the plantation, and the distance between traps was approximately 10 m. All pitfall traps were placed under olive trees or under grapevine stumps. They were positioned at least 20 m from the field margins, to avoid edge effects. As the number of traps and their exposure period differed among sites and sampling periods, catch for each species at each site for the total sampling period was standardised as activity density (AD):

$$AD = \frac{N(sampled\ specimens)}{\sum n[traps \times days]} \quad (1)$$

where n is the number of sampling periods, N is the number of sampled specimens, *traps* is the number of open pitfall traps, and *days* refers to the number of days that traps were active.

Saturated aqueous NaCl solution was used to preserve trapped beetles. Traps were emptied every two to three weeks and the material was transferred in 80% ethanol. Beetles were identified to species in the

Table 1 Study sites with applied pest managements, ground vegetation, soil mechanical treatments where the data was available, and study references (Abbreviations: IPM Integrated Pest Management, OM Organic Management, N/A not available)

Type of study site	Location	Site (mark)	Pest management type	Ground vegetation and weed procession	Mulching	Ploughing	References
Olive orchards	Poličnik, Zadar County, Croatia	OLOM1	OM	Rocky soil with little plant coverage and regular mowing	Yes	No	Our study
	Škabrnja, Zadar County, Croatia	OLIPM1	IPM	Grass coverage, surrounded by coppice, regular mowing	Yes	No	Our study
	Tuscany, Central Western Italy	OLIPM2, OLIPM3, OLIPM4	IPM	Regular weed mowing	No	No	Albertini et al. (2017)
	Fthiotida, Central Greece	OLOM2, OLOM3	OM	N/A	No	No	Chapman (2014)
Vineyards	Nadin, Zadar County, Croatia	VYOM1	OM	Tilled soil with weeds	No	Yes	Our study
	Baštica, Zadar County, Croatia	VYIPM1	IPM	Tilled soil with weeds	Yes	Yes	Our study
	Val d'Agri, Basilicata, Italy	VYOM2	OM	N/A	N/A	N/A	Letardi et al. (2015)
Control	Suhovare, Zadar County, Croatia	Con1	Unmanaged	Maquis and garrigue with *Juniperus*, *Pinus* and *Quercus* species	No	No	Our study
	Tuscany, Central Western Italy	Con2	Unmanaged	Coniferous and *Quercus* species, poor understory vegetation	No	No	Albertini et al. (2017)
	Island of Kos, Greece	Con3	Unmanaged	Arid habitats with pine and cedar forests	No	No	Assing (2017)

laboratory. In total, seven sampling events occurred across all sites. Ground beetles were isolated and identified to species using taxonomic keys by Trautner and Geigenmüller (1987), Freude et al. (2004), and Hurka (1996), and following the nomenclature of Fauna Europaea (Vigna-Taglianti 2013).

To determine whether distribution traits of ground beetle assemblages can be linked to agricultural practice three ecological and morphological traits were selected. These were: feeding preferences, body size and wing development and life traits commonly used to describe ground beetle assemblages in agricultural fields (Cole et al. 2002; Pizzolotto et al. 2018). Each trait was subdivided into the following attributes: (1) feeding preferences (carnivores, omnivores, and herbivores), (2) average species' body size (very small (<5 mm), small (5–10 mm), medium (10–15 mm), large (>15 mm)), and (3) wing development (macropterous, dimorphic, brachypterous). Informations on the selected traits were obtained from the online database http://www.carabids.org (Homburg et al. 2014) and recent literature (Cole et al. 2002; Kosewska et al. 2014; Albertini et al. 2017; Pizzolotto et al. 2018).

Data analysis

A Shapiro-Wilks test was used to test the normality of the data. A nonparametric Kruskal–Wallis test was performed to analyze if there was a significant difference in the proportion of traits between unmanaged sites, sites under OM, and sites under IPM, and to test the difference in the functional diversity between the management types. Redundancy analysis (RDA) was performed for visualization of trait composition with respect to agricultural practice. A Rao coefficient was calculated as described in Lepš et al. (2006) to summarize different facets of functional composition and diversity in ground beetle assemblages. Firstly, it was calculated for every site using presence-absence data, and secondly for Croatian sites only using abundance data, to compare the results. All analyses were performed using STATISTICA 13 (Statistica Inc. TIBCO Software*)*, PAST 4.03 (Hammer et al. 2001*)*, and Microsoft Excel 2010.

Results

Meta-analysis of life traits in ground beetle assemblages

113 ground beetle species were found within the 13 agroecosystems selected across the Mediterranean basin. 81 beetle species were recorded in olive orchards, 54 species were recorded in vineyards, and 28 species were recorded on unmanaged sites (Supplementary Table S1). The Kruskal–Wallis tests showed significant differences (Table 2) for the proportion of carnivores based on the management type (unmanaged sites, OM, IPM) (Fig. 1a). Multiple comparisons tests (two-tailed) showed that unmanaged sites had significantly higher proportions of carnivorous species than OM sites ($p=0.018$), but not IPM sites ($p=0.202$). There were no significant differences in proportion of different size and dispersal ability in the ground beetle assemblage as a function of management type. However, IPM sites had a higher percentage of small and macropterous individuals when compared to OM and unmanaged sites (Fig. 1b, c). Variations in ground beetle assemblages between different managements, according to their feeding preferences, wing development, and body size are presented on the F1 × F2 ordination plot of RDA. The first three axes explained 22.75%, 8.93%, and 0.86% of variance for olive orchards, vineyards and unmanaged sites (Fig. 2). The first axis separated unmanaged sites and OLOM1 from other managed sites, with carnivorous, large, and brachypterous species being more abundant in unmanaged sites, as confirmed by the Kruskal–Wallis test.

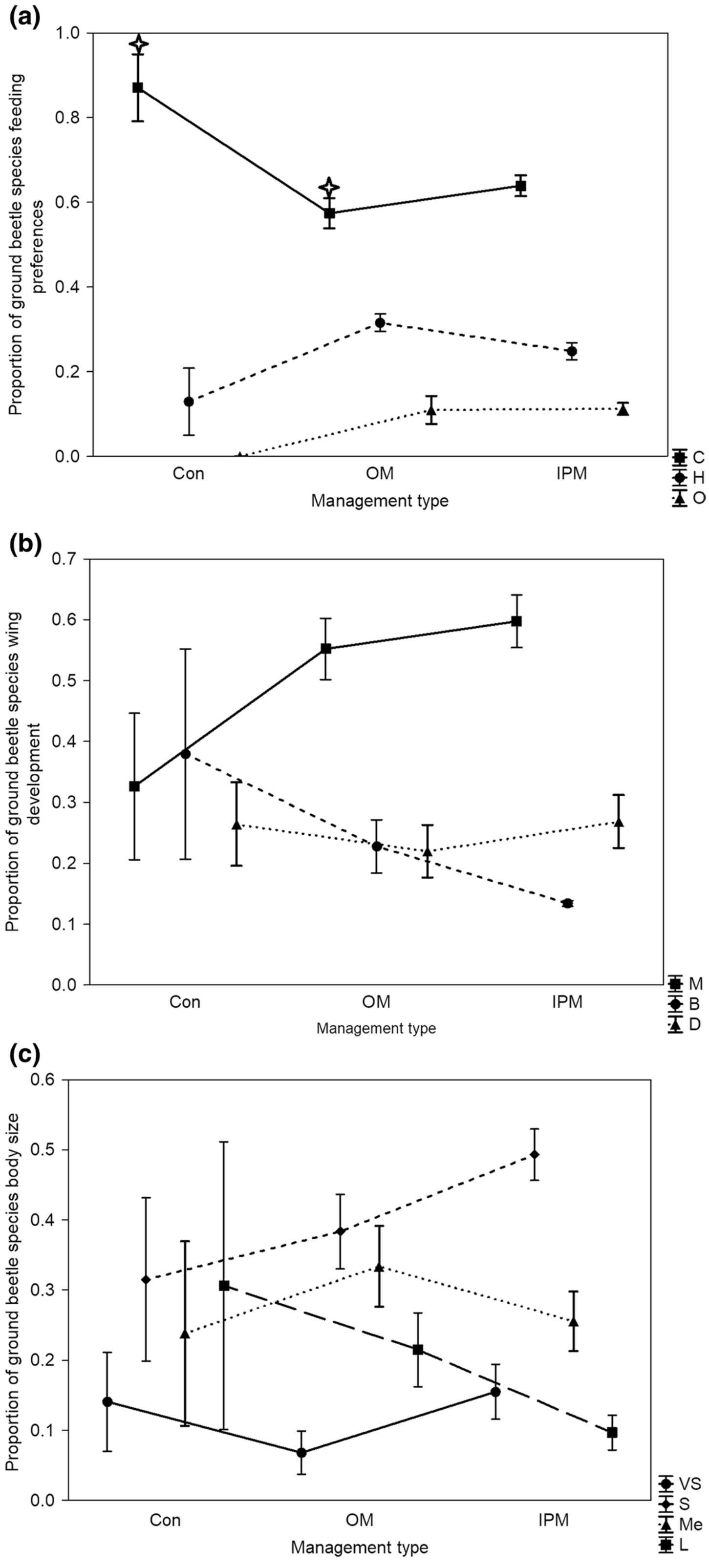
The Rao index showed the lowest values for all three traits on unmanaged sites compared to agricultural sites (Fig. 3). When data for the two management types were pooled (unmanaged sites, agricultural sites), the Kruskal–Wallis test showed that functional diversities for feeding preferences were significantly lower in the unmanaged sites (Table 2). Conversely, when agricultural sites were separated by management type (OM and IPM), there was no significant difference in the Rao index values between management types (unmanaged sites, sites with OM, and sites with IPM).

Table 2 Results of Kruskal–Wallis tests on the proportions of traits and Rao index values

	N (sites)	df	χ^2	*p*
Proportion of the traits				
Carnivores	13	2	6.593	**0.037**
Herbivores	13	2	5.406	0.067
Omnivores	13	2	5.507	0.064
Macropterous	13	2	3.288	0.193
Brachypterous	13	2	4.478	0.106
Dimorphic	13	2	1.307	0.52
Very small	13	2	1.939	0.379
Small	13	2	3.473	0.176
Medium	13	2	1.554	0.459
Large	13	2	2.142	0.342
Functional diversity				
Feeding preferences	13	1	4.828	**0.028**
Wing development	13	1	0.714	0.398
Body size	13	1	4.828	**0.028**

Management type was the independent (grouping) variable: three (Unmanaged, OM, IPM) for the proportion of the traits; two (unmanaged, managed) for the Rao index. *p* values lower than 0.05 are bolded

Fig. 1 The average proportion of: **a** carnivores (C), herbivores (H), and omnivores (O); **b** macropterous (M), brachypterous (B), and dimorphic (D); and **c** very small (Vs), small(S), medium (Me), and large (L) ground beetle species depending on agricultural management. (Con unmanaged habitats, OM sites with organic management, IPM sites with integrated pest management). Vertical bars denote ± SE. Star denotes the statistical difference in the proportion of carnivores between unmanaged sites and sites with OM ($p < 0.05$)



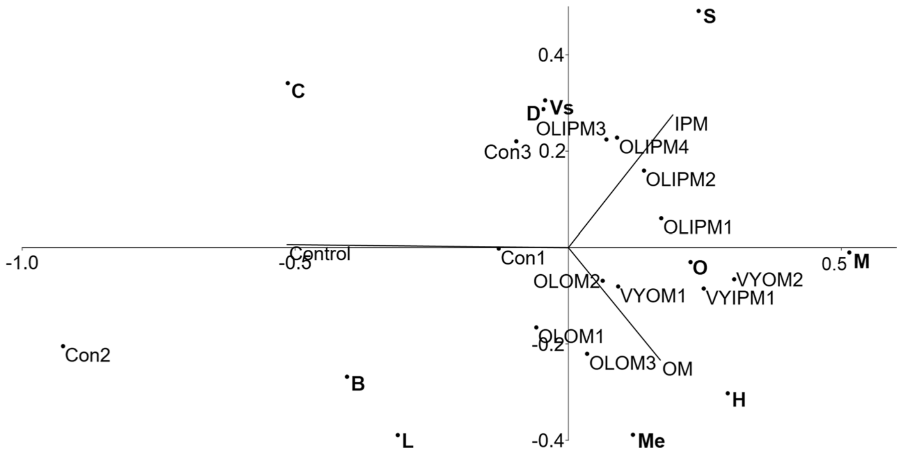


Fig. 2 Redundancy analysis (RDA) biplot of axes 1 and 2 of RDA for the proportion of ground beetle traits in olive orchards and vineyards (C carnivores, H herbivores, O omnivores, M macropterous, B brachypterous, D dimorphic, VS very small, S small, Me medium, L large). First two axes explain 31.68% of variance. For site abbreviations see Table 1. The environmental variables (management types) analyzed are indicated as vectors

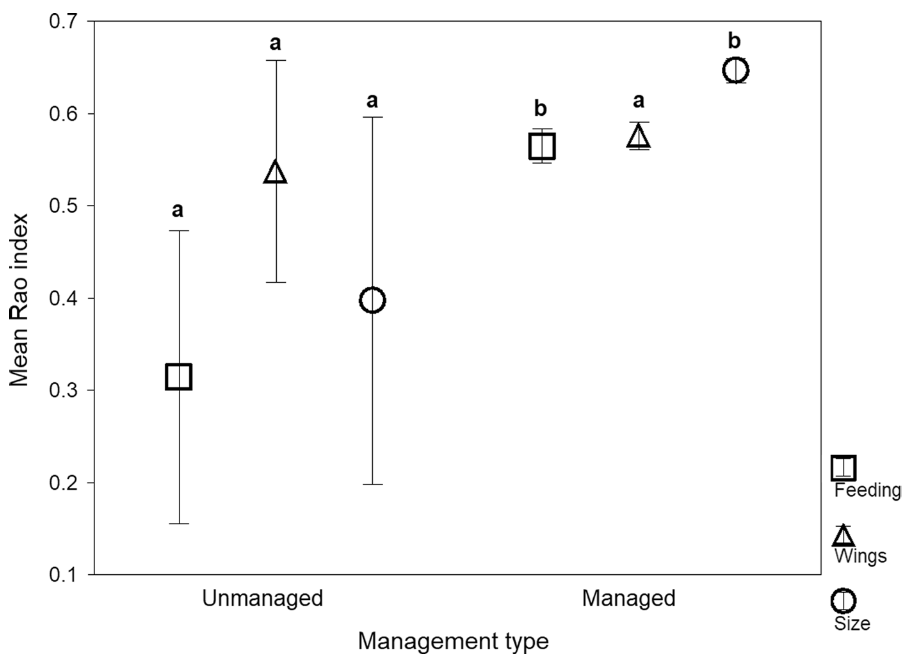


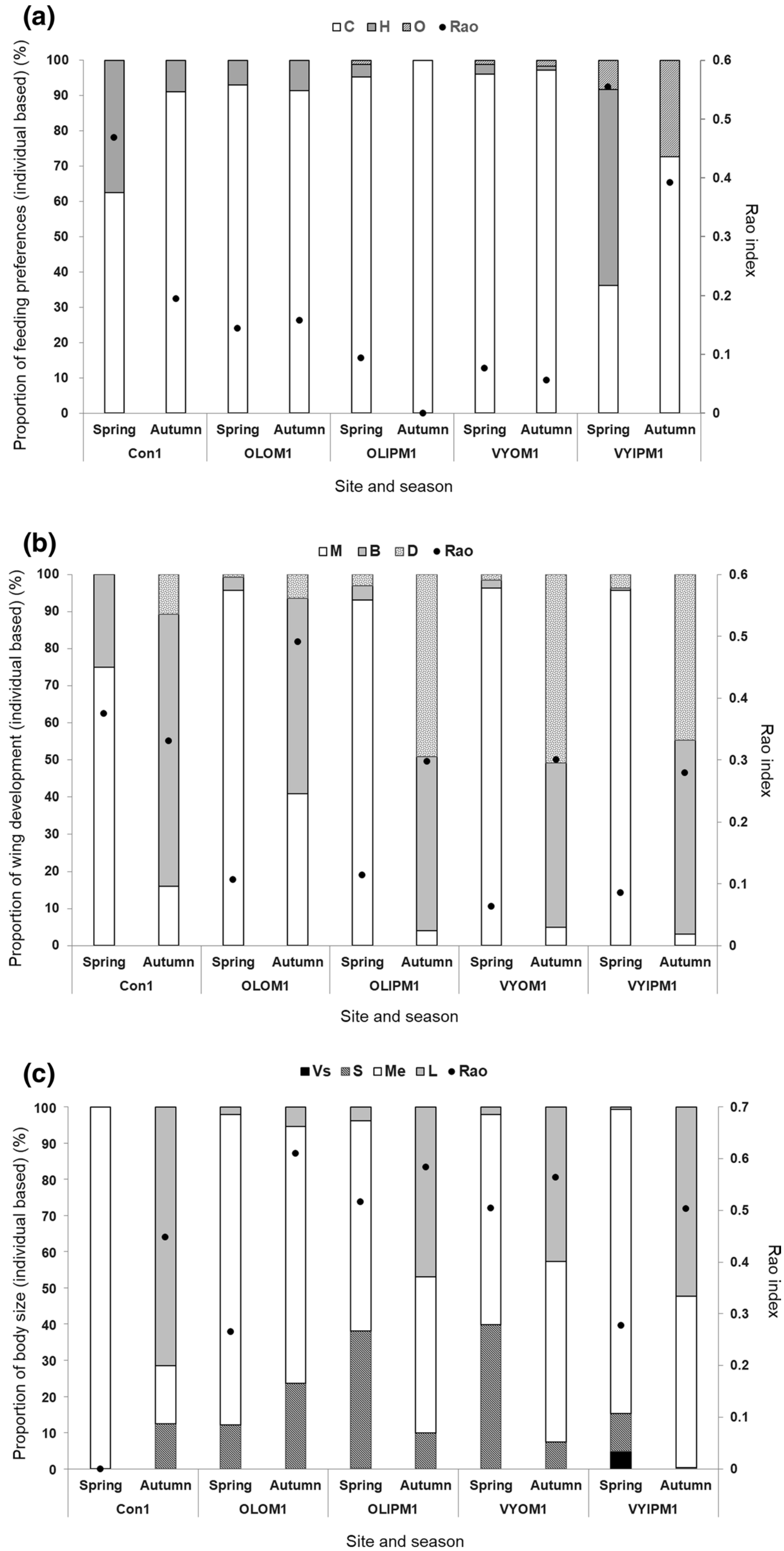
Fig. 3 Mean of Rao index values grouped by management (unmanaged, managed) according to the traits. Different letters denote statistically significant difference ($p < 0.05$) in functional diversities for each trait depending on the management type. Vertical bars denote ± SE

Ground beetle assemblages and traits found in Zadar County

A total of 4, 344 individuals belonging to 66 species and 26 genera of Carabidae were recorded (Supplementary Table S2). Carnivorous ground beetle individuals were the dominant feeding group found at each site (Fig. 4a). This was particularly evident at OLIPM1 and VYOM1, where their proportion was 96.58% and 96.44%, respectively. This is in contrast to the proportion of carnivorous species which was 68.8% and 58.6%, respectively, at these sites.

In terms of dispersal ability, macropterous individuals were the most numerous at every site with the exception of Con1, where brachypterous beetles dominated (Fig. 4b). The majority of the sampled

Fig. 4 The proportion of individuals according to the traits (feeding preferences (**a**), wing development (**b**), and body size (**c**)) they shared at each site within Zadar County, through the spring/early summer and autumn seasons, corresponds to the left axis. Rao indices, according to the traits and seasons, are depicted as black dots and correspond to the right axis. (C carnivores, H herbivores, O omnivores, M macropterous, B brachypterous, D dimorphic, VS very small, S small, Me medium, L large). For site abbreviations see Table 1



ground beetles were larger than 5 mm in size. Very small individuals (< 5 mm) comprised only 0.55% of the total catch, and were most numerous at VYIPM1, where their proportion was 3.11%. Medium-sized individuals dominated every site except sites Con1 and OLIPM1, where the large-sized and small-sized ground beetles were the dominant groups found, respectively (Fig. 4c). The Rao index values were highest for category "*size*" and lowest for category "*diet*" at each site except for VYIPM1, where diet had the highest Rao index value (Fig. 4a–c). Diet also had the lowest value in the meta-analysis when only the presence-absence data were used.

Discussion

Meta-analysis of life traits in ground beetle assemblages

Ground beetle composition and distribution of traits within agroecosystems are driven by a complex net of edaphic, physical, ecological, and anthropogenic factors (Eyre et al. 2013; Albertini et al. 2017), only some of which were examined in this study. Using presence-absence data, ground beetle assemblage from unmanaged sites differed from the assemblages in the agroecosystems for the distribution of traits examined. The Kruskal–Wallis for the meta-analysis confirmed that unmanaged sites had significantly more carnivorous species (Fig. 1a, Table 2), while the managed sites had a higher proportion of macropterous and small to medium-sized species (Fig. 1b, c). These results were confirmed by RDA which separated unmanaged sites from agroecosystems, with large, brachypterous and carnivorous species preferring the unmanaged sites (Fig. 2). This trend was noted in studies outside the Mediterranean agroecosystems as well. For example, Cole et al. (2002) observed that large predators from the genus *Carabus* were the most affected by the type of agricultural practice used on Scottish farmlands. It is expected that for habitats with higher anthropogenic disturbances to have a lower proportion of strictly predatory ground beetles, as carnivores are more sensitive to landscape changes compared to omnivores and herbivores (Purtauf et al. 2005; Gobbi and Fontaneto 2008; Šerić Jelaska & Durbešić 2009). Conversely, herbivores had the highest relative abundance at managed sites (Fig. 1a). Functional diversity (presence-absence based) for feeding preferences and size was significantly lower at unmanaged sites compared to the pooled data of both management types. However, there was no notable difference in functional diversity between the OM and IPM managements types examined in this study (Fig. 3). The low functional diversity in control plots and unmanaged forests was also noted for forest ground beetles communities by Elek et al. (2021) and Šerić Jelaska et al. (2011), in which larger, flightless carnivores dominated. These findings suggest that available stable habitats have established assemblages with the dominant large carnivorous species. IPM and OM programs encourage management practices that are non-invasive and sustain beneficial arthropod efficiency in pest control (Albertini et al. 2017; Picchi et al. 2017). Here we showed that IPM sites support predatory ground beetles and functional diversity of beetle assemblage as efficiently as OM sites. It should be borne in mind that it is based on the number of predatory species instead of the total abundance.

Ground beetle assemblages and traits analyses at Croatian study sites

The AD data was used to calculate the proportion of selected traits during spring–summer and autumn period, and active carnivores were recorded as late as November in olive orchards, overlapping with the life cycle of *B. oleae* larvae and pupa when they are found on the ground, and thus act as potential prey for ground-dwelling predators such as ground beetles (Lasinio and Zapparoli 1993). Their activity tended to be higher in the autumn months. Herbivores were more active in spring on Con1, OLIPM1, and VYIPM1, while in VYOM1 and OLOM1 they appear equally across both seasons (Fig. 4a). The unmanaged site was the only study site where the brachypterous, and large species were dominant, especially during autumn (Fig. 4c). Large species and autumn breeders have longer-lasting larval stages that are more prone to soil disturbances (Gobbi and Fontaneto 2008; Šerić Jelaska et al. 2011). The unmanaged site was free of practices such as tillage or pesticide use which may otherwise have a negative effect on the ground beetles and thus presents a more stable habitat among the researched sites (Holland and Luff 2000; Ivanković Tatalović et al. 2020). The increasing habitat persistence can lead to a higher proportion of brachypterous species (Brandmayr 1991; Hof et al. 2012) and brachypterous individuals in dimorphic species (Lövei and Sunderland 1996). Blake et al. (1994) concluded that disturbed habitats support a ground beetle fauna of smaller average body size and that ground beetle body size decreases as management intensity increases. These findings support our observations at the Croatian study sites where the highest percentage of small individuals was from OLIPM1, a site with frequent mulching (Fig. 4c). This result is further corroborated by the results of the meta-analysis we undertook (Fig. 1c).

Functional diversity calculated by the Rao index was highest for *size* and lowest for feeding preferences at every site except for VYIPM1, where feeding preferences had the highest diversity (Fig. 4a, c). VYIPM1 is a site where the soil is tilled under and between grapevines, which generally has a negative impact on ground beetles AD (Shearin et al. 2007). On the other hand, some herbivorous and omnivorous species, such as *Pseudoophonus rufipes*, can withstand frequent tillage (Miñarro and Dapena 2003). This led to a more even ratio of individuals with different feeding preferences and higher functional diversity for that trait. Ground beetles have been recognized for their contribution to biocontrol of weed through consumption of weed seeds (Shearin et al. 2007). OLIPM1 and VYIPM1 have slightly higher average functional diversity than unmanaged and sites under OM, which is in contrast to the research by Hevia et al. (2019) conducted on the ant community. These authors suggest that functional diversity in ant communities decreased slightly with the increasing intensification of olive grove soil management.

To conclude, our hypothesis that unmanaged sites and sites with OM will support an assemblage consisting of more large, flightless carnivores, compared to IPM sites was only partially confirmed. Both unmanaged sites, and sites with OM had higher proportions of large and brachypterous species than IPM sites, and unmanaged sites had a statistically higher proportion of carnivorous species compared to agricultural sites. These results were further confirmed by RDA which separated unmanaged sites from the agricultural sites, and by functional diversity, which was significantly higher at agricultural sites, but not between OM and IPM. Unmanaged, natural habitats in the study supported the ground beetles assemblage with more large, flightless carnivores. Nonetheless, differences among organic and integrated pest management in studies sites appear not to have a significant influence on the proportion of ground beetles traits. Croatian agricultural sites had a high proportion of predatory ground beetle individuals of different size categories that were active through a year. They can act as a biocontrol to a wide range of prey. Understanding the distribution of functional traits of ground beetles between different agricultural practices and unmanaged sites is important in supporting the practices that sustain ecosystem services and ensuring a better understanding of insect biodiversity in Mediterranean ecosystems.

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Author contributions LŠJ and LIT designed the study and wrote the manuscript; LIT sorted sampled material; LIT, LŠJ and FK provided data analyses and visualization; TK provided sampling design and organized field sampling; LŠJ supervised this work and provided financial support through MEDITERATRI Project (HRZZ UIP 05-2017-1046) as a project leader. All authors have read and agreed to the published version of the manuscript.

Data availability Ground beetle samples have been deposited in the entomology lab at the Faculty of Science, University of Zagreb.

Declarations

Conflict of interest The authors declare no conflict of interest.

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