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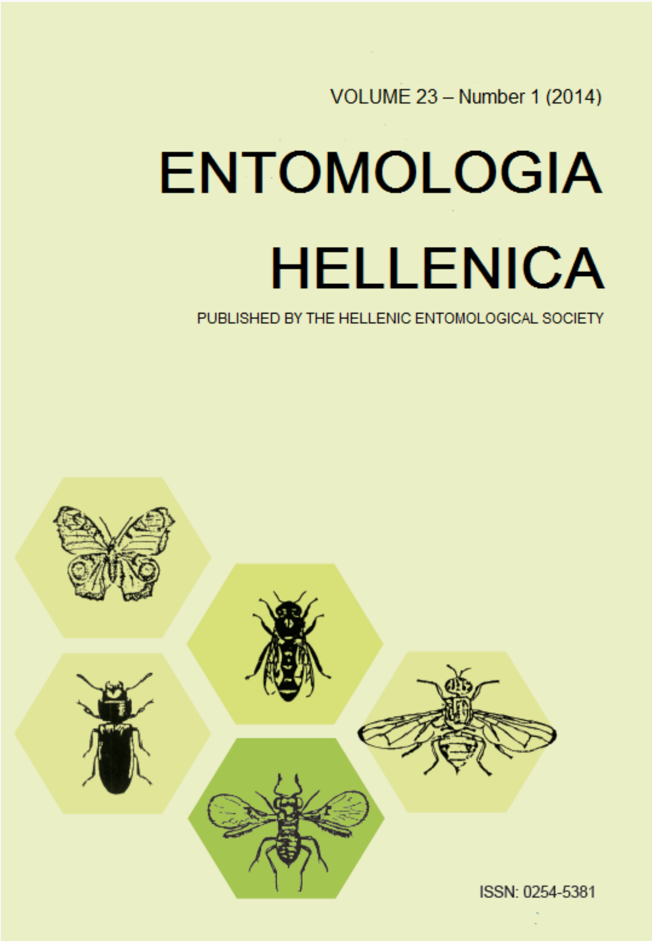

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Soil arthropod biodiversity in plain and hilly olive orchard agroecosystems, in Crete, Greece

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ABSTRACT

Soil arthropod biodiversity was monitored in 24 olive orchards located in eight different sites in Messara, Crete, covering the two main agroecological zones of olive oil production, hilly and plain. Monitoring was done weekly for five weeks per season, from autumn 2011 to summer 2012, using pitfall traps. Subgroups of functional taxa were defined with respect to services of biological pest control and of nutrient cycling. Comparison of the different agroecological zones in terms of abundance and diversity of soil arthropods and functional subgroups was performed. Coleoptera (39.52%), Formicidae (27.3%), Araneae (8.77%) and Collembola (5.32%) were the most abundant taxa found in the olive orchards. Hilly orchards presented higher total arthropod diversity, but lower abundance due to family Tenebrionidae. Arthropod richness did not differ between agroecological zones. Functional arthropods were a major part of total abundance (76.7%) and presented a trend of higher catches abundance in the hilly orchards arthropods with seasonally statistically significant differences. Shannon Index of Diversity showed higher arthropod diversity in the hilly orchards, being significantly higher in spring. The less intensive olive production in hilly areas appeared to favour soil arthropod diversity.
KEY WORDS: olive, soil arthropods, diversity, functional biodiversity, olive agroecosystem, agroecological zone.

Introduction

Olive production in the Mediterranean is often a conventional agricultural protocol with high chemical inputs especially in intensive modern olive orchards. Such production often faces ecological problems (Kabourakis 1996, Kabourakis 1999, Volakakis et al. 2012). Biodiversity is particularly affected by intensive farming methods, forcing agroecosystems to impoverishment (Biaggini et al. 2007).

Olives are cultivated in different agroecological zones, predominately in plain

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and hilly ones. These agroecological zones differ in terms of elevation, landscape structure, pedoclimatic conditions and biotic factors. These differences lead to different management practices in the olive orchards and different input use. Hilly agroecological zones are less suitable for intensification of farming practices and inputs due the limitations posed by the terrain and the pedoclimatic conditions (Kabourakis 1996, Metzidakis et al. 2008).

Enhanced agroecosystem biodiversity provides several services and supports soil fertility, crop protection and productivity, when correctly assembled (Altieri 1999). Soil biodiversity is especially regarded as offering stability against disturbance and stress in agroecosystems (Brussaard et al. 2007). The elements of agricultural biodiversity providing such desired services has been regarded as “functional” with several definitions emerged, depending on stakeholder’s objectives and priorities (Moonen and Bàrberi 2008, Bàrberi 2013).

Nutrient cycling and decomposition is a major function that many soil arthropods deliver, by among others fragmentation of litter, grazing of microflora and improvement of soil structure (Reichle 1977). Main decomposers and detritivores among the soil arthropod community are Scarabaeidae, Tenebrionidae, mites (Acari), springtails (Collembolla), woodlice (Isopoda) and Thysanura (Petersen and Luxton 1982, Moore et al. 1988, Stork and Eggleton 1992, Wurst 2013).

Soil arthropod community of the olive agroecosystem can deliver as well substantial services in terms of biological control of olive fly (*Bactrocera oleae* (Rossi), Diptera: Tephritidae), the main olive pest worldwide (Daane and Johnson 2010). Several studies have showed that predatory soil arthropod community can inflict mortality on the Tephritidae pupae (Bateman 1972, Cavalloro and Delrio 1976, Bigler et al. 1986, Orsini et al. 2007). Typical potential predators of the Tephritidae pupae are taxa such as Araneae, Carabidae, Staphylinidae, Formicidae and Opiliones (Bateman 1972, Cavalloro and Delrio 1976, Wong et al. 1984, Bigler et al. 1986, Allen and Hagley 1990, Thomas 1995, Hennessey 1997, Hodgson et al. 1998, Urbaneja et al. 2006, Gonçalves and Pereira 2012).

This investigation was designed to optimise the efficiency of soil arthropod diversity management in olive orchards taking into consideration the effect of agroecological zone. The diversity of soil arthropod fauna in twenty four olive orchards in southern Crete was monitored for a whole year period using a standard sampling method, as part of a wide-ranging investigation into a number of aspects of olive production. Soil arthropod fauna diversity and its functional counterpart were monitored among different agroecological zones. Low intensity management in olive orchards related to the hilly agroecological zone was assumed to favour soil arthropod diversity. In addition, the response of the functional part of the soil arthropods to the agroecoecological zone was investigated for drawing conclusions of the robustness of such an approach.

Materials and Methods

Orchard survey

The survey took place in twenty-four pilot orchards located in eight different sites in Messara valley southern Crete, Greece, a representative olive producing region of Crete. The area has a semi-arid Mediterranean climate with annual mean temperature of 17.5^{o}C and precipitation of approximately 600 mm/year (Kabourakis 1996).

Landscape consists mostly of olive orchards, both plain and hilly, covering the main agroecological zones of olive production. These two agroecological zones, hilly and plain, were differentiated regarding the elevation, the terrain, the abiotic environment (soil type and fertility, rainfall, temperature, humidity), the biotic environment (fauna and flora), the landscape and the intensity of management applied in the olive orchards. Plain orchards are regarded as more intensive compared to the hilly ones in terms of input and farming methods intensity.

Orchards were selected following discussions with stakeholders in the area of study, based on previous research carried out in the area (Kabourakis 1996, Kabourakis 1999, Vassiliou 2000, Volakakis 2010, Volakakis et al. 2012). All orchards were managed commercially and their management represented the diversity of practices occurred in the study area. Orchard size had an average of 0.53 ha, ranging from 0.17 to 1 ha. Four of the study sites were located on the plain agroecological zone, being orchards of intensive farming practices and high-input use and four on the surrounding hills, being less intensive. Soil management in the plain orchards was more intensive and included the use of the soil rotavator in all orchards with all orchard surface intensively cultivated. On the contrary, soil management in the hilly orchards was less intensive due to the terrain and the stoniness of the olive orchards. Soil management included an extensive use of the light soil cultivator while in two orchards there was no soil cultivation. Plain orchards were irrigated with higher amounts of water, also due to its availability in the plain. Hilly orchards were irrigated with lower amounts of irrigation water due to its scarcity and low quality in the hilly orchards.

The sampling period included five weekly measurements per each season, from autumn 2011 to summer 2012 (in total 20 weeks/year), covering a standard production year in terms of climatic conditions.

Six trap stations per hectare were defined in each orchard with a minimum of two traps per olive orchard.

Soil arthropod fauna monitoring

Pitfall traps were used for soil arthropods collection. The traps were plastic, colourless, of 7.5 cm diameter and 11.5 cm height, filled with propylene glycol and they were left in site for 7 days. Traps were randomly placed both under canopy and between olive trees.

The ground was carefully dug and the top of the trap was placed at the same level with soil surface, in order to achieve minimum terrain disturbance. Samples collected were transported in plastic bags to laboratory, filtered and cleaned of debris and inorganic material. The collected insects were placed in Petri dishes and identified by stereomicroscope (C-PS, Nikon).

The arthropods were identified down to order level of taxonomy and to the level of class for Chilopoda and Diplopoda. Such higher taxa level taxonomization is regarded as appropriate for rapid biodiversity surveys, saving time and resources (Biaggini et al. 2007). Coleoptera were further taxonomized for the families of Scarabaeidae, Carabidae, Staphylinidae and Tenebrionidae due to their functionality. Family Formicidae was counted independently from order Hymenoptera due to its abundance.

Data analysis

Agroecological zones were compared in terms of arthropods abundance, represented by number of total catches per orchard surface. Richness (S) and Shannon Index of diversity (H’) were calculated. Catches of functional fauna were grouped regarding the important and prioritized agroecosystem services of biological pest control and soil nutrient cycling they deliver (Table 1).

SPSS 20.0 for MS Windows was used to carry out statistical analyses. Data normality was assessed by the Shapiro-Wilk test ($p<0.05$) and were found to be not normally distributed, even after several transformations. A non-parametric Mann-Whitney test was run to test for differences in terms of total and functional abundance and Shannon Index between agroecological zones. Significance was reported at the level of $P<0.05$.

Rank abundance curves (Whittaker plots) were formulated, to represent visually the species abundance distribution (SAD) for management systems and agroecological zones. Such visualization is one of the best known and most informative methods (Magurran 2004), considered to be of intermediate complexity between univariate descriptors such as species richness and diversity indices and labeled lists of species abundances typically analyzed by multivariate statistics (McGill et al. 2007).

TABLE 1. Functional taxa delivering services in the olive agroecosystem.

Olive agroecosystem service	**Taxa**
Biological pest control	Araneae Chilopoda Coleoptera 1. Carabidae 2. Staphylinidae Dermaptera Formicidae Opiliones
Nutrient cycling	Acari Coleoptera 1. Scarabaeidae 2. Tenebrionidae Collembola Diplopoda Isopoda Thysanrura

Results and Discussion

Total arthropod's abundance

Total number of arthropods captured during the whole sampling period amounted to 118,035 individuals. In the plain orchards 59,250 individuals were collected, whereas 58,785 in the hilly ones. The arthropods were classified into 16 taxa, represented in all agroecological zones (Table 2). Chilopoda, Dermaptera and Diplopoda are not presented in the tables due to their scarcity (less than 1%). Diptera, Lepidoptera, Mecoptera were not considered in the analysis, as not being true soil inhabitants.

The differences in total arthropod abundance were not statistically significant between agroecological zones in all seasons (Table 2). Nevertheless, the numbers of arthropods were higher in plain orchards in spring (30,479±249.49), winter (3,075 ±35.11) but not in summer (20,519 ±115.17) or autumn (5,177 ±24.35).

Main reason of such higher abundance in the plain orchards was the high presence of Coleoptera, especially Tenebrionidae (Tables 2, 3). When this taxon is excluded total catches appeared higher in the hilly orchards. Subsequently, this could be attributed to more favourable abiotic parameters for Coleoptera found in the plains of Messara, especially in the seasons of lower-mild temperature.

In the Whittaker plots visualizing taxa abundance distribution (Fig. 1), agroecological zones appear to have relatively steeper slopes in spring and in summer, indicating that plain and especially, hilly orchards presented higher dominance. Small seasonal differences appear in species richness (< 2 species) for all sampling periods, except in spring (see also S values in Tables 2, 3).

Specific taxa abundance

The most abundant arthropods throughout the four sampling periods were Coleoptera with 45,556 catches (39.52% of total abundance), dominated by Tenebrionidae (21,965). Coleoptera were seasonally peaked in autumn and spring and presented significantly higher catches in the plain orchards ($U=116$, $z=2.54$, $p<0.01$), in spring (Tables 2, 3).

Coleoptera were among the most abundant taxa in olive agroecosystems. In Santos et al. (2007) were the third most abundant taxon, after Formicidae and Collembola, from April to July. In Ruano et al. (2004) were the fifth and ninth most abundant in two-year study from March to October.

TABLE 2. Abundance of soil arthropod taxa per hectare, functional taxa and values of richness and biodiversity indices for hilly and plain agroecological zones in autumn and winter.

Season	**Autumn**				**Winter**			
Agroecological zone	**Hilly**	**SE**	**Plain**	**SE**	**Hilly**	**SE**	**Plain**	**SE**
Taxa								
Acari	108	2,56	93	1,65	62	1,30	42	0,89
Araneae	768	6,67	1004**	6,68	527	6,81	1158**	17,81
Coleoptera	1045	12,96	1452	19,03	453	4,73	410	5,25
Scarabaeidae	275*	7,19	30	1,18	21	0,71	0	0,00
Carabidae	263	3,22	379*	2,24	59	1,36	65	1,13
Staphylinidae	219	3,42	268	3,72	189	3,57	191	2,57
Tenebrionidae	20	0,62	57*	1,10	6	0,34	49*	1,86
Other	268	3,73	719	17,41	178	2,99	106*	1,47
Collembola	673	16,47	897	14,61	790	10,87	709	11,55
Dictyoptera	0	0,00	4	0,23	13	0,84	13	1,11
Formicidae	1129	14,01	922	14,74	94	1,57	120	2,52
Hemipt./Heteropt.	16	0,43	5	0,34	2	0,17	0	0,00
Hemipt./Homopt.	48	1,22	31	0,56	97	1,19	75	2,00
Hymenoptera	56	1,13	59	1,08	10	0,40	13	0,49
Isopoda	231	4,24	281	5,47	31	0,72	31	1,10
Opiliones	1390**	25,36	295	6,07	906**	19,19	401	6,36
Orthoptera	31	1,12	45	1,00	7	0,29	27	0,94
Thysanura	29	1,46	22	0,56	8	0,33	14	0,37
Other arthropods taxa counted: Chilopoda, Dermaptera, Diplopoda (<1%)								
Total Abundance	5543	41,37	5177	24,35	3061	28,66	3075	35,11
Functional taxa	5103	41,06	4247	25,36	2693	26,40	2780	33,05
BPC	3768	35,02	2868	16,32	1775	25,37	1935	22,09
NC	1335	18,34	1379	13,72	918	10,32	845	13,64
S	14		16		16		14	
H'	1,468		1,569		1,388		1,344	

BPC: Biological Pest Control, NC: Nutrient Cycling, S: Richness, H’: Shannon Index,
* *P*<0.05
** *P*<0.01

TABLE 3. Abundance of soil arthropod taxa per hectare, functional taxa and values of richness and biodiversity indices for hilly and plain agroecological zones in spring and summer.

Season	**Spring**				**Summer**			
Agroecological zone	**Hilly**	**SE**	**Plain**	**SE**	**Hilly**	**SE**	**Plain**	**SE**
Taxa								
Acari	2048*	59,76	651	12,68	818	21,24	1125	40,3
Araneae	1784	23,30	1401	12,01	2055	18,78	1701	8,3
Coleoptera	11848	134,24	20038**	232,44	4257	41,91	6053	62,8
Scarabaeidae	1072**	59,18	57	2,60	15	0,50	3	0,2
Carabidae	267	4,11	749**	8,62	35	1,48	73	1,4
Staphylinidae	874	11,26	1025	11,12	15	0,45	18	0,6
Tenebrionidae	5758	130,89	13043*	182,15	1960*	34,15	934	40,2
Other	3876	36,92	5164	72,06	2232**	31,46	5024	62,9
Collembola	758	15,64	888	10,99	1185	31,80	254	9,8
Dictyoptera	39	1,23	57	1,80	996	23,92	2742*	50,0
Formicidae	7133	98,23	5060	107,38	11032*	146,37	6069	88,9
Hemipt./Heteropt.	194**	4,68	46	0,74	628	34,45	47	1,4
Hemipt./Homopt.	658*	7,97	325	3,88	178	4,09	127	2,2
Hymenoptera	177*	4,37	49	0,86	188	3,10	434*	7,5
Isopoda	869	29,49	1013	9,35	465	17,02	434	9,6
Opiliones	2358**	26,66	656	10,09	3	0,24	4	0,3
Orthoptera	88	2,17	166	4,33	107	4,18	494	17,4
Thysanura	76**	1,81	11	0,33	19	0,62	36	1,0
Other arthropods taxa counted: Chilopoda, Dermaptera, Diplopoda (<1%)								
Total Abundnce	28217	255,30	30479	249,49	21964	197,88	20519	115,17
Functional taxa	22998	254,21	24555	238,84	17601*	192,93	11723	140,37
BPC	12417	128,06	8891	118,25	13139*	154,24	8453	91,84
NC	10581	162,27	15664	159,77	4462	75,79	3269	65,19
S	16		16		15		16	
H'	1,510**		1,169		1,380		1,575	

BPC: Biological Pest Control, NC: Nutrient Cycling, S: Richness, H': Shannon Index,
* *p<0.05*
** *p<0.01*

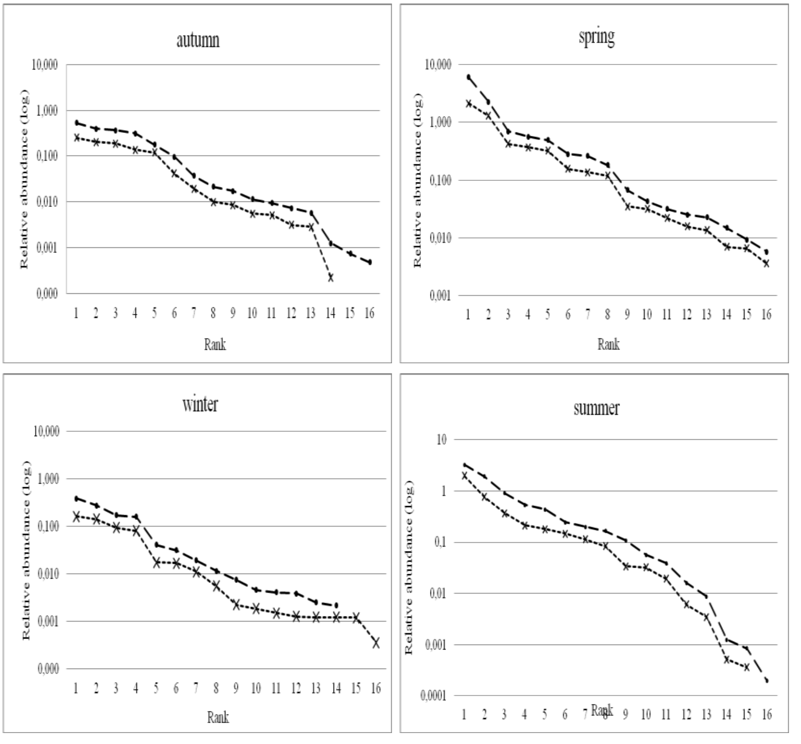

FIG. 1. Rank abundance curves of hilly (**X**) and plain agroecological zone (•).

Family Formicidae followed (31,190 catches and 27.3% of total abundance), with highest seasonal abundances found in summer and spring, as expected due to their tolerance to high temperatures and low humidity (Table 2). Significantly higher Formicidae catches were found in the hilly orchards (U=36, z=-2.08, P<0.05), in summer (Table 2). Formicidae are mentioned to be the most abundant taxon in the soil of olive orchards (Morris and Campos 1999, Santos et al. 2007, Cotes et al. 2010).

Araneae ranked third (10,348 catches and 8.77% of total abundance) among taxa, with the highest catches appearing in winter. Significantly higher abundances were found in the plain orchards, in autumn (U=108.3, z=2.109, P<0.01) and winter (U=188.5, z=2.108, P<0.05) (Table 2). Araneae is also mentioned as being amongst the most abundant taxa in the olive agroecosystem (Morris et al. 1999).

Order Collembola followed in abundance (6,276 and 5.32% of total abundance), with the highest seasonal catches found in winter (1,499 individuals), ranking second after Araneae. This winter peak could be attributed to the high seasonal humidity, favouring the specific taxa. Gonçalves and Pereira (2012) found Collembola to be the most abundant in the soil of olive orchards, justifying accordingly their findings by seasonality of measurements and environmental conditions. No significant differences of Collembola catches appeared between agroecological zones.

In general, the comparison in each taxon abundance between agroecological zones showed hilly orchards as having significantly higher catches in the cases of ten taxa, when plain orchards, had higher taxa abundances in seven cases (Table 2). The highest seasonal number of significant differences between agroecological zones was found in spring (seven taxa), followed by summer (three taxa) and then autumn and winter (two taxa each). Other surveys, comparing olive management systems, found highest numbers of different taxa in May and June (Cotes et al. 2010), as well as in July (Ruano et al. 2004), with most differences occurring in June.

Functionally relevant taxa abundance

Functional arthropods captured throughout the whole sampling periods numbered 90,627 individuals, representing 76.7% of total arthropod catches. 52,658 of them belonged to the biological pest control group (BPC) and 37,969 to the nutrient cycling group (NC).

In hilly orchards 48,396 functional arthropods were found (BPC: 31,100 and NC: 17,296), whereas 42,232 in the plain ones (BPC: 21,558 and NC: 20,674).

Agroecological zones comparison showed that total functional arthropods and BPC catches of the hilly orchards were statistically significantly higher in the summer (total: U=31, z=-2.714, p<0.05, BPC: U=34.5, z=-2.166, p<0.01) and the NC catches of the plain orchards in the spring measurements (U=108, z=-2.078) (Table 3). Main reason of higher values of NC in spring was the high number of Tenebrionidae catches.

Biodiversity indices

Shannon index (H’) presented higher values in the hilly orchards except in autumn and summer. Differences between the agroecological zones were statistically significant in spring measurements (Table 3) where biodiversity appeared to be higher in the hilly orchards (U=12, z=-3.464).

Conclusions

Hilly orchards presented the majority of significantly higher values of functional fauna abundance and Shannon Index, as well as in terms of specific taxa abundance. The most dominant taxa found were similar to the results of previous surveys, affecting the comparison of soil arthropods both in terms of total catches and functional subgroups.

Sub-grouping of total arthropods with regards to prioritised agroecosystem services proved to be an interesting approach for a biodiversity survey, providing significant results when agroecological zones were compared.

Orchard management encountered in hilly zones, attributed as less intensified and lower disturbance appeared to contribute to increasing soil arthropod diversity, but the effect of specific management practices should be further investigated. Therefore, future research may focus on the specific management practices effect, as well as their timing, that may result in greater overall and functional soil arthropod activity. Potential future changes in environmental factors (such as higher summer temperatures and irregular rain periods) and landscape aspects may also have to be taken into account when considering measures for increasing soil arthropod diversity.

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Βιοποικιλότητα εδαφόβιων αρθροπόδων σε αγροοικοσυστήματα πεδινών και λοφωδών ελαιώνων στην Κρήτη

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ΠΕΡΙΛΗΨΗ

Μελετήθηκε η βιοποικιλότητα της εδαφόβιας πανίδας αρθροπόδων σε 24 ελαιώνες, οι οποίοι βρίσκονται σε οκτώ διαφορετικές τοποθεσίες στην περιοχή της Μεσσαράς, Κρήτη, και καλύπτουν τις κύριες αγροοικολογικές ζώνες της ελαιοπαραγωγής, πεδινή και λοφώδη. Οι μετρήσεις της εδαφόβιας πανίδας περιλάμβαναν πέντε εβδομαδιαίες δειγματοληψίες σε κάθε εποχή του έτους, με χρήση παγίδων παρεμβολής εδάφους (pitfall traps). Επίσης, ορίστηκαν ομάδες λειτουργικής πανίδας, που αφορούν την βιολογική καταπολέμηση των εχθρών της ελιάς και την ανακύκλωση των θρεπτικών συστατικών του αγροοικοσυστήματος των ελαιώνων. Έγινε σύγκριση μεταξύ των διαφορετικών αγροοικολογικών ζωνών, όσον αφορά την αφθονία και την ποικιλότητα των εδαφόβιων αρθροπόδων και των λειτουργικών τους ομάδων. Στις ταξινομικές ομάδες με μεγάλη αφθονία απαντώνται τα Coleoptera (39.52%), η οικογένεια Formicidae (27.3%), τα Araneae (8.77%) και τα Collembola (5.32%). Η λοφώδης αγροοικολογική ζώνη παρουσίασε υψηλότερη ολική ποικιλότητα αρθροπόδων, ωστόσο χαμηλότερη αφθονία, λόγω της παρουσίας της οικογένειας Tenebrionidae. Ο πλούτος των ταξινομικών ομάδων δεν διέφερε μεταξύ των αγροοικολογικών ζωνών. Η ολική λειτουργική πανίδα αντιπροσώπευσε ένα μεγάλο ποσοστό της ολικής βιοποικιλότητας (76.7%) ενώ παρουσίασε μια τάση υψηλότερης σχετικής αφθονίας στους λοφώδεις ελαιώνες, με εποχικές στατιστικά σημαντικές διαφορές. Ο δείκτης βιοποικιλότητας Shannon υπέδειξε υψηλότερη βιοποικιλότητα στους λοφώδεις ελαιώνες, με στατιστικά σημαντικές διαφορές την άνοιξη. Γενικά, η λιγότερο εντατική ελαιοπαραγωγή των λοφωδών ελαιώνων φάνηκε να ευνοεί την βιοποικιλότητα της εδαφόβιας πανίδας αρθροπόδων.