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A comparison of butterfly communities in irrigated and non-irrigated Mediterranean farmlands

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Highlights

- Irrigation is an important form of agricultural intensification in particular in arid regions.
- Irrigation effects on butterfly diversity were measured in eastern Mediterranean (Cyprus).
- Modified agricultural practices linked to irrigation may contribute to changes in species abundance.
- Butterfly diversity and abundance was strongly correlated with irrigation.

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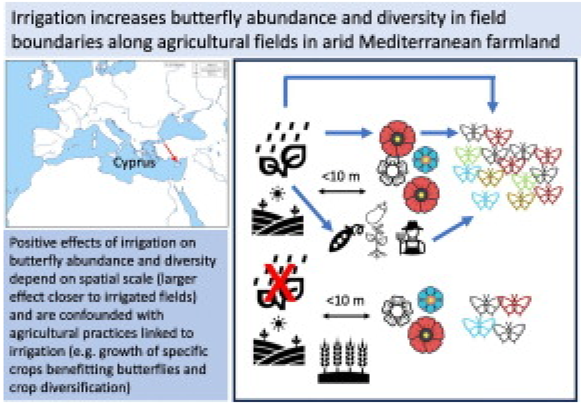
- The impact of irrigation on biodiversity may differ depending on geographical region.

Abstract

Irrigation is considered a form of agricultural intensification and is of significant importance in arid and semi-arid regions, such as those in the Mediterranean basin. This region differs substantially from temperate ones, in terms of climate, land-use policies and types of agricultural systems. Therefore, how biodiversity is affected by agricultural intensification may also differ substantially from countries in north-western Europe. We investigated the effect of irrigation on butterfly diversity and abundance at two different spatial scales in an agricultural region in northern Cyprus, an area representative of typical lowland agricultural practices of the Eastern Mediterranean. We investigated how local field-scale management (irrigated vs rain-fed) and the proportion of irrigated land at a larger scale of 0.25 km^2 affected the abundance and diversity of butterflies and herbaceous plant species. Butterflies and herbaceous plants were surveyed in field boundaries adjacent to agricultural fields located in paired plots that had contrasting levels of irrigation. Butterflies in the field boundaries along agricultural fields were strongly positively affected by irrigation in the adjacent fields both in terms of abundance and species diversity, whereas the effect of irrigation at the larger scale of the 0.25-km^2 plot was less prominent. Species composition of butterflies and plants did not correlate. However, plant abundance and alpha diversity of the vegetation in the field boundaries correlated with both abundance and alpha diversity of the butterflies when the abundance of plants was relatively low, in particular, when grasses were omitted from the data set. Crop species associated with irrigated fields contributed to the observed patterns. Comparing the results of this study with those reported for temperate regions in northwestern Europe reveals that the effectiveness of management schemes on biodiversity depend on biogeographical region, highlighting the risk of making broad assumption on the effectiveness of management strategies on biodiversity.

Graphical abstract



Keywords

Agricultural intensification; Biodiversity loss; Butterfly conservation; Cyprus; Drought; Irrigation

1. Introduction

In much of temperate Europe there is now overwhelming evidence to suggest that there is a severe decline in farmland biodiversity (Brooks et al., 2012; Hallmann et al., 2017; Gregory et al., 2019; Seibold et al., 2019) and that this is predominantly a consequence of changes in traditional farming practices and agricultural intensification (Krebs et al., 1999; Benton et al., 2003; Tscharntke et al., 2005). Agri-environmental schemes (AES) are European-Union (EU) governed conservation programmes designed to help farmers to manage their land to restore biodiversity (Kleijn et al., 2011; Batáry et al., 2015). Although the effectiveness of these schemes has been debated (Bengtsson et al., 2005; Hole et al., 2005; Kleijn et al., 2006), extensive research has led to a general consens such interventions do increase biodiversity relative to conventional practices, but th magnitude of the effect can vary substantially depending on external factors that are unrelated to farm management practices (Rundlöf and Smith, 2006; Rundlöf et al., 2008; Tuck et al., 2014). Such factors include the context of the wider landscape and the taxa studied (Bengtsson et al., 2005; Fuller et al., 2005; Rundlöf and Smith, 2006; Holzschuh et al., 2007).

The trajectories of agricultural intensification in the 20th century differ greatly across Europe depending on political ideologies (e.g., collectivism in the Eastern bloc) and biogeography (Batáry et al., 2015). Where in north-western Europe natural grassland and heath were displaced by agricultural fields (crops and grasses), in southern Europe farmlands have been abandoned in mountainous areas and intensified in more accessible agricultural areas (Debussche et al., 1999; Robinson and Sutherland, 2002; Batáry et al., 2015). Compared to temperate Europe, the effects of agricultural intensification and implemented AES on biodiversity in the Mediterranean region has received less attention (but see González-Estébanez et al., 2011; Concepción et al., 2012; Tuck et al., 2014). Given that the Mediterranean region has been recognized as a global hotspot for biodiversity (Medail and Quezel, 1999; Myers et al., 2000; Cuttelod et al., 2009), this is an important oversight. Moreover, a large proportion of the region's biodiversity has a strong association with land under traditional farm management (Blondel, 2010), which is potentially threatened by agricultural intensification (Concepción et al., 2012).

Mediterranean regions differ substantially from temperate ones, in terms of climate, land-use policies and types of agricultural systems (Caraveli, 2000). For instance, in Mediterranean regions a relatively large proportion of the soils are of poor quality and the region is prone to drought events due to low precipitation. Therefore, how biodiversity is affected by agricultural intensification and/or implemented AES may also differ substantially between north-western Europe and the Mediterranean region. Batáry et al. (2011) emphasized the risks of making broad assumptions on the effectiveness of management schemes on biodiversity across farming systems and the importance of considering the local characteristics of the landscape in the region where the management schemes are applied.

Irrigation is considered a form of agricultural intensification with over 70% of the world's freshwater withdrawals being used for this purpose (FAO, 2020). In the seven Mediterranean countries of the EU, total water withdrawal for irrigation is significantly higher than in the other twenty member states (51 vs 6 km^3/year, data for 2020) (FA). Moreover, irrigation expansion has been especially great in east Mediterranean co Benoit and Comeau, 2012). Irrigation is responsible for several environmental problems, such as the depletion of aquifers and inland water sources (Iglesias et al., 2011; Fuentes-RodrÍgues et al., 2013), soil degradation due to waterlogging and salinization (Singh, 2021), eutrophication of rivers and wetlands, and increased sedimentation (

Stoate et al., 2001; Monteagudo et al., 2012). However, the direct effects of irrigation schemes on farmland biodiversity are poorly understood (González-Estébanez et al., 2011). Though intensification through irrigation may be crucial in helping to meet future worldwide food demands, negative impacts such as loss in biodiversity should also be considered as they are important for the functioning and health of (agro)ecosystems (Kadiresan and Khanal, 2018). Consequently it is important to establish whether there is a trade-off between the high yields achieved with irrigation management and potential loss of biodiversity, as has been observed for other types of intensive agricultural management practices in temperate Europe (Kleijn and Sutherland, 2003; Kleijn et al., 2009; Gabriel et al., 2013). Without improving our understanding of region-specific effects of irrigation on farmland biodiversity, it will be difficult to develop effective AES for the Mediterranean basin (González-Estébanez et al., 2011) and to mitigate possible negative effects on biodiversity resulting from altered irrigation patterns under climate change (Hannah et al., 2013).

Seasonal water availability, which is highly variable in the Mediterranean and other semi-arid and arid systems, may further influence biodiversity responses to irrigation practices. For example, for some taxa, such as butterflies, water availability, particularly in lowland areas, has been found to be a key factor in determining species richness (Stefanescu et al., 2011). For these groups of organisms, sufficient availability of water could outweigh or offset any potential negative indirect influences of irrigation intensification of farmland in the Mediterranean region, such as increased use of agrochemicals and the loss and degradation of habitats (Warren et al., 2021). The influence of seasonal water availability may also vary depending on the surrounding landscape context. For example the ability of soils to retain water may vary between landscapes with different soil and vegetation types, or where different levels of natural habitat remain (Ryan et al., 2010) and is also affected by soil management strategies (Eden et al., 2017).

How biodiversity responds to irrigation management in Mediterranean regions may also depend on the spatial scale at which it is applied. Here, we investigated the effect of irrigation at different spatial scales on butterfly diversity and abundance in an agricultural region in northern Cyprus. This area is representative of typical lowland agricultural practices of the Eastern Mediterranean. This study is timely, as the area under irriga[illegible] management in this region is likely to expand rapidly in the coming years due to an agreement with Turkey to bring water to the island via an undersea pipeline (already underway). Butterflies are often used as indicators of environmental quality, because of their vulnerability to habitat deterioration. In the last decade many studies have reported the decline in diversity and abundance of Lepidoptera and other insect families (

Dirzo et al., 2014; Sánchez-Bayo and Wyckhuys, 2021; Wagner et al., 2021). Butterflies are strongly associated with water availability in Mediterranean climates (Stefanescu et al., 2011; Herrando et al., 2019) and may therefore serve as an important indicator taxon to study the effect of irrigation management on its abundance and diversity.

The aim of this study was to investigate how local field-scale management (irrigated vs rain-fed) and the proportion of land under irrigation management at a larger scale of 0.25 km^2 affect the abundance and diversity of butterflies and herbaceous plants. Butterflies and herbaceous plants were surveyed in field boundaries adjacent to agricultural fields located in paired plots that had contrasting levels of irrigation. Study sites were located in two regions of the Mesaoria (or Mesarya) plain in the north of Cyprus. As butterfly diversity has been shown to correlate with water availability in hotter regions (Stefanescu et al., 2011), we hypothesize that butterfly abundance and diversity will be strongly affected by irrigation at the level of the agricultural field. Moreover, availability of resources (nectar and food for butterfly larvae) provided by herbaceous plants may also be affected by irrigation. We therefore expect that diversity of butterflies and herbaceous plants will covary.

2. Materials and methods

2.1. Study area and sampling design

Butterflies and herbaceous plants were surveyed in two agricultural regions in the Mesaoria Plain in northern Cyprus. The Mesaoria Plain is intensively farmed with low retention of remnant semi-natural habitats. Currently 85–90% of the region comprises rain-fed cereal crops (wheat and barley) and the remaining 10–15% comprises irrigated crops (e.g., alfalfa, melon, artichoke, cabbage, potato, kidney bean, broad bean, olive). Farmers in this region fertilize their fields by spraying an aqueous solution of nitrogen and phosphorous when precipitation is low or apply urea when rain conditions are more favourable. Cypermethrin, a pyrethroid insecticide, is applied on cereal crops to control moths and fly infestations. Fertilizers and pesticides, including herbicides, are usually applied once a year. Agricultural land in this the Mesaoria plain has been irrigated for the past 10 years or longer. One of the two selected regions, referred to as Central-Mesaoria, was situated more central, ea Nicosia, and covered an area of approximately 25 by 20 km. Eight sites were selecte area and the distance between sites ranged between 2 and 22 km (Fig. 1a). The seco referred to as Yildirim, covered a smaller area (8 by 8 km), and was situated more to the west, closer to the Famagusta Bay. This area is similar to the other sampling region, except that it has a higher proportion of semi-natural grasslands still remaining (Table 1). We cannot exclude that the areas differ in some soil and geological characteristics, but these have not been determined. In Yildirim six sites were selected with a minimum distance of 2 and a maximum distance of 5 km (Fig. 1a).

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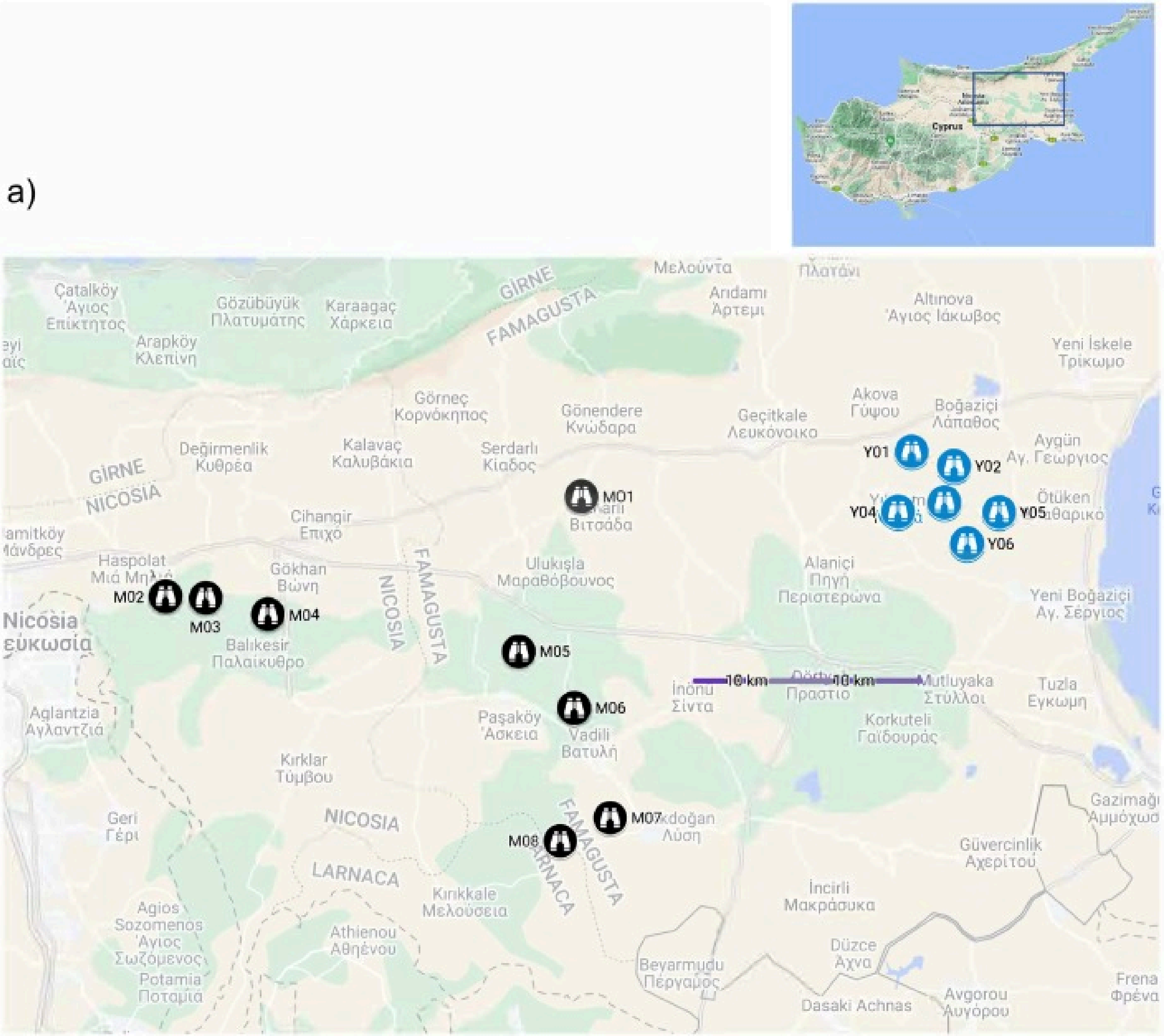
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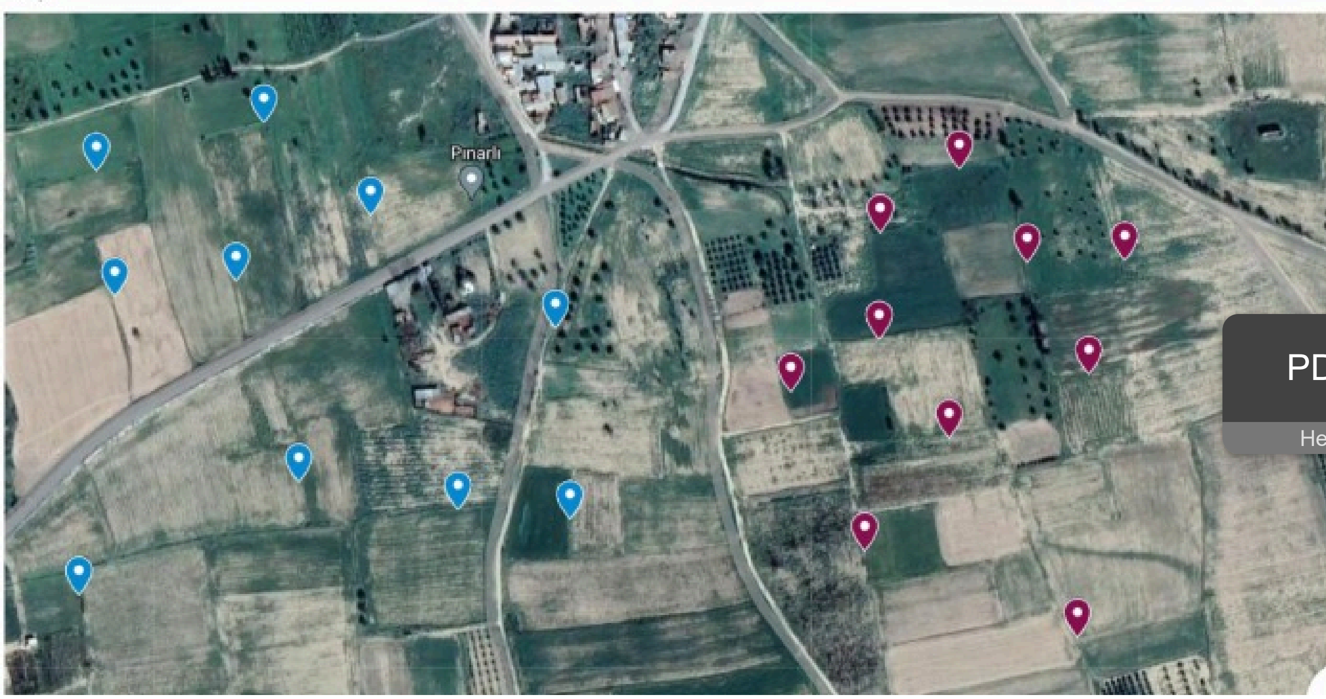
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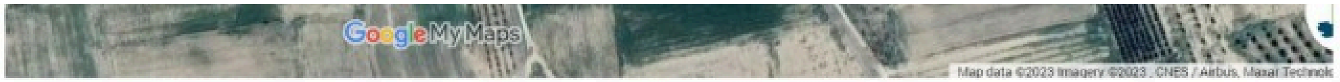

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Fig. 1. Location of the study sites situated in two regions of the Mesaoria plain, Central-Mesaoria (n=8, black symbols) and Yildirim (n=6, blue symbols) (a), and an example of locations of the transects within a site. Two 0.25-km^2 plots were selected at each 1-km^2 site: one with a high and one with a low proportion of irrigated land. Markers in blue depict transects in the plot with predominantly non-irrigated fields and markers in purple depict transacts in the plot with predominantly irrigated fields. In each plot, transects were selected in the field boundaries adjacent to agricultural fields (Google Maps, n.d.).

Table 1. Characteristics of the agriculture fields at a 0.25-km^2 plot scale in two regions of the Mesaorian plain, Central Mesaoria and the Yildirim region. Asterisk denote significant differences (*t*-tests; *, $P \leq 0.05$; **, $P < 0.005$) between High_Irr and Low_Irr plots within each region with n is the number of sites.

Characteristics	**Central Mesaoria**		**Yildirim region**	
	High_Irr (n=8)	**Low_Irr (n=8)**	**High_Irr (n=6)**	**Low_Irr (n=6)**
Arrable land (%)	95.5±2.4	93.0±1.4	78.2±5.9	71.7±8.0
Irrigated land cover (%)	42.1±6.7	14.8±3.6**	27.9±4.2	6.7±1.5**
Number of fields	22.6±2.8	22.1±2.3	16.0±2.1	13.3±1.3
Mean field size (ha)	23±3	22±3	19±1	23±1*

Satellite imagery, preliminary site visits and conversations with farmers in the region were used to select 1-km^2 square study sites containing irrigated and non-irrigated fields adopted the method used by Rundlöf et al. (2008). Two contrasting 0.25-km^2 study were chosen with high and low fractions of irrigated land, respectively, constrained to be paired within the 1-km^2 study sites. Fields under irrigation management were defined as those with a crop receiving irrigation from April to September each year. Paired plots differed in the proportion of land irrigated but not in the area of arable land, mean field size or mean number of fields, with the exception of the mean field sizes in the Yildirim region which were smaller in the plots with relative high levels of irrigation (Table 1). We refer to the irrigation management strategy at the plot level as Low_Irr and High_Irr, respectively.

We focused here on butterfly abundance and diversity in the area surrounding the agricultural fields, i.e. in the field boundaries. Field boundaries were defined as any area of non-crop habitat acting as a border between two adjacent agricultural fields or between a field and a farm trail. Field boundaries were selected within each plot based on irrigation in the adjacent agricultural fields (yes or no). We selected field boundaries adjacent to fields similar to and contrasting with the predominant irrigation treatment at the level of the plot. Crop species were determined during the first visit in each year (Appendix Table A). Non-irrigated fields were predominantly planted with cereal crops, whereas irrigated fields were often planted with alfalfa (Central Mesaoria) or melon (Yildirim region). During the first visit, the width of each field boundary was recorded at the midway point of the 50-m transects. It varied between 0 and 7.1 m (median 1.2 m) in Central Mesaoria and between 0 and 10.6 m (median 0.7 m) in the Yildirim region. Butterflies were surveyed along ten transects per plot, within the selected field boundaries. The final study system consisted of field boundaries adjacent to irrigated and non-irrigated fields (referred to as field-level irrigation) within pairs of matched, non-overlapping, plots which differed in the proportion of land under irrigation management (referred to as plot-level irrigation). In Central-Mesaoria, 61 boundaries were selected adjacent to irrigated fields and 19 adjacent to non-irrigated fields in High_Irr plots, and 19 vs 61 transects, respectively, in Low_Irr plots. For the Yildirim region these distributions were 40 vs. 20 in High_Irr plots and 11 vs. 49 in Low_Irr plots.

2.2. Butterfly and plant surveys

Butterflies were surveyed using a standardized counting method (Pollard, 1977). Along 50-m transects, reflecting the small sizes of fields in this region, all butterflies observed up to 5 m ahead and 2.5 m on either side of the observer were counted while walking along the transect at a slow pace (10 m/min). Ten transects were surveyed in the field boundaries selected in each of the High_Irr and Low_Irr plots. Each transect was surveyed twice in succession in opposite directions (100 m in total) and the higher number of individuals of a species recorded on either occasion was used in the data analysis. All surveys were conducted on sunny days with a minimum temperature of 17 °C and no strong wind (Pollard and Yates, 1993). Butterflies were identified to the species level based on (Makris, 2003) and Tolman and Lewington (2008). If a butterfly species was not identifiable in flight it was temporarily caught with a hand-net for identification and then immediately released.

Sites were visited and butterflies were surveyed along all transects three times in 2014: from May 14 to June 21, from July 2 to August 8, and from August 19 to September 25. Additionally, butterflies were surveyed in Central Mesaoria again in 2015 from March 22 to April 29. Transects within a site were always visited on the same day. The order of the visits to plot boundary pairs within each site was randomized between each visit to avoid bias related to time of day. Butterflies were surveyed between 8.20 and 16.30.

Along the same transects where butterflies were surveyed, data were collected on plant species diversity and abundance. These surveys coincided with the first visits to both study areas in 2014 and the fourth visit to Central Mesaoria in 2015. Each transect was divided into five 10-m sections. Plants were surveyed in the first, third and fifth section. Within each of these three sections, a 0.25 m^2 square quadrant was placed randomly along the length of the section, but as near as possible to the mid-point of the field boundary's width at that location. Consequently three quadrats were surveyed per transect. Each quadrant was divided into 25 equally sized sections and the presence/absence of each plant species in each section was counted, generating numbers between 0 and 25 per quadrant. Plant abundance and species richness were calculated per transect based on the pooled data for the three quadrants. Plants were identified to the species level based on Viney, 1996, Viney, 2011 and Blamey and Grey-Wilson (2004).

2.3. Data processing and analysis

The units of replication in all analyses were the transects within field boundaries. As the number of individual butterflies and the number of species counted along transects tended to be very low, counts were pooled per transect over the repeated visits. This resulted in 20 data entries per study site, 10 for each of the two plot-irrigation levels (low and high). Transects in the field boundaries were further categorized according to irrigation at the level of the agricultural field, i.e., whether the field boundaries were bordering an irrigated or a non-irrigated agricultural field. Thus transects were in four different field boundaries: transects in Low-Irr plots with or without irrigation applied at the agriculture field and transects in High-Irr plots with or without irrigation applied at the agriculture field. To investigate whether the frequency of surveys during which no butterflies were recorded differed among the four irrigation treatment, an extra column was added in the butterfly data sheet with the incidences of zero butterfly counts per visit.

We used non-metric dimensional scaling (NMDS) to visualize dissimilarities in butterfly composition and abundance in field boundaries according to their irrigation scheme at larger scales (plot level of 0.25 km^2) and at a smaller scale (bordering an irrigated or non-irrigated agricultural field, max distance of 10 m). The dissimilarity matrix was calculated using Bray-Curtis indexing, subsequently substituted by ranks. Grouping patterns were based on maximation of rank-order correlations in ordination space. The number of dimensions (k) was set at 2 unless the final stress level was high (>0.2), and an additional dimension was added. Stress is a measure of the disagreement between the ordination configuration and the predicted values from the regression model (low stress is better). To test whether beta-dispersion was similar among the samples of each group of interest, we used the betadisper function in the vegan package (Oksanen et al., 2022). This is the multivariate-ordination variant for testing whether the variance among samples is similar among groups. Beta dispersions based on Bray Curtis dissimilarity indices were analyzed using a GLM on the four irrigation groups. In unbalanced designs, as was the case here, detection of significant effects becomes more conservative when variance are positively correlated with groups sizes, and vice versa, detection becomes more liberal when variance and groups sizes are negatively correlated (Anderson and Walsh, 2013). As neither was the case in our study, we did not control for significant differences among beta-dispersions. Moreover, samples sizes were more balanced when considering main effects only and PERMANOVA tests are relative insensitive to heterogeneity of variance among groups (Anderson and Walsh, 2013). We followed with NMDS analysis to compare whether butterfly composition differed depending on the level of irrigation at the level of the plot, the field, or both, using the adonis2 function. This function partitions distance matrices among sources of variation (here irrigation at the plot and field level) using permutation tests. If any of these terms was significant, pairwise comparisons were conducted using the adonis.pair function of the EcolUtils package (Salazar, 2023). To determine which butterfly species characterized grouping of the community, the multipatt function of the idicspecies package was used (De Caceres and Legendre, 2009).

Alpha diversity computed as the Hill's Shannon index (Roswell et al., 2021) was also subjected to GLM analysis with the same explanatory variables as described for the NMDS analysis. In some cases, the assumption of equal variance was violated and a Kruskal Wallis test was performed followed by pairwise Wilcoxon test with a Holm's correction for Type I errors when the Kruskal Wallis test was significant. Total abundance of butterflies (or the natural logarithm of total abundance when the assumption of equal variance was violated) was compared using a general linear model with the same explanatory variables as other models.

For the analysis of the vegetational composition a similar analysis was applied as for the butterflies with irrigation at the level of the plot, field, or both, as explanatory variables. Pooled frequencies of plant species in the three quadrants in each transect served as data entries. To analyze whether there was a correlation between the composition of the vegetation and the butterflies, we compared the Bray-Curtis (dis)similarity matrices obtained for the plants and the butterflies using Mantel tests (Spearman correlation, permutations=9999) from the vegan package. For the butterflies we only used the data obtained during the visits that both plants and butterflies were surveyed (first visit both regions, fourth visit Central Mesaoria). Data for the two visits in Central Mesaoria were analyzed separately. In addition, Spearman rank correlation tests were conducted between butterfly and plant attributes (alpha diversity and abundance) for each visit.

Crop species identity often coincided with irrigation. For example alfalfa and melon were almost exclusively grown in irrigated plots, whereas in non-irrigated fields cereals dominated. Moreover, crop plant species may require specific management strategies, such as the use of the insecticide cypermethrin on cereals. This limited the possibility to test the effect of crop species identity on butterfly diversity and abundance in the analyses above. However, to disentangle, to some extent, the effect of irrigation and crop species identity on butterfly abundance some basic statistical tests were performed. Five of the recorded butterfly species (see Table 1) use alfalfa (*Medicago sativa*) as larval host plants. To test whether presence of alfalfa (yes or no) affected the abundance of these butterflies in transects adjacent to irrigated fields in Central Mesaoria, where this crop is almost exclusively grown, we used Mann-Whitney *U* tests. We did the same for total abundance of butterflies excluding the ones of which the larvae can feed on alfalfa. In addition, we tested the abundance of butterflies in transects bordering irrigated and non-irrigated fields planted with cereals in Central Mesaoria.

All statistics were performed in R (R Core Team, 2020). Where applicable, statistics are given when each term was added last (Type III analysis).

3. Results

3.1. Butterflies

In total 22 species were recorded (Table 2). Interestingly, 12 out of the 22 species were oligophagous (Table 2), whereas these contributed only 25% to the total species cou Most of these butterfly species have three or more generations on Cyprus and are ac year (13 species) or only less active during winter (December–February, 7 species). T species had a more restricted flight period, *Eucholoe ausonia* (n=1) and *Lycaena ceteon* (n=3), and are only active in spring and summer. These two species also have fewer generations per year than the other species. Nearly all species are widely distributed across the island and are commonly encountered in agricultural ecosystems, waste or fallow land, and urban areas. Two species, *Luthrodes galba* and *Tarucus balkanicus*, have a more restricted distribution and are mainly found in the Mesaoria plain (=study area) where their preferred host plants, *Prosopis farcta* and *Zizipuhs lotus*, respectively, are seasonally abundant. Thus, the study area (Mesaoria plain) and the agriculture setting largely determined the composition of the butterfly community.

Table 2. Butterfly species recorded in two regions of the Mesaoria Plain, Central Mesaoria and Yildrim, respectively. Butterflies were counted during four visits in the Mesaoria Plain, and three times in the Yildirim area. Count data are pooled for the repeated visits. Association depicts whether butterflies were associated with specific transect groups where 'Irrigated' means that butterflies were associated with field boundaries adjacent to irrigated agricultural fields irrespective of plot level irrigation (High_Irr or Low_Irr). *Maniola cypricola* was the only recorded endemic species. Host plant species were based on records mentioned in Butterflies of Cyprus (John and Makris, 2022). Butterflies were further classified in the first column as oligophagous (O) or polyphagous (P).

Species	**Family**	**Central Mesaoria**		**Yildirim region**		**Host plants**
		Counts	**Association**	**Counts**	**Association**	
Carcharodus alceae (O)	Hesperiidae	291	Irrigated	48		Malvaceae: *Malva sylvestris*, *Hibiscus*
Colias crocea (O)	Pieridae	614	Irrigated	12	Low_Irr/yes	Fabaceae: *Medicago sativa*, *Lupinus*, *Trifolium*
Eucholoe ausonia (O)	Pieridae	1				Brassicaceae: *Hirschfeldia incana*
Freyeria trochilus (P?)	Lycaenidae			37		Euphorbiaceae: *Andrachne telephioides*, potentially *Heliotropium* (Boraginaceae)
Gegenes pumilo (O)	Hesperiidae	4				Poaceae: *Hyparrhenia hirta*
Hyponoephele lupina (O)	Nymphalidae	1				Poaceae
Lampides boeticus (P)	Lycaenidae	620	High_Irr/yes	92	High-Irr/yes	Fabaceae: *M. sativa*, *Pisum*

Species	Family	Central Mesaoria		Yildirim region		Host plants
		Counts	Association	Counts	Association	
Leptotes pirithous (P)	Lycaenidae	335	Irrigated	49		Fabaceae: *M. sativa*; Plumbaginaceae: *Plumbago auriculata*
Luthrodes galba (O)	Lycaenidae	970	Irrigated			Fabaceae: *Prosopis farcta*
Lycaena phlaeas (O)	Lycaenidae	8	1			Polygonaceae: *Rumex*
L. thersamon (O)	Lycaenidae	77	2			Polygonaceae: *Polygonum equisetiforme*
Maniola cypricola (O)*	Nymphalidae	1	1			Poaceae
Papilio machaon (P)	Paplionidae	20	9			Umbelliferae*: Foeniculum vulgare*, *Amni majus*, *Daucus carota*
Pieris brassicae (P)	Pieridae	121	High_Irr/yes	93		Brassicaceae: *Sinapis, Eruca sativa, H. incana*
P. rapae (P)	Pieridae	1421	Irrigated	329	Irrigated	Brassicaceae: *Sinapis*, *Eruca sativa*, *H. incana*
Polyommatus icarus (P)	Lycaenidae	2801	Irrigated	2		Fabaceae: *M. sativa*, *Lotus*, *Ononis*
Pontia daplidice (P)	Pieridae	416	249			Brassicaceae: *Erucaria hispaica, Sinapis, H. incana*
Tarucus balkanicus (O)	Lycaenidae	109	214			Rhamnaceae: *Ziziphus lotus*
Thymelicus action (O)	Hesperiidae	3				Poaceae
Vanessa atalanta (O)	Nymphalidae	1				Asteraceae: *Urtica*

Species	Family	Central Mesaoria		Yildirim region		Host plants
		Counts	Association	Counts	Association	
V. cardui (P)	Nymphalidae	132	High_Irr/yes	28		Malvaceae: *Malva multiflora*; Asteraceae: *Echinops spinosissimus, Carduus*
Zizeeria karsandra (P)	Lycaenidae	1367	Irrigated	83	Irrigated	Poygonaceae: *P. equistiforme;* Fabaceae: *M. sativa*; Amaranthaceae: *Amaranthus*
Total counts		9313		1249		

3.1.1. Central-Mesaoria

In total, the dataset included 9313 butterflies of 21 different species counted at the 8 sites during four surveys (Table 2). The three most abundant species, *Polyommatus icarus*, *Zizeeria karsandra* and *Pieris rapae* accounted for 60% of the total number of individuals. Betadispersions differed significantly among the four irrigation groups (Pseudo $F_{3, 156}$ = 43.5, P = < 0.001). Mean betadispersion of the samples of the High_Irr/YES group was significantly lower than that of the other three groups, which did not differ among each other. Butterfly composition was significantly affected by both irrigation at the plot level (Pseudo $F_{1, 56}$=43.5, P=0.001, Fig. 2a) and irrigation in the agricultural fields adjacent to the field boundaries in which the butterflies were surveyed (Pseudo $F_{1, 56}$=4.71, P=0.004, Fig. 2 a). The interaction term was almost significant (Pseudo $F_{1, 56}$=2.21, P=0.06). Irrigation at the field level explained more of the variation in species composition than irrigation at the plot level (18% vs. 2%). Pairwise comparisons among the four irrigation groups showed that all irrigation treatments differed from each other (P=0.001) except for the transects bordering fields with no irrigation in the High_Irr and Low_Irr plots (P=0.37). *Lampides boeticu*[illegible] *brassicae* and *Vanessa cardui* were mostly associated with the High_Irr/YES group (Ta[illegible] Species associated with irrigated fields, irrespective of irrigation at the plot level, w[illegible] *Colias crocea*, *Zizeeria karsandra*, *Polyommatus icarus*, *Luthrodes galba*, *Carcharodus alceae*, *Pieris rapae* and *Leptotes pirithous* (Table 2). Incidences in which no butterflies were observed predominantly occurred in transects adjacent to non-irrigated fields (value of association 0.47, P<0.001).

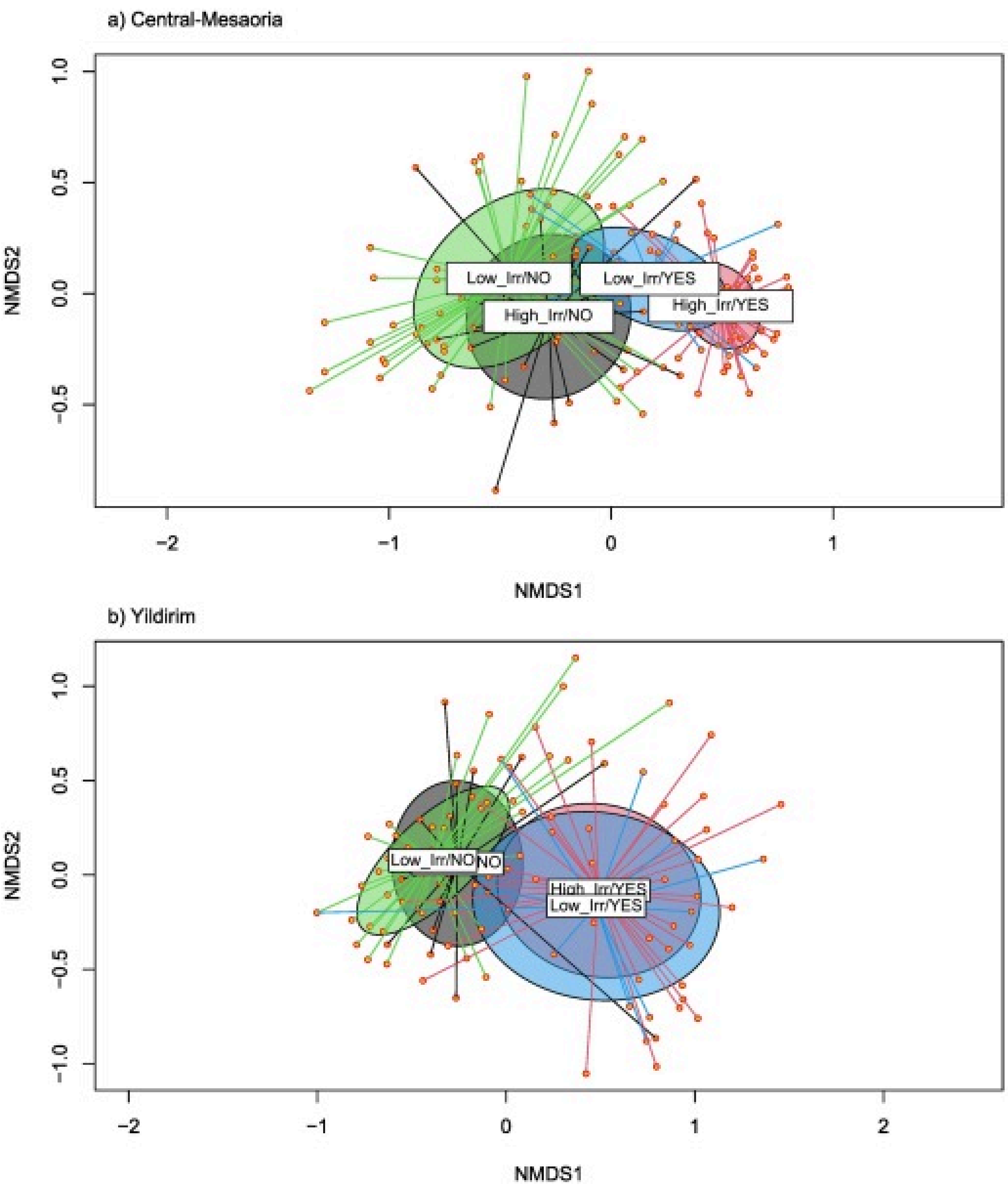

Fig. 2. NMDS ordination plots based on butterfly surveys conducted along transects in paired plots with contrasting levels of irrigation, High_Irr and low Low_Irr, at 8 sites in Central Mesaoria (a) and 6 sites in the Yildirim region (b). Data entries for the NMDS are species counts per transect (20 per plot, 10 for each plot-irrigation level) pooled over four visits (Central Mesaoria) and three visits (Yildirim). Transects within plots were furt classified according to irrigation (YES or NO) in the agricultural fields adjacent to th boundaries in which the transects were located. Each point with a line is a sample and the ellipses depict the centroids (+1 standard deviation) for each of the four irrigation groups (High_Irr/NO with n=19/20 (Central Mesaoria/Yildirim), High_Irr/YES with n=61/40, Low_Irr/NO with n=61/49, Low_Irr/YES with n=19/11). The data matrix was subjected to a

Wisconsin (square root) transformation. Stress of the NMDS was 0.185 with k=2 dimensions for Central Mesaoria and 0.199 (k=2) for Yildirim.

Butterfly diversity reflected the results reported above. Alpha diversity, i.e., the Hill's Shannon index, was affected by irrigation at the field level ($F_{1, 156}$=66.4, P<0.001) and irrigation at the plot level ($F_{1, 156}$=12.5, P<0.001) (Fig. 3a). Butterfly diversity was 1.6 times higher in transects adjacent to irrigated fields (ignoring irrigation at the plot level) and 1.45 times higher in plots with high levels of irrigation than in plots with low levels of irrigation (ignoring irrigation at the field level). Abundance of butterflies also differed among the four irrigation groups (Kruskal Wallis test, X^2=106, df=3, P<0.001, Fig. 4a). Significantly more butterflies were counted along irrigated than along non-irrigated fields in both, High_Irr and Low_Irr plots, whereas abundance of butterflies along non-irrigated and irrigated fields, respectively, did not differ between High_Irr and Low_Irr plots (Fig. 4a).

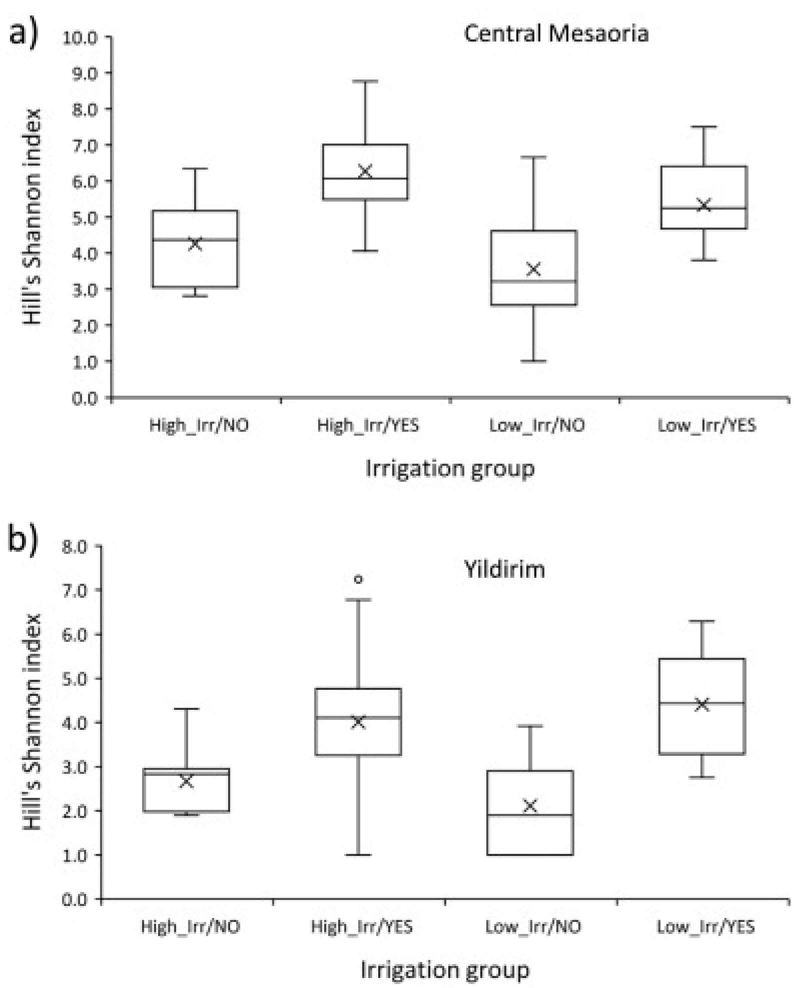

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Fig. 3. Boxplots depicting alpha diversity of butterflies, i.e., Hill's Shannon diversity index, in field boundaries of the four irrigation groups in Central Mesaoria (a) and the Yildirim region

(b). Calculation of the index is based on butterfly counts along transects in paired plots with high (High_Irr) or low levels of irrigation (Low_Irr) at 8 sites in Central Mesaoria and 6 sites in the Yildirim region. Data entries are species counts per transect (20 per plot, 10 for each plot-irrigation level) pooled over four visits (Central Mesaoria) and three visits (Yildirim). Transects within plots were further classified according to irrigation (YES or NO) in the agricultural fields adjacent to the field boundaries in which the transects were located. Sample sizes are given in Fig. 2.

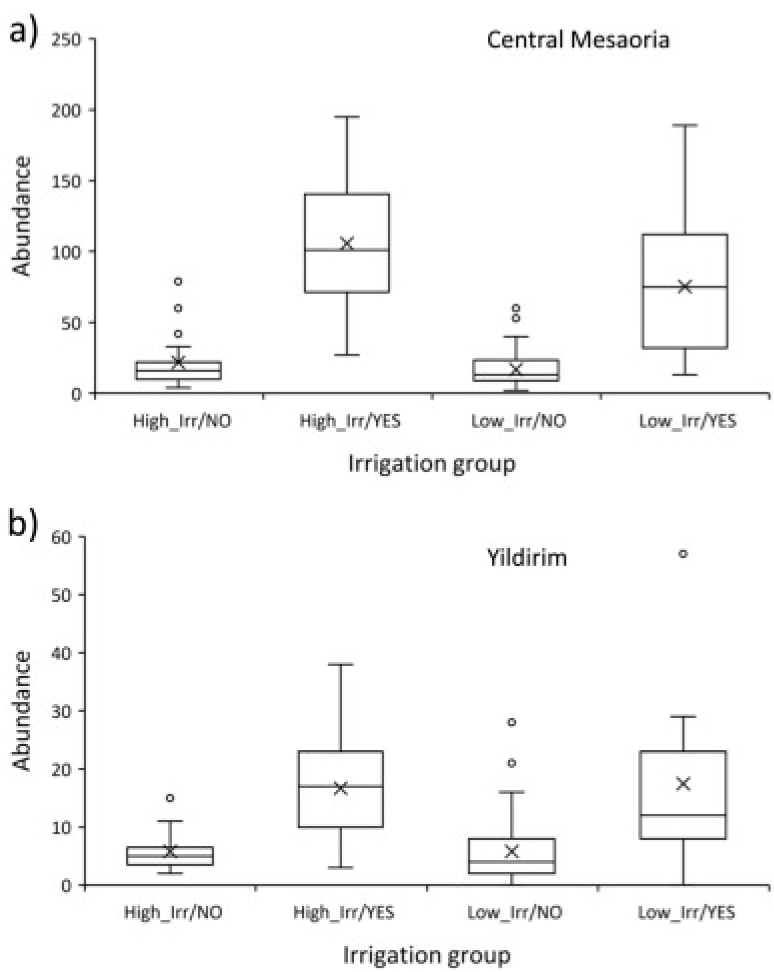

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Fig. 4. Boxplots depicting abundance of butterflies in field boundaries of the four irrigation groups in Central Mesaoria (a) and the Yildirim region (b). Butterflies were counted transects in paired plots with high (High_Irr) or low levels of irrigation (Low_Irr) at Central Mesaoria and 6 sites in the Yildirim region. Data entries are total counts per transect (20 per plot, 10 for each plot-irrigation level) pooled over four visits (Central Mesaoria) and three visits (Yildirim). Transects within plots were further classified according to irrigation

(YES or NO) in the agricultural fields adjacent to the field boundaries in which the transects were located. Sample sizes are given in Fig. 2.

3.1.2. Yildirim

Butterfly counts were lower in the Yildirim region (n=1249) and less different species (16) were observed compared to Central-Mesaoria, even considering that there were fewer sites (n=6 compared to n=8 in West-Mesaoria) that were also visited one time less (Table 2). The three most abundant species *P. rapae*, *Pontia daplidice* and *Tarucus balkanicus* contributed >60% of the counts. *Taracus balkanicus* was the only species that was more abundant in this region than in Central Mesaoria and *Freyeria trochylus* was the only species that was only recorded in this region and not in West-Mesaoria. Betadispersions differed significantly among groups (Pseudo $F_{3, 116}=3.10$, $P=0.02$, Fig. 2b). It was lower for the High_Irr/NO group compared to the High_Irr/YES and the Low_Irr/YES group. Only irrigation at the field level (Pseudo $F_{1, 116}=15.5$, $P=0.001$) affected species composition and not irrigation at the plot level (Pseudo $F_{1, 116}=0.79$, $P=0.55$). Neither was the interaction between the two terms significant (Pseudo $F_{1, 116}=1.77$, $P=0.12$). The species that were associated with irrigated plots were similar as in Central Mesaoria (Table 2) and incidences with no butterflies were more frequent in transects along non-irrigated fields in both plots (association coefficient 0.46, $P<0.001$). Butterfly diversity (Hill's Shannon index) was marginally affected by the interaction between irrigation at plot and field level ($F_{1, 112}=3.98$, $P=0.048$). The effect of irrigation on butterfly diversity at the field level was more pronounced in Low_Irr than in High_Irr plots (Fig. 3b). Overall, alpha-diversity was 1.8 times higher in field boundaries along irrigated than along non-irrigated fields (main effect of irrigation at the field level, $F_{1, 112}=57.0$, $P<0.001$; plot level, $F_{1, 112}=0.11$, $P=0.74$). Butterfly abundance also differed among the irrigation groups (Kruskal Wallis test, $X^2=45.4$, df=3, $P<0.001$, Fig. 4b). Abundances only differed at the field level irrigation (all pairwise comparisons were significant except for High_Irr/NO vs Low_Irr/NO and High_Irr/YES vs Low_Irr/YES).

3.2. Vegetation

3.2.1. Central-Mesaoria

At both times that vegetation was surveyed in this region, the composition of the ve

in the field boundaries only differed depending on whether the adjacent fields were irrigated or not, whereas irrigation at the plot level did not have a significant effect on plant species composition (Table 3, Appendix Figs. A.1a, A.2a). The species that were significantly more associated with field boundaries along irrigated fields during both visits were

Medicago sativa, *Polygonum equisetiforme* and *Ecballum elaterium*, whereas grasses and *Centaurea hybrids* were more frequently observed in field boundaries adjacent to non-irrigated fields (Appendix Table B). The most contrasting vegetations were found in the High_Irr/YES and Low_Irr/NO plots (P=0.006, both visits), whereas the other treatments did not differ from each other. The effect of field-level irrigation on alpha diversity was significant, whereas at both visits the effect of plot-level irrigation was not (Table 3, Appendix Figs. A.1b, A.2b). Abundance of plant species, which was overall lower at the first compared to the second visit, was only affected by irrigation at the field-level scale during the first visit (Table 3, Appendix Figs. A.1c, A.2c). Diversity and abundance of plant species was higher along irrigated fields than non-irrigated fields.

Analysis of the distribution matrices of plants and butterfly species composition were not correlated (Mantel tests: visit 1, rho=0.015, P=0.33; visit 2, rho=0.014, P=0.35). Correlations between alpha diversity and abundance of butterflies and plants were inconsistent across the two visits (Table 4). While all attributes determined for the first survey were positively correlated, this was only the case for butterfly abundance and plant diversity, and butterfly diversity and plant abundance excluding grasses for the second survey. Remarkably, abundance of butterflies and plants including grasses were negatively correlated for the second survey. Correlations were stronger when grasses were excluded (Table 4).

Table 3. Statistical results on NMDS analysis, alpha diversity (Hill's Shannon index) and abundance of plants surveyed in Central Mesaoria and the Yildirim region. The vegetation was recorded in three 0.25 m^2 quadrants along the same transects along which butterflies were monitored. Transects were located in paired 0.25-km^2 plots with either high or low levels of irrigation (plot effect) at 8 sites in Central Mesaoria and 6 sites in the Yildirim region. Transects within plots were further classified according to irrigation (YES or NO) in the agricultural fields adjacent to the field boundaries in which the transects were located (field effect). Abundance of species was pooled for the three quadrants surveyed per transect. Data entries were species frequencies per transect (20 transects per plot, 10 for each plot-irrigation level). Factors in the analysis were plot and field level irrigation and their interaction. The vegetation was recorded twice in Central Mesaoria and once in Yildirim. Statistics are given when each term was added last (Type III analysis). Sign effects are denoted in bold italics.

		Central_Mesaoria						Yildirim		
		First visit (2014)			Second visit (2015)			First visit (2014)		
	Factor	**F-value**	**df's**	**P-value**	**F-value**	**df's**	**P-value**	**F-value**	**df's**	**P-value**
NMDS	βdisp	4.68	3, 152	0.004	3.75	3, 151	0.012	4,13	3115	0.008
	Plot	1.35	1, 152	0.17	0.76	1, 151	0.67	1.12	1, 115	0.32
	Field	***3.18***	***1, 152***	***0.006***	***2.78***	***1, 151***	***0.004***	***3.72***	***1, 115***	***0.003***
	Interaction	1.18	1, 152	0.26	0.50	1, 151	0.87	1.03	1115	0.376
Hill's Shannon index	Plot	3.61	1, 152	0.059	0.95	1, 151	0.33	***6.08***	***1, 115***	***0.015***
	Field	***11.4***	***1, 152***	***0<0.001***	***10.0***	***1, 151***	***0.002***	***7.03***	***1, 115***	***0.009***
	Interaction	0.76	1, 152	0.38	1.04	1, 151	0.31	1.08	1, 115	0.30
Abundance	Plot	0.21	1, 152	0.64	1.14	1, 151	0.28	2.84	1, 115	0.094
	Field	***6.33***	***1, 152***	***0.013***	2.31	1, 151	0.13	3.40	1, 115	0.067
	Interaction	0.026	1, 152	0.87	0.25	1, 151	0.62	0.81	1, 115	0.37

Table 4. Statistics on correlation analysis (Spearman rank correlation tests) of plant a butterfly species attributes (abundance and Hill's Shannon index) that were surveye in Central-Mesaoria and once in Yildirim. Abundance of plants species was based on pooled occurrence frequencies in three 0.25-m^2 quadrants along the 50-m transects used for the butterflies surveys. Correlation between plant abundance and butterfly species attributes were also determined when grasses were omitted. Correlation coefficients (rho) are

depicted with asterisks indicating statistical significance (*, 0.01≤P≤0.05; **, 0.001≤P<0.01; ***, P<0.001).

		Plants		Plants_no_grasses
Central-Mesaoria (visit 1)				
		Abundance	**Shannon**	**Abundance**
Butterflies	Abundance	0.28**	0.27**	0.42***
	Shannon	0.29***	0.37***	0.50***
Central Mesaoria (visit 4)				
		Plants		**Plants_no_grasses**
		Abundance	**Shannon**	**Abundance**
Butterflies	Abundance	−0.26**	0.17*	−0.11
	Shannon	0.11	−0.05	0.20*
Yildirim (visit 1)				
		Plants		**Plants_no_grasses**
		Abundance	**Shannon**	**Abundance**
Butterflies	Abundance	0.12	0.33***	0.46***
	Shannon	0.21*	0.26**	0.39***

3.2.2. Yildirim

Results on the vegetation in the Yildirim region were quite similar as those obtained during the first visit in Central Mesaoria, which took place during the same period. Both sp composition and alpha diversity differed significantly depending on whether transe adjacent to fields that were irrigated or not (Table 3, Appendix Fig. A.3a, b). Nine out of the 48 plant species (grasses excluded) were significantly more associated in field boundaries along irrigated fields (Appendix Table B). Similar as for Central Mesaoria, the vegetation of field boundaries along non-irrigated fields was grasseous. Moreover, irrigation at the plot level also had a significant effect on plant species diversity. Plant species diversity was positively affected by both irrigation at the plot and the field level (Table 3, Fig. S3b), whereas plant abundance was not affected by irrigation (Table 3, Appendix Fig. A.3c).

Species similarity matrices of plants and butterflies were not correlated (Mantel tests: rho=0.03, P=P=0.18). Pairwise correlations between abundance and alpha diversity of plants and butterflies, respectively, were all significant, except for the correlation between abundance of butterflies and plants when grasses were included (Table 4). As for the Central-Mesaoria region, correlation greatly improved when grasses were excluded (Table 4).

3.2.3. Importance of crop plant species on butterfly distribution and abundance

The larvae of five butterfly species recorded in this study, *P. icarus*, *Z. karsandra*, *C. crocea*, *L. boeticus*, and L. *pirithous*, respectively (Table 2) can feed on alfalfa. In the Central Mesaoria region, of the 80 transects that bordered irrigated agricultural fields, 55 in 2014 and 46 in 2015 were along alfalfa fields, whereas this was the case for only 2 and 3 transects, respectively, along non-irrigated fields. Counts of alfalfa-associated butterflies were 3 to 3.5 times higher along transects bordering irrigated alfalfa fields compared to irrigated fields planted with a different crop (Mann-Whitney *U* test: 2014, W=204, P<0.001; 2015, W=388.5, P<001). Total counts of other butterflies did not differ depending on whether alfalfa was grown in the adjacent field (2014: W=511, P=0.11; 2015: W=727, P=0.59). In the Yildirim region, where alfalfa was not grown and irrigated fields were often planted with melon, only three species that can feed on alfalfa were observed and these contributed only 11.5% to the total butterfly count. All but one of these butterflies were recorded in transects along irrigated fields. When only cereals crops were present in the agricultural fields, irrigation did not affect total abundance of butterflies in the adjacent field boundaries (2014: W=351.1, P=0.16; 2015: W=839, P=0.86). Interestingly, the second most abundant butterfly species was *P. rapae*, which is often associated with cabbage and oil seed crops, while these crops were not grown in the agricultural fields studied in the Central Mesaoria region and only in three fields in the Yildirim region. These results suggest that crop plant identity and irrigation can both play a role in determining species composition and abundance of the butterfly community.

4. Discussion

Butterfly abundance and diversity were studied in two agricultural regions in the Mesaoria Plain in northern Cyprus where irrigation is an important management strategy. Butterflies in the field boundaries along agricultural fields were strongly positively affected by irrigation in the adjacent fields both in terms of abundance and species diversity, whereas the effect of irrigation at the larger scale of the 0.25-km^2 plot was less evident. Ordination plots based on species composition of butterflies, on the one hand, and plants, on the other hand, did not correlate, which suggest that the composition of the butterfly community cannot be directly linked to species composition of the vegetation in the field boundaries. However, plant abundance and alpha diversity of the vegetation in the field boundaries correlated with both abundance and alpha diversity of the butterflies when the abundance of plants was relatively low (first visits in both regions), in particular, when grasses were omitted from the data set. Alfalfa, which is almost exclusively grown in irrigated fields in Central Mesaoria, positively correlated with abundance of some of the butterfly species in transects bordering these fields.

Hawkins and Porter (2003) found that of the eleven environmental factors tested, actual evapotranspiration explained >70% of the variance in species richness of western Palearctic butterflies. All other variables, including the summer vegetation index (a measure of 'greenness') and plant species richness, explained each <4% of the variation in butterfly species richness (Hawkins and Porter, 2003). Evapotranspiration is a water-energy variable that is used in a range of fields including agronomy, ecology, climatology and meteorology and is, among others, used to predict or estimate ecosystem productivity (Kool et al., 2014; Scott et al., 2021). Actual evapotranspiration could act on butterflies either directly through physiological processes or indirectly through plant productivity. We found that irrigation applied to agricultural fields adjacent to the field boundaries in which the surveys were conducted strongly increased alpha diversity and abundance of butterflies, whereas it only increased plant diversity and not their abundance. Nevertheless, abundance and diversity of butterflies and that of the plants were positively correlated but only when the abundance and diversity of plants were low.

Hawkins and Porter (2003) further reported only a weak positive association between species richness of butterflies and that of plants. Presence and abundance of specific plant species such as host plants for butterfly offspring and flowering plants providing nectar for the adults may predict butterfly diversity and their abundance better than overall pl diversity (e.g. Pywell et al., 2004). This conclusion is supported by the fact that whe were omitted from the analysis, correlations between plant and butterfly attributes stronger. Native grasses can provide food for numerous butterflies, but these were not recorded frequently in this study (only nine butterflies of three species feeding on grasses were counted in Central Mesaoria and none in the Yildirim region). Many of these species belong to the Noctuidae and are mostly active during the night, which may explain low numbers of these butterflies in the surveys. The addition of high-quality flower strips, i.e., strips with high numbers of flowering plant species, adjacent to crop fields can greatly enhance the diversity and abundance of butterflies (Wix et al., 2019). In addition to the presence of specific plants, moisture can affect butterflies directly by providing a suitable microclimate (Kati et al., 2012). Interestingly, in the study by Kati et al. (2012) humidity but not the number of flower heads significantly explained variance in butterfly abundance in grass wetlands in NW Greece further suggesting that overall vegetation characteristics poorly predict butterfly diversity and abundance. Three species that were also recorded in the present study, *Pieris rapae*, *Papilio machaon* and *Thymelicus acteon*, were in particular affected by humidity in the study by Kati et al. (2012), i.e., these species preferred wetter habitats. In the present study, only *P. rapae* was found in sufficiently high numbers to be detected in the statistical analysis as a species that was more abundant in transects bordering irrigated fields. González-Estébanez et al. (2011) investigated the effect of agricultural intensification on butterfly diversity in Mediterranean farmlands in northwest Spain. They found that among factors associated with agricultural intensification, irrigation and landscape heterogeneity affected butterfly diversity the most. More diverse butterfly communities were associated with irrigated landscapes. In contrast to our results showing a positive association between butterfly abundance and irrigation, abundance of butterflies was highest in dry cereal landscapes in the González-Estébanez et al. (2011) study, suggesting that some butterfly species prefer dry habitats and dominated the butterfly community. González-Estébanez et al. (2011) further reported that butterfly species richness was negatively correlated with field size and positively with the number of trees and large shrubs counted along the study transects. This and other studies (Dover et al., 1997; Merckx et al., 2010) have highlighted the importance of linear structural vegetational elements such as tree lines and hedgerows for some butterfly species in providing protection against adverse environmental conditions such as those occurring during the warmest part of the day.

Irrigation is often linked to specific crops and some crop species can provide food for adult butterflies (e.g., nectar) or their offspring. Alfalfa was grown in >55% of the irrigated fields in Central Mesaoria and presence of this crop correlated strongly with the abundance of butterflies of which the larvae can feed on this plant (80–85% of total abundance). In contrast, the presence of this crop did not affect total abundance of other butterflies. Moreover, in the Yildirim region, where alfalfa was not grown at the time of the survey, abundance of alfalfa-associated butterflies was much lower, i.e., 12% of total butterfly abundance. However, these butterflies were almost exclusively found in transects along irrigated fields. Non-irrigated fields in the study are predominantly planted with cereals, whereas irrigated fields are planted with a range of different crop species, sometimes within a single field. Thus, irrigation is often associated with the cultivation of specific crops and or crop diversification and this may also have consequences for butterfly abundance and diversity. It cannot be excluded that crop-specific agricultural practices, such as the use of the insecticide cypermethrin on cereals, have contributed to the observed effects.

Stefanescu et al. (2004) investigated the relative importance of environmental and anthropogenic factors that drive species richness of butterflies in Catalonia (Spain) in the northwestern part of the Mediterranean basin. They found that species richness correlated negatively with temperature but positively with rainfall (Stefanescu et al., 2004). These results contrast with those found for butterflies in the UK in northwestern Europe, i.e., a positive association has been reported between butterfly abundance and dry and warm summers (Pollard, 1988; Roy et al., 2001). This discrepancy between results for butterflies in the UK and the Mediterranean can be explained by opposing climatic conditions: cold and wet in the north vs. hot and dry in the south. These differences may give rise to butterfly-abundance relationships with temperature and moisture, respectively, that vary latitudinally, where the abundance of butterflies at higher latitudes in temperate regions is limited more by temperature and at lower latitudes in the Mediterranean region more by moisture (Stefanescu et al., 2004).

The results of this study also reveal the importance of spatial scale at which irrigation is applied to affect butterfly abundance and diversity in this arid terrain. The effect of irrigation on butterflies at the level of the agricultural fields adjacent to the field boundaries exceeded the effects at a coarser scale of the 0.25-km^2 plots. Butterfly abundance and species diversity was highest in field boundaries directly adjacent to irrigated fields. Irrigation at the level of the 0.25 km^2 plots had only an effect on butterfly composition, abundance, and species diversity in Central-Mesaoria and not in the Yildirim region. At the study sites in Central Mesaoria the overall level of irrigation was higher than In the Yildirim region (Table 2). In the drier Yildirim region, butterflies may respond more strongly to localized effects of irrigation and concentrate in field boundaries along irrigated agricultural fields. Other studies have pointed at the importance of landscape heterogeneity at different spatial scales when investigating their impact on butterfly species diversity and abundance (Weibull et al., 2000; Krauss et al., 2003). For instance, Weibull et al. (2000) found i Sweden that small-scale landscape heterogeneity (0.4 by 0.4 km) affected butterfly d and large-scale heterogeneity (5 by 5 km) affected butterfly abundance. Moreover la heterogeneity was found to be more important than farming management practices (i.e., conventional vs. organic farming). Butterfly community structure in semi-natural calcareous grasslands in central Germany was affected by landscape diversity but only at a scale of 250 m radius around the grassland habitat (Krauss et al., 2003). Though, these studies above have been conducted in various biogeographical regions, they all stress the importance of scale when considering the factors affecting butterfly diversity and abundance in agricultural landscapes. Moreover they show that the importance of factors may differ according to the biogeographical range but also that these effects may differ between taxonomic groups (Herrando et al., 2019). In the Herrando et al. (2019) study the relationship between species population trends and local precipitation was positive for butterflies but negative for birds suggesting that these two taxonomic groups differ in precipitation requirements. Vulnerability to drought, either directly or indirectly, through changes in food plant quality is severe in endothermic insects, especially for the immobile or less mobile life stages such as eggs and larvae (Harvey et al., 2023).

This and other studies (Stefanescu et al., 2004; González-Estébanez et al., 2011; Stefanescu et al., 2011; Herrando et al., 2019) show the importance of water availability on butterfly abundance and diversity in the Mediterranean basin. Periodic precipitation deficits are characteristic for this region, but lack of precipitation combined with relative high temperatures has been more frequent in the beginning of the 21st century in eastern Mediterranean (Guiot and Cramer, 2016). Mediterranean climate regions are considered biodiversity hot spots both in terms of species richness and endemism (Medail and Quezel, 1999; Cuttelod et al., 2009; Underwood et al., 2009). Because of their sensitivity to changes in climate and land use, they are predicted to be more prone to biodiversity loss than other biomes (Sala et al., 2000). At the same time, agriculture is of vital economic importance in this region and the proportion of irrigated crop land is predicted to increase in this region as a whole (Fader et al., 2016) and in the study area, in particular, due to an agreement with Turkey to build an undersea pipeline. Though we found that irrigation can positively benefit butterfly diversity and abundance and can potentially mitigate some of the negative effects of drought, environmental costs of this management strategy should not be ignored. Irrigation, which is considered a form of agricultural intensification, is often accompanied by an increase in fertilizer and pesticide input, and increases soil and water quality degradation, which in turn have a negative impact on regional farmland biodiversity. Therefore, increasing irrigation requires a careful evaluation of how to implement this in such a way that potential benefits do not outweigh the costs (Fader et al., 2016; Harmanny and Malek, 2019). Sustainable agricultural sy[illegible] are characterized by agricultural practices, such as AES, that aim to protect biodivers[illegible] to be environmentally safe, and at the same time be profitable. It is therefore importan[illegible] also disentangle how agricultural practices associated with irrigation, such as the use of agrochemicals, crop identity and diversification, affect farmland butterflies in the Mediterranean. Protecting farmland biodiversity has not only environmental benefits but can positively influence agricultural production in the long term through the ecosystem services it can provide (e.g. pollination by butterflies and other insects), especially when conventional practices are increasingly restricted. However, the consequences of specific management strategies and their effects sizes on biodiversity may strongly depend on the geographical region where they are implemented and may vary between taxonomic groups.

CRediT authorship contribution statement

Rieta Gols: Writing – review & editing, Writing – original draft, Visualization, Formal analysis. **Andrea Barden:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Özge Ozden:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendices. Supplementary data

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Appendix Table A. Crop identity in agricultural fields.

Download: Download spreadsheet (13KB)

Appendix Table B. Plant species frequencies.

Download: Download Word document (1MB)

Appendix Figs. A 1–3 NMDS ordination plots, alpha diversity and abundance of plants in relation to irrigation at the plot and field level in the two study areas.

Data availability

Data will be made available on request.

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