Yellow or transparent? Comparison of sticky traps for monitoring functional arthropod diversity in an olive agroecosystem

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Abstract
Yellow or transparent? Comparison of sticky traps for monitoring functional arthropod diversity in an olive agroecosystem. A diverse and balanced arthropod community is known to play an important role in the olive canopy but monitoring methods are not always well defined. We monitored canopy arthropods in an olive orchard over two years, comparing the performance of yellow sticky traps and transparent sticky traps. Data used to compare the two types of traps were arthropod abundance, richness, diversity indices, species abundance distribution and aggregation of taxa in functional groups based on prioritized agroecosystem services. The total abundance of arthropods caught in the yellow traps was higher than that in the transparent traps but diversity in both traps was similar. Transparent traps may therefore be a valid option to assess biodiversity in an olive agrosystem as besides being less labor demanding than yellow traps, they are low cost and replicable, and do not damage the overall arthropod.

Key words: Olive, Canopy, Agrobiodiversity, Trapping, Agroecology

Resumen
¿Amarillas o transparentes? Comparación de trampas adhesivas para estudiar la diversidad funcional de los artrópodos en el ecosistema de los olivares. El valor de una comunidad de artrópodos diversa y equilibrada en el dosel de los olivares se ha descrito con frecuencia, no obstante, no siempre se ha definido debidamente una metodología adecuada para determinar dicho valor. Durante dos años se estudiaron los artrópodos del dosel de un olivar mediante trampas adhesivas amarillas y transparentes. Para comparar ambos tipos de trampa, se utilizaron los índices de abundancia, riqueza y diversidad, la distribución de la abundancia de las especies y la agregación de taxones en grupos funcionales según los servicios agroecosistémicos considerados prioritarios. Aparecieron diferencias en la abundancia total y varios taxones, y las trampas amarillas presentaron la mayor abundancia esperada, sin embargo, las trampas transparentes mostraron una comunidad de artrópodos del dosel con un grado parecido de diversidad y uniformidad. Utilizar trampas adhesivas transparentes como método de bajo costo, susceptible de ser reproducido y que exige menos trabajo puede resultar adecuado para determinar la biodiversidad sin perjudicar a la comunidad de artrópodos en su conjunto.

Palabras clave: Olivar, Dosel, Agrobiodiversidad, Trampeo, Agroecología

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Introduction

Olive groves in the Mediterranean region often serve as the main land cover in a variety of agroecological zones, such as hilly areas and plain areas (Gkisakis et al., 2016). Their ecological impact as functioning agroecosystems is of high value. Olive groves can provide ecosystem services such as reduction of soil erosion rate and enhancement of biodiversity, and they may also have socio–economic relevance (Loumou and Giourga, 2003). However, these well–established agroecosystems are often at risk as intensive cultivation practices replace the traditional low–input olive cultivation, leading to a homogeneous landscape and significant biodiversity degradation (Sokos et al., 2013).

Biodiversity in an agroecosystem provides stability and resilience (Altieri, 1999; Jackson et al., 2007), especially when considering the role of functional biodiversity (Ricotta, 2005). Indeed, the functional part of biodiversity delivers important agroecosystem services and has a greater influence on both individual and overall ecosystem processes than classical species diversity. As such, its assessment becomes a highly valuable process (Tilman et al., 1997). Additionally, abundance and diversity of arthropod communities often becomes a useful aspect to assess the short–term impact of agricultural practices and reflect on the deeper changes in the ecosystem over a longer period of time (Missa et al., 2009).

The olive agroecosystem hosts a unique assembly of organisms, especially arthropods, that have the potential to enhance orchard productivity (Gkisakis et al., 2015). The canopy stratumsupports a particularly high arthropod diversity (Ozanne, 2001) that provides valuable agroecosystem services (Gkisakis et al., 2018). Through their parasitic and predatory behavior towards key pests to the olive crop, beneficial arthropods in the canopy act as a biological pest control (Ruano et al., 2004; Rei et al., 2010). Additionally, the olive canopy can provide shelter to some species that are sensitive to environmental stress and as such they can be used as an indicator of the overall agroecosystem health (Scalercio et al., 2009).

Studying arthropod diversity is important for two main reasons (Clergue et al., 2005): (i) it represents a holistic agroecological approach to the biodiversity concept with accent on its beneficial aspects; and (ii) it serves to identify appropriate assessment methods to estimate, observe and manage agrobiodiversity. The ultimate goal of measuring and studying functional biodiversity is to understand the components that can improve crop productivity and achieve a satisfactory level of agricultural sustainability (Bárberi, 2013).

A main challenge when assessing arthropods in habitats, such as the olive tree canopy, is the selection of suitable and standardized trapping methods (Basset et al., 1997). Three criteria must be considered for trapping canopy arthropods (Yi et al., 2012): (i) the feasibility of sampling costs; (ii) the ease of replication; and (iii) the suitability of the design both for the characteristics of the selected agroecosystem and the high mobility of the targets. Passive trapping methods are often chosen as they rely on the movement of the arthropods towards the traps (Gullan and Cranston, 2005) and are a non–selective method that provides sufficient sampling intensity without repercussions on the arthropod populations (Missa et al., 2009).

Sticky traps may be a reasonable option for continuous sampling, preserving individuals in a suitable condition for identification (Yi et al., 2012). These devices consist of a surface coated with highly adhesive glue that traps arthropods when they land or crawl on it (Basset et al., 1997). Sticky traps may be: i) non–attractive, in which case they are transparent and odorless; or ii) attractive, in which case they have appealing colors, shapes, or smells, and they may be set in specific positions to target certain arthropod group(s) (Young, 2005). When they are further characterized by low cost and ease of collection, sticky traps can be used in larger number and replications (Basset et al., 1997; Young, 2005), a significant advantage for rapid biodiversity assessments.

The aim of our study was, first, to compare two types of sticky traps, transparent and yellow, as potentially passive trapping methods in order to assess the canopy arthropod community, especially its functional part, in the olive agroecosystem, and second, to evaluate the results for use in monitoring studies.

Material and methods

Study sites and sampling

The study was conducted in a 0.7 ha sub–plot within a 28 ha olive orchard located in the region of Chania, in the north–west part of the island of Crete, Greece (35º 20' N, 24º 17' E) (fig. 1). The location is situated at an altitude of 120 m, in a zone that primarily has a Mediterranean climate with a mean annual temperature of 14.3ºC and mean annual precipitation of 840 mm. The olive orchard under study has been cultivated for commercial purposes for the last 30 years, following the organic farming standards of EU legislation (EC) 834/2007. The orchard is planted with 'Koroneiki' olive tree variety (sp. *Olea europaea* var. *microcarpa alba*), one of the most prevailing Greek olive cultivars in Crete.

Twenty weekly measurements were conducted over the course of the two–year study (in autumn 2017 and spring 2019). Sampling took place in autumn and spring and lasted five weeks, coinciding with optimal arthropod activity in the olive agroecosystem. The two–year duration provided a full observation over the biennial cycle of olive trees (Lavee, 2007).Ten study sites were used throughout the sampling period, following a randomized experimental approach, for full area coverage and higher uniformity (fig. 2). Therefore, a total of four hundred sampling units were used, as summed up by multiplying twenty sampling weeks by ten study sites and two trap types.

Trapping methodology

At each site, two types of traps, yellow sticky traps (YST) and transparent sticky traps (TST) were set in the central part of the canopy, on a metal wire,

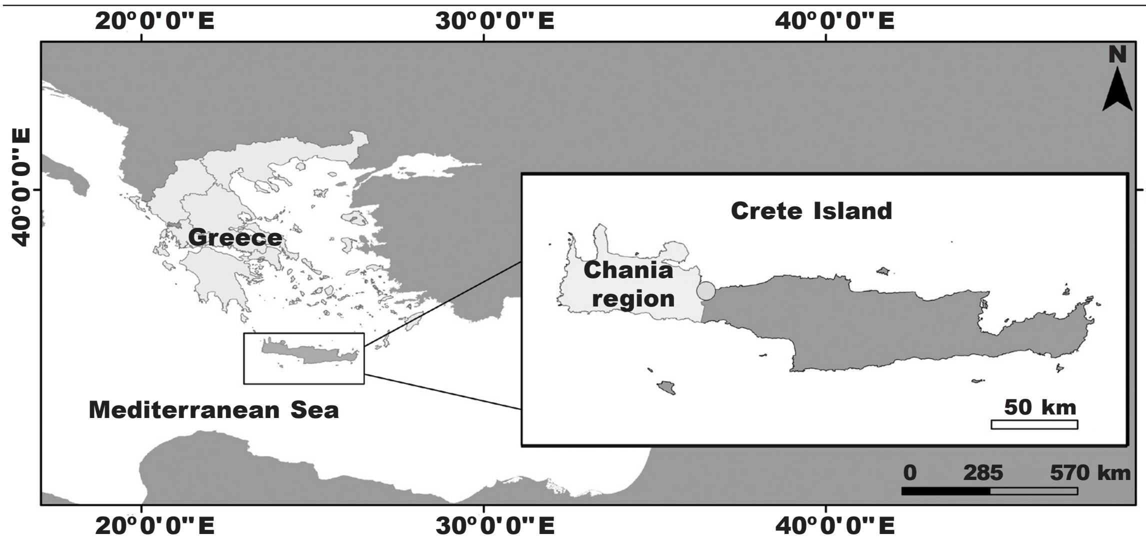

Fig. 1. Location of the olive orchard monitored. Light–shaded area on the map of the island indicates the county of Chania, where sampling took place.

Fig. 1. Localización del olivar estudiado. El área sombreada en gris claro del mapa de la isla indica el condado de Chania, donde se realizó el muestreo.

at an average height of 1.70–2 m. For convenient replacement, traps were attached on the wire with metal binder clips, spaced out at 1.5 m intervals, and on an unobstructed position from branches and leaves to avoid overlapping and to assure similar trapping conditions. YST (25 x 10 cm) was a commercially available, ready–to–use product Horiver® (Kopper B. V. The Netherlands) without any volatile attractants; it is used for monitoring several different types of insects. TST was prepared before each sampling, by homogenously applying a thin layer of TemoPlastic® glue (Kollant SpA, Vigonovo, Italy) on both sides of a PVC binding cover, of A4 format (21 x 29.7 cm). The traps were collected weekly, immediately transported in colorless plastic membranes, and preserved under laboratory conditions, thus avoiding any trap damage before taxonomization.

Arthropods were identified on the traps using a stereomicroscope (Novex AP Euromax®, Holland). A central sub–part of the TST, corresponding to the size of YST, was marked and taken into consideration. Taxa were identified to taxonomic level of order as a practical and relevant approach to assess biodiversity (Cotes et al., 2011; Gkisakis et al., 2018). Following a functional diversity approach based on the prioritized agroecosystem services of biological pest control and the 'dis–services' delivered by pests, we established two separate functional groups (Barberi, 2013): the pest

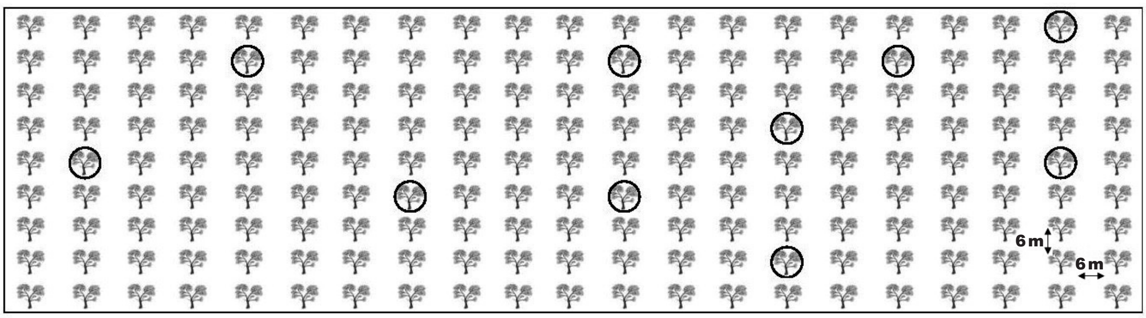

Fig. 2. Map of the randomized experimental design of the sub–plot. Indicated trees refer to the monitoring sites.

Fig. 2. Mapa del planteamiento del diseño experimental aleatorizado de la subparcela utilizada. Los árboles indicados se refieren a los sitios de control.

Table 1. Abundance per hectare of canopy arthropods, pests and functional taxa, richness and diversity indices of trapping methods in seasonal sampling and sum abundance for autumn 2017 and spring, 2019: YST, yellow sticky traps; TST, transparent sticky traps; BPC, biological pest control group of arthropods; Pests, main olive pests group; S: Richness; J, Pielou's index; H', Shannon index; 1–D, reverse Simpson's index; Σ, sum abundance for the whole sampling period (other taxa counted but not presented due to scarcity (< 0.05 %): Syrphidae, Margaronia Unionalis, Prays Oleae, Chrysopidae, Hemerobiidae).

Tabla 1. Abundancia por hectárea de artrópodos de dosel, plagas y taxones funcionales, valores de los índices de riqueza y diversidad de diferentes metodologías de captura en muestreo estacional y suma de abundancia, para en el período comprendido entre otoño de 2017 y primavera de, 2019: YST, trampas adhesivas amarillas; TST, trampas adhesivas transparentes; BPC, grupo de control de artrópodos para plagas biológicas; Pests, principal grupo de plagas del olivar; S, riqueza; J, índice de Pielou; H', índice de Shannon; 1–D, índice recíproco de Simpson; Σ, suma de la abundancia de todo el período de muestreo (hay otros taxones contados que no se han representado debido a su escasez (< 0,05 %): Syrphidae, Margaronia Unionalis, Prays Oleae, Chrysopidae, Hemerobiidae).

	Monitoring season					
	Autumn		Spring		Σ	
Trap	YST	TST	YST	TST	YST	TST
Araneae	212	76	250	196	462	272
Diptera	19,299	4,142	20,289	9,037	39,588	13,179
Asilidae	2,670	910	3,633	1,118	6,303	2,028
Bactrocera oleae	289	33	14	3	303	36
Hemiptera/Heteroptera	128	100	343	154	471	254
Other Hemiptera	1,641	138	690	217	2,331	355
Hymenoptera	3,308	1,229	4,492	2,621	7,800	3,850
Psytallia concolor	97	44	89	24	186	68
Ichneumonidae	497	98	643	307	1,140	405
Lepidoptera	286	248	498	383	784	631
Neuroptera	221	82	548	377	769	459
Psocoptera	8,532	995	961	302	9,493	1,297
Thysanoptera	5,413	541	8,401	1,214	13,814	1,755
Coleoptera	116	48	308	296	424	344
Total abundance	39,156	7,599	36,780	14,797	75,936	22,396
Pests	289	33	14	3	303	36
BPC	3,498	1,137	4,634	1,663	8,132	2,800
S	10	10	10	10	10	10
J	0.619	0.629	0.578	0.576	0.590	0.602
H'	1.425	1.448	1.331	1.325	1.390	1.386
1–D	0.684	0.653	0.627	0.586	0.655	0.620

group (PG), and the biological pest control (BPC) group. The PG group was considered to have a negative function and included the main pests of the olive crop sp. *Bactrocera oleae* (Rossi) (Diptera, Tephritidae), sp. *Prays oleae* (Bernard) (Lepidoptera, Yponomeutidae) and sp. *Margaronia unionalis* (Hübner) (Lepidoptera, Crambidae) (Delrio, 1992). The BPC group was considered to have a positive function and referred to arthropods that showed parasitic and predatory behavior towards the main olive pests (Ruano et al., 2004; Rei et al., 2010; Gkisakis et al., 2018). These main pests included the order Araneae, families Syrphidae and Asilidae (order Diptera), family Ichneumonidae and species *Psyttalia concolor* (Szépligeti) (Hymenoptera:

Table 2. Results of the Mann–Whitney test, including U, *Z* and *p* values, as applied to the comparison between two trapping methods (YST and TST) in seasonal samplings (autumn and spring) and sum abundance (Σ) for autumn 2017–spring, 2019. Predetermined levels of significance used: * $p < 0.05$, ** $p < 0.01$; obtained *p*–values that are less than 0.001 are recorded as < 0.001.

Tabla 2. Resultados de la prueba de Mann–Whitney, incluidos los valores U, Z *y* p*, como aplicados a la comparación entre dos diferentes metodologías de captura diferentes (YST y TST) en muestreos estacionales (otoño y primavera) y la suma de abundancia (Σ) para en el período comprendido entre otoño de 2017 y primavera de 2019. Niveles predeterminados de significancia utilizados: ** p *< 0,05, *** p *< 0,01; los valores de* p *obtenidos inferiores a 0,001 se registran como < 0,001.*

	Monitoring season								
	Autumn			Spring			Σ		
	U	*Z*	*p*	U	*Z*	*p*	U	*Z*	*p*
Araneae	5.50**	–3.37	< 0.001	42.50	–0.57	0.570	109.00*	–2.46	0.014
Diptera	7.00**	–3.25	< 0.001	18.00*	–2.42	0.016	44.00**	–4.22	< 0.001
Asilidae	40.50	–0.72	0.472	32.00	–1.36	0.174	149.50	–1.37	0.172
Bactrocera oleae	3.00**	–3.57	< 0.001	28.00	–1.88	0.060	96.00**	–2.90	< 0.001
Hemiptera/Heteroptera	54.00	0.30	0.762	18.50*	–2.39	0.017	152.00	–1.30	0.193
Other Hemiptera	0.00**	–3.78	< 0.001	12.00**	–2.88	< 0.001	14.00**	–5.04	< 0.001
Hymenoptera	10.00**	–3.03	< 0.001	21.00*	–2.19	0.028	68.50*	–3.56	< 0.001
Psytallia concolor	45.50	–0.35	0.730	17.00*	–2.52	0.012	128.50	–1.95	0.051
Ichneumonidae	13.00**	–2.80	< 0.001	14.50**	–2.69	< 0.001	70.00**	–3.52	< 0.001
Lepidoptera	49.50	–0.04	0.970	41.00	–0.68	0.496	179.50	–0.56	0.579
Neuroptera	20.00*	–2.27	0.023	33.00	–1.29	0.198	113.50*	–2.34	0.019
Psocoptera	18.00*	–2.42	0.015	30.00	–1.51	0.131	102.00**	–2.65	< 0.001
Thysanoptera	19.00*	–2.34	0.019	13.00**	–2.80	< 0.001	73.50**	–3.42	< 0.001
Coleoptera	17.00*	–2.50	0.012	44.00**	–0.45	< 0.001	130,00	–1.90	0.058
Total abundance	7.00**	–3.25	< 0.001	0.00*	–3.78	< 0.001	17.00**	–4.95	< 0.001
Pests	3.00**	–3.57	< 0.001	33.50	–1.47	0.142	104.00**	–2.69	0.007
BPC	28.00	–1.66	0.096	23.00*	–2.04	0.041	110.00*	–2.44	0.015
J	56.00	0.45	0.650	46.50	–0.27	0.791	207.00	0.19	0.850
H'	57.50	0.57	0.570	46.00	–0.30	0.762	208.50	0.23	0.818
1–D	49.00	–0.08	0.940	42.50	–0.57	0.570	182.50	–0.47	0.636

Braconidae: Opiinae), and families Chrysopidae and Hemerobiidae (order Neuroptera). Taxa of the suborder formerly known as Homoptera, were classified as 'other Hemiptera'. The hymenopteran family Formicidae was not considered due to the inappropriateness of the applied trapping method.

Data analysis

The two trapping methods were compared through measures of: i) total and specific taxa abundance, and abundance of functional groups (BPC and PG); ii) taxa richness (S); and iii) a set of diversity indices including Pielou's index (J), representing community evenness, Shannon index (H') and the reverse Simpson's index of diversity (1–D). These measures, except richness, were compared following a univariate statistical analysis approach, in SPSS 20.0® for Windows. Data normality was assessed by the Shapiro–Wilk test ($p < 0.05$) and was found to be not normally distributed, even after applying several transformation types. Therefore, the non–parametric Mann–Whitney test was run to assess the differences between the two trapping methods, with a significance reported at the predefined levels of $p < 0.05$ and $p < 0.01$.

Whittaker plots (rank abundance curves) were also generated in order to visually represent the species abundance distribution (SAD) for the two trapping

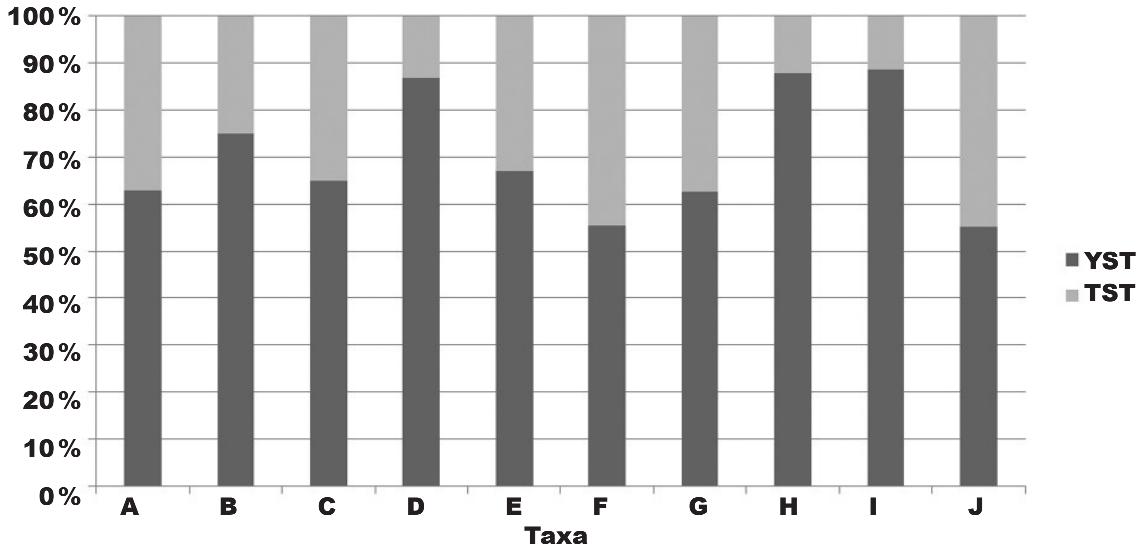

Fig. 3. Distribution (%) of the most dominant arthropod taxa in the YST and TST: A, Araneae; B, Diptera; C, Heteroptera; D, Homoptera; E, Hymenoptera; F, Lepidoptera; G, Neuroptera; H, Psocoptera; I, Thysanoptera; J, Coleoptera.

Fig. 3. Distribución (%) de los taxones de artrópodos más dominantes en las trampas amarillas (YST) y las trampas transparentes (TST).(Para las abreviaturas de los taxones, véase arriba).

methods. This approach is considered well known and informative (Magurran, 2004), being 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).

Results

Arthropod abundance and diversity

We captured a total of 98,332 arthropods during the sampling over the two years. Samples were classified in 10 orders and all were found in both types of traps. A total of 75,936 individuals were captured in the YST (77.22 % of total catches) and 22,396 (22.78 %) in TST (table 1). Univariate analysis delivered a significant difference ($p < 0.01$) between YST and TST in total abundance. This difference remained constant during sampling seasons in both years (table 2).

Diptera was the most dominant taxon throughout the sampling period and for both trapping methods. It accounted for 52,767 catches, of which 39,588 (75.02 % of total catches) were in YST and 13,179 (24.98 %) were in TST. Thysanoptera, Psocoptera and Hymenoptera followed as the most abundant species in YST, while the other orders were present in abundance < 4 %. In TST, the most abundant taxa after Diptera were also Hymenoptera, Thysanoptera and Psocoptera, while the other orders were present in abundance < 3 % (fig. 3).

Abundance was higher in YST than in TST for the orders Araneae, Diptera, other Hemiptera, Hymenoptera, Neuroptera and Thysanoptera, families Asilidae (Diptera) and Ichneumonidae (Hymenoptera) and *Bactrocera oleae* (table 2). Results were similar when autumn and spring captures were considered alone, with the exceptions of Coleoptera (significantly higher for YST only in autumn), Heteroptera (significantly higher for YST only in spring), and Neuroptera and Psocoptera (no significant differences between traps, in spring captures) (table 2).

Bactrocera Oleae was the most dominant pest, with 339 individuals captured in both traps, accounting for only 0.34 % of the total catches (table 1). The total number of pests captured by YST was significantly higher in autumn and in terms of total catches (table 2).

The BPC functional group consisted of 10,932 individuals (11.12 % of total arthropod catches). Most BPC arthropods were captured by YST (74.39 % of the BPC group total catches), being statistically higher than those captured by TST (table 2). However, the percentages of BPC catches were 12.5 % for TST and 10.71 for YST. Asilidae was the most abundant arthropod in the BPC group accounting for 77.51 % of BPC arthropods in YST and 72.43 % in TST, followed by Ichneumonidae (14.02 % in YST and 14.4 6% in TST) and Araneae (5.68 % in YST and 9.71 % in TST). Abundance in the remaining groups was > 10 % (table 1).

Diversity indices did not present any statistical differences between traps in any cases, either in spring or autumn sampling, over the two–year period (table 2).

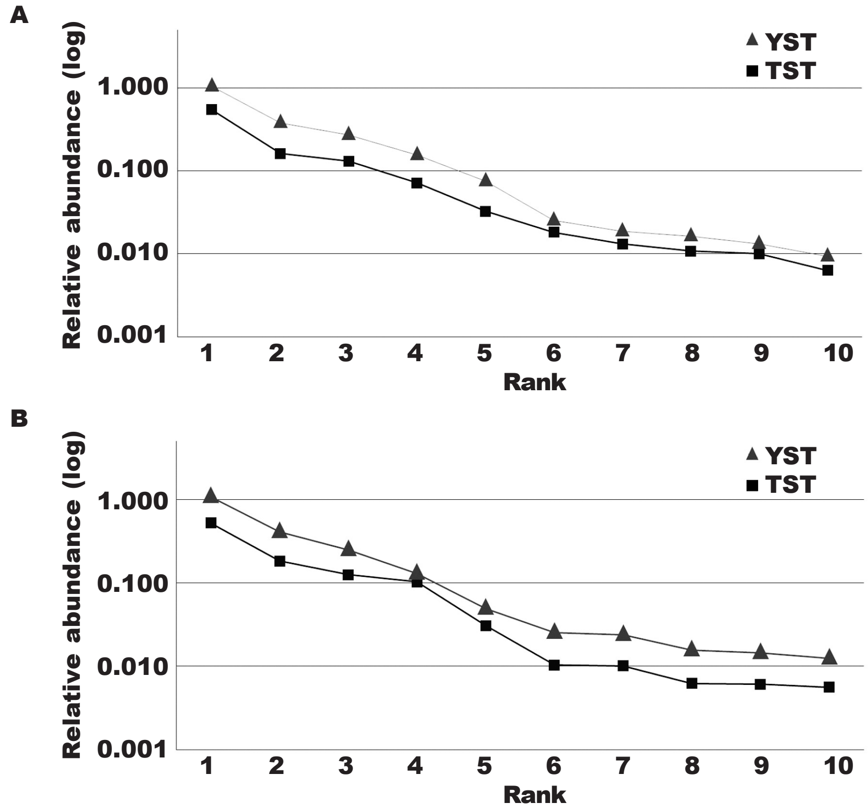

Fig. 4. Whittaker plots (rank abundance curves) of YST and TST for autumn (A) and spring (B) measurements.

Fig. 4. Gráficos de Whittaker (curvas de rango-abundancia) para las trampas amarillas (YST) y las trampas transparentes (TST) en las mediciones de de otoño (A) y primavera (B).

Nevertheless, both Pielou's index of evenness and the Shannon index presented relatively higher absolute numbers for TST, especially in autumn (table 1).

In Whittaker plots, visualizing taxa abundance distribution (fig. 4), YST and TST appeared to have similarly shallow slopes, indicating relatively high evenness and confirming the higher evenness found using Pielou's index (table 1).

Discussion

The differences in catches between YST and TST were evident in our study for almost all taxa captured over the two–year study period. Significant differences were observed in both seasons for several orders, indicating a natural preference towards yellow for taxa such as Diptera (Bekker et al., 2017), Homoptera (Castro et al., 2017), Hymenoptera (Thomson et al., 2004; Gullan and Cranston, 2005) and Thysanoptera (Thomson et al., 2004).

The outcome was similar when the accumulative numbers of the catches of functional groups were considered, delivering statistically significant differences for both Pests and BPC group. The significantly higher numbers of catches of *Bactrocera oleae* by YST was expected, as the pest is often mentioned to be attracted to the colour yellow (Petacchi and Minnocci, 1994; Bekker et al., 2017). Additionally, the pest population in both traps was higher in autumn due to its natural cycle that corresponds to the maturation of the olives (Therios, 2009). With regards to the functional BPC group, the higher abundance of arthropods caught in spring both by YST and TST is also consistent with previous studies that reported a higher arthropod abundance in this season (Morris et al., 1999; Ruano et al., 2004; Gkisakis et al., 2018).

Although the overall arthropod abundance on the YST was much higher in all cases than in TST, the level of arthropod diversity and richness in both traps was similar. Indeed, no statistically significant differences occurred between the several diversity indices used, the overall richness of species, or the species abundance distribution. Also, TST interestingly captured a relatively more representative portion of functional arthropods delivering BPC, when compared to YST. In a previous study, Thomson et al. (2004) compared YST and TST in vineyards and found similar results in terms of arthropod richness, while YST appeared more effective in sampling Hymenoptera, Thysanoptera, Hemiptera, Diptera, Araneae and Coleoptera, and TST in sampling Lepidoptera and Neuroptera. This is consistent with our results and also explains the statistically significant difference for Araneae and Ichneumonidae (Hymenoptera) in favor of the YST.

The above outcomes support the acceptance of both trapping methods as suitable for providing a clear representation of the constituents of the BPC groups. TST appears to be especially appropriate for rapid diversity assessments of canopy arthropods, as its non–attractive and interceptive nature avoids very high number of catches, but diversity and evenness is well represented. It has the added advantage that it can avoid damage to a high percentage of individuals in the traps and also ease the taxonomization effort (Yi et al., 2012). Furthermore, a high number of the catches achieved with YST were arthropods that are beneficial for olive production. Indeed, parasitic arthropods in the olive canopy have been reported to have a general preference towards YST, so a destructive effect on beneficial arthropod community is generated when they are used (Neuenschwander, 1982; Mazomenos et al., 2002). Other desirable properties of a trapping method, such as low cost, adaptability and potentiality of continuous passive sampling on study sites (Özden and Hodgson, 2016) also support the use of TST. As such, TST may offer greater potential in terms of biodiversity assessment, combining representative but non–damaging sampling of functional groups of arthropods of the olive canopy with economical and practical features.

Conclusions

The variety of arthropods in the canopy in the olive crop implies that more than a single sampling method may be adequately used in terms of biodiversity assessment. Specifically, TST proved to be a representative, easily replicable and low cost method that may enable acquisition of a broad data set for biological pest control strategies, within an agroecological framework in olive production. Additionally, arthropod identification at higher taxonomization levels, along with the arthropod organization in functional groups, has been further proven to be convenient and with a potential for use by non–entomological experts, in rapid on–field observations. Such an approach would be potentially useful for both agronomy–oriented and biodiversity conservation studies. Additional research, where TST would be observed alongside other trapping methods, is required to yield more comparative data, both in perennial and annual crops, and to contribute towards better understanding of the agroecosystem in question.

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