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Insect taxa as biodiversity indicators at selected coastal landscape

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ABSTRACT

For monitoring responses of insect arthropods to disturbance, a dataset of 1831 insects was considered. We studied faunal diversity of insects in terraces habitats located on the coast of Lebanon. Insects were sampled from 12 sites having different habitats with one sampling method of combined pitfall-pan trap. This study resulted in nine insect orders and 129 morphospecies. Hymenoptera was the most abundant order in all habitats (63.57%) followed by the orders Diptera, Homoptera, Coleoptera, Orthoptera, Hemiptera, Lepidoptera, Dictyoptera and Thysanoptera. This coast was classified with medium biodiversity index (D) of 0.51 for insect orders and high D of 0.83 for morphospecies. The highest (D) was in field crops habitat (H1) of 0.64 and 0.91 for insect orders and morphospecies, respectively; followed by scrublands (H3), greenhouse areas (H2) and olive orchards (H4). These results indicated that human intervention was affecting the diversity in natural habitats. Five insect orders: Coleoptera, Dictyoptera, Diptera, Hymenoptera, and Lepidoptera were significantly selected as potential biodiversity indicators in this coastal area. Thus, for monitoring these bioindicators, a protocol based on operating our combined trap method appears practical in design and yield very diverse material with the target of sustaining these insect populations in the coastal area.

KEY WORDS Biodiversity; Coast; Habitat; Insect order; Lebanon.

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INTRODUCTION

One of the Millennium Ecosystem Assessment (MEA) findings is that "*human actions are depleting Earth's natural capital*". The loss in biodiversity due to human activities had been quite rapid in the past decades, and the most important drivers of biodiversity loss are habitat change, including fragmentation of wild natural habitats, and climate change (MEA, 2005); habitat change would contribute much more to biodiversity loss mainly in arthropods than climate change (Sala et al., 2000) with rates of biodiversity loss being expected to increase.

Invertebrates respond quickly to modifications of their environment due to their short generation time; their populations are known to be sensitive to short-term impacts of land management, as well as to long-term ecosystem changes (Basset et al., 2001; Underwood & Fisher, 2006). In general, high

number of arthropods can be easily collected with different techniques without harming their populations; for these various issues, they represent potential organisms for biological monitoring (Kremen et al., 1993). Insects represent about 80% of the world's species; these large numbers of insect species in nature were related to several factors including their long geological history, their capability of flight, their general adaptive abilities to the environment, and their remarkable reproductive abilities (May, 1988; Chowdhury et al., 2023).

Ecosystems are important for biodiversity maintenance, assuring species survival and continuance. The loss of environment identity promotes lack of biological diversity. Human actions not based on sustainable principles have damaged forests and fields due to need of increasing agricultural spaces to enhance production to feed an increasing population. Progress in agricultural practices and technological advances of modern industry did not guarantee the permanence of different ecosystems; the diversity of these ecosystems is threatened, as well as the balance of the chains that depend on them (MEA, 2005). In this context, the balance of the environment can be measured by observing the population characteristics of groups of specific organisms, considered bioindicators, of the alteration degree or the weakening point in the disturbed ecosystem with different habitats as forest and non-forest agricultural ecosystems. The most important indicators are insects due to their most diverse group in terms of species number and due to their easy sampling process (Russo et al., 2011; Gerlach et al., 2013; Chowdhury et al., 2023).

The entomological literature is relatively scarce on applying thorough statistics to estimate arthropod affinity for particular trapping methods. These methods and target taxa could be identified with biodiversity inventory at the higher taxa level of order (Kitching et al., 2001) or at the family level (Rohr et al., 2007). The common goal of a taxon inventory is to document as completely as possible the taxonomy and ecology of taxa within a certain area (Basset et al., 2004). Whereas, biological monitoring seeks to repeat sampling over time to identify population patterns (Underwood & Fisher, 2006; Conrad et al., 2007). In general, monitoring goals may include detecting the presence of invasive species; recording population trends of endangered or principle species; assessing ecosystem change or evaluating land management decisions (Underwood & Fisher, 2006).

It is increasingly clear that a multi-species approach appears to be better than using one indicator species to monitor the responses of invertebrates to disturbance (Basset et al., 2001). Using a multi-taxon approach overcomes this problem, as the variety of taxonomic responses is built into the study design, particularly when taxa with a wide range of feeding guilds and mobility are used (Pryke & Samways, 2012). In the ground layer, arthropod bioindicators could include some species of ants, millipedes, beetles, and spiders, but foliage-inhabiting indicators could include other species of ants, beetles, moths, and spiders; these basic sets might be supplemented by other taxa where appropriate (Gerlach et al., 2013). Knowing that the task of monitoring a sufficient number of taxa at various locations with adequate time might be a non-soothing process.

Many studies considered the relative merits of modifying a particular sampling method, but relatively few compared different methods of sampling terrestrial arthropods for biological monitoring (Southwood & Henderson, 2000; Kitching et al., 2001). Four of the most used sampling methods for this monitoring are: pitfall, Malaise, flight-interception and yellow pan traps (Niemelä, 2000; Southwood & Henderson, 2000; Kitching et al., 2001; Rohr et al., 2007); the former three are passive traps whereas the latter is active trap type (Wolda et al., 1998; Kitching et al., 2001). In our study, we considered a combination of pitfall and yellow-white pan trap in one sampling method to monitor insects in terraces habitats. Terracing had been one of the most important systems for preventing soil erosion, conserving water, and increasing agricultural production. Such habitats usually have a higher biodiversity in agriculture landscapes, compared to the slopes of mountain areas; mainly due to increased amount of nutrient and rainfall absorption in agricultural terraces that benefit the plant growth (Shimoda & Koyanagi, 2017; Deng et al., 2021).

For baseline surveys, trapping techniques may be preferable, especially when comparing different habitats or the same habitat over time. Trapping methods used in biological monitoring must fulfill several criteria; such as being simple, inexpensive, and non-disturbing to the study system. They have a negligible impact on arthropod populations and

are easy to deploy and maintain in the field. These methods usually behave more or less consistently across sites with respect to the profile of arthropods collected. They are relatively insensitive to abiotic factors or the potential effects of abiotic factors on trap catches could be measurable. Trapping quickly provide representative baseline data and repeatable results with low variability; produce seasonal and annual replicates of the same sampling units, provide a variety of material and/or is efficient for specific focal taxa, provide quality material and taxonomically tractable taxa (Kitching et al., 2001). Nevertheless, limited studies had dealt with using a range of sampling methods for inventorying arthropods in temperate regions (King & Porter, 2005; Barnes et al., 2016; Wong et al., 2019).

Entomologists had indicated that, as some recommendations are available to survey whole arthropod assemblages in the tropics (Kitching et al., 2001), few guidelines exist for designing monitoring protocols in the temperate regions (Rohr et al., 2007). There are multiple reasons for the latter, due to complex issues of sampling methodology, spatio-temporal replication to characterize well assemblages, and taxonomic impediment (Niemelä, 2000; Rohr et al., 2007).

The main objective of our research work is to study the abundance and level of insect species diversity in different habitats of terraces in the coastal areas of Lebanon including local agricultural systems versus natural habitats. Our research seeks to assess the effects of anthropogenic disturbance, such as urban sprawl and land conversion into agriculture use, on insects, in different habitats. This subject had not been studied locally and warrants extensive investigation as taxa of agricultural pests had been the focus of most previous research studies.

MATERIAL AND METHODS

This study was conducted in different locations at the coastal side lowlands (about 400 m asl) in Lebanon, Middle East region, dealing with field monitoring and collection of insects and other encountered arthropods from July until September 2020. The limitation of our survey for the 3 months of the summer season in 2020, was due to logistics of that period, especially Covid-19 restrictions. Research work with the arthropod specimens was executed at the Department of Plant Protection, Faculty of Agriculture and Veterinary Sciences, Lebanese University.

Study area

Site selection was based on consultation with the National Council for Scientific Research in Lebanon that provided needed geographical maps, based mainly on presence of agricultural lands and natural habitats in terraces; knowing that primary plantations along the coast as citrus, bananas, and other subtropical species had declined extensively in the last decades due to anthropogenic action mainly by clearing lands for annual agriculture use and invasion of concrete buildings to the coastal line. The mean annual temperature is 15 ºC in the country with summers (June to September) being hot and humid, with temperatures crossing 35 °C in August and the mean annual rainfall ranging between 700 and 1,000 mm along the coast (Anon., 2021). Twelve sites (App. A: Figs. A.1 – A.12) were selected in 3 different sectors on the coastal side between the capital Beirut and town Batroun. Each sector ensured presence of one habitat type with 3 replicates for each type. Four sites were chosen in each sector based on specific criteria such as accessible land area (m^2), presence of terraces, and four habitat types (Table 1) that included: field crops as intensive high input agriculture system (H1), protected agriculture in form of greenhouses for vegetables and ornamentals as high intensive agriculture system (H2), scrubland with some dispersed old trees as a natural habitat (H3), and olive orchards as low input agriculture system (H4).

Experimental set-up

The research work in this study was divided into two parts, field and laboratory. For field monitoring and collection of arthropods, the following materials were required for building a modified trap type, combining pitfall with pan trap: a white round plastic container (500 ml) of 15 cm in diam. by 20 cm deep was placed in the soil so that the rim leveled with ground surface; inside the white container, a yellow plastic cup (40 ml) was placed upside down and one yellow plastic plate (15 cm diameter) was cut into half with each half being folded to fit around the small yellow cup, so the trap looked yel-

Site No.	Location	Coordinates	Habitats (Total No. of traps per habitat)[a]	Land Area (m^2) and Traps No. per area	Main Crops (with plant duration availability in summer 2020)[b]
1	Tamish Monastery	35°37'7.437"E 33°56'33.469"N	H1 (6)	8,190 (2)	Tomato (until end of Aug.); strawberry, cucumber, eggplant, cowpea (starting Aug.); cabbage, lettuce, watermelon, pepper
2	St. Roukoz Monastery	35°33'34.259"E 33°51'58.289"N	H2 (9)	32,268 (3)	Cucumber (until end of Aug., then replanted); ornamental plants: Croton *Codiaeum variegatum* (L.) Rumph. ex A. Juss. and Paper flower *Bougainvillea glabra* L.; cowpea
3	Tamish Monastery	35°37'7.437"E 33°56'33.469"N	H3 (11)	30,669.91 (3)	Oak, pine, thyme, myrtle and miscellaneous annual plants.
4	St. Roukoz Monastery	35°33'34.259"E 33°51'58.289"N	H4 (7)	17,010 (2)	Olive trees
5	Eddeh - Jbayl	35°40'28.879"E 34°8'19.758"N	H1	8,316 (2)	Corchorus *Corchorus olitorius* L. (Jute mallow or Molokhia as local naming), cowpea, zucchini, corn, cucumber (until Aug.); parsley, okra, eggplant, pumpkin (until Sep.)
6	Jbayl	35°39'42.394"E 34°7'52.062"N	H2	30,240 (3)	Tomato (until July and replanted in Aug.), eggplant, parsley, pepper, cucumber (until Aug.)
7	Ghazir	35°38'46.495"E 34°0'45.427"N	H3	145,139 (4)	Carob, *Lantana* sp. (Verbenaceae) on the edges and miscellaneous annual plants.
8	Jbayl	35°39'42.394"E 34°7'52.062"N	H4	18,148 (2)	Olive trees
9	Batroun	35°40'12.08"E 34°15'11.942"N	H1	7,056 (2)	Cucumber (replanted), corn, melon, watermelon, tomato, zucchini (until Aug.), okra, cowpea, *Corchorus olitorius*
10	Batroun	35°40'12.08"E 34°15'11.942"N	H2	32,399 (3)	Roses, Ruscus sp. (Asparagaceae), Gerbera sp.
11	Batroun	35°40'12.08"E 34°15'11.942"N	H3	69,802 (4)	Cypress trees *Cupressus* sp. (Cupressaceae), oaks, pines and miscellaneous annual plants.
12	Koubba	35°40'30.82"E 34°16'14.389"N	H4	30,240 (3)	Olive trees

Table 1. Description of selected sites according to terraces habitat type and other criteria. a: H1 = Intensive production irrigated field crops; H2 = Protected agriculture habitat; H3 = Natural habitat; H4 = Low input production olive orchards. b: Plant duration: is not mentioned for crops that were available during the whole sampling duration of the study.

low from inside, simulating a flower for attracting flying insects mainly. Each trap was filled with 400 ml white vinegar (10% acetic acid, local production). In the laboratory the following materials were used: ethyl alcohol (70%) for storage of collected specimens until further identification and for preservation, and stereomicroscope (BOEC, Germany) for arthropod identification.

Arthropod collection and processing

Insects and other arthropods at the 12 sites were monitored biweekly through trapping. The number of traps placed at each site varied according to the land area (Table 1); 2 traps for less than 30,000 m^2, 3 traps for area between 30,000 and 60,000 m^2, and 4 traps for area of more than 60,000 m^2, i.e. one trap would be covering approx. 15,000 m^2 with distance between 2 traps at least about 1 ha (10,000 m^2). Each site was sampled for 6 times during the experimental period. In each sampling date, a monitoring template form was completed to assess type of crops planted, weather conditions (temperature, humidity), and other noticeable conditions that might

affect the insects and/or flora population; such as fire, ploughing, or other agricultural activities.

Each site was equipped with set of traps recommended for the biological monitoring of the crawling and flying arthropods in the canopy of trees, crops, and weeds. In traps, the collecting fluid of white vinegar could be left out in the field for 1–15 days; this vinegar usually does not preserve DNA and causes specimens to become brittle, but in general it keeps the specimens from rotting (Aristophanous, 2010; Moreau et al., 2013; Skvarla et al., 2014). Our traps had been operated for 14 days and were checked weekly for ensuring the presence of enough vinegar for preserving the collected specimens.

The arthropod material collected were first sorted into higher taxa as Classes and Orders by the parataxonomist then most specimens were classified to the Family level using specialized identification keys (Borror et al., 1989). Each specimen belonging to various focal taxa was preserved in ethyl alcohol (70%), and was coded by appropriate sample number. The insect taxa were sorted to morphospecies; these are described as unnamed species characterized by standard taxonomic characteristics (Missa et al., 2009), but a few were identified to species level.

Statistical analysis

Our analyses considered two datasets for increasing taxonomic resolution and accuracy: higher taxa (arthropod orders) and morphospecies from insect focal order taxa. The collected data of insect and other arthropod specimens sampled in different sites was analyzed using the General Linear Model - multivariate analysis with two factors: habitat type and sampling date. Data was collected in the form of dead adult and immature specimens. Means were used in analysis of data and were separated by Student Newman's test, if significant F values were obtained at 0.05% level of significance, using the SPSS statistical package (SPSS version 24; SPSS Inc., Chicago, IL, USA).

For our data sets, diversity indices which are statistical representations of biodiversity in different aspects (richness, dominance, and evenness) were determined; a diversity index is a quantitative measure that reflects on how many different types, such as species or groups of species (Ex. orders), exists in a dataset representing a community (Ex. habitat). Many different indices were applied to measure diversity in the selected habitats of this study.

- The Simpson's Diversity Index (D): is commonly used to measure biodiversity as follows (Simpson, 1949):

$$D = 1 - {}^{s}\Sigma_{i=1} (n_i / N)^2$$

n_i = number of individuals of species or (group of spp. as order);

N = Total number of individuals of all species.

$n_i/N = p_i$ (proportion of individuals of species i), and S = species richness.

High scores of D (close to 1) indicate high diversity and low scores (close to 0) indicate low diversity.

- Shannon-Weiner Index (H') is an information statistic index (Shannon & Weaver, 1949).

$$H = - {}^{s}\Sigma_{i=1} (pi * lnpi)$$

p_i = proportion of individuals of species i (p_i = n/N), and ln is the natural logarithm, and S = species richness.

The value of H ranges from 0 to H_{max}; H_{max} is different for each community and depends on species richness.

- For community similarity, Sorenson's Coefficient (CC) was determined as follows (Sørenson, 1948):

$$CC = 2C / (S1 + S2)$$

S1 is the total number of species or group of species (order) found in community or habitat 1.

S2 is the total number of species or group of species (order) found in community or habitat 2.

This CC is between 0 and 1: the closer the value to 1, the more the communities have in common; complete community overlap is equal to 1; complete community dissimilarity is equal to 0.

- Evenness Index: Species evenness was determined to reflect on how close in numbers each species or group of species (order) in a habitat is.

The evenness of a community (J) can be represented by Pielou's evenness index (Pielou, 1966) as follows:

$$J = H / H_{max}$$

H_{max} is the highest of Shannon-Weiner Index values.

The value of J ranges from 0 to 1: higher values indicate higher levels of evenness; at maximum evenness, J = 1; low J indicates that 1 or few species dominate the community.

For most analyses, a sample was equivalent to 14 days of collection of 33 traps (as described above). Datasets at the ordinal resolution for morphospecies lacked discriminating power, as indicated by our analysis. Thus, we compared the abundance and diversity of the material collected by this sampling method with standard statistics used in ecology.

RESULTS

Results of our study indicated that 9 insect orders and 5 other arthropod groups were sampled from the four different habitats selected at the coastal sites under measured temperature of 30.29 $\pm$ 0.76 °C and RH of 52.88 $\pm$ 5.11% during the experimental period. The identified insect specimens were classified in the following Orders: Coleoptera, Dictyoptera, Diptera, Hemiptera (suborder Heteroptera), Hemiptera (suborder Homoptera), Hymenoptera, Lepidoptera, Orthoptera, and Thysanoptera. The arthropod specimens (other than insects) were classified into the Class Arachnida (Orders Araneaea and Scorpiones), Class Malacostraca (Order Isopoda), Class Chilopoda (centipedes), and Class Diplopoda (millipedes). In all habitats, the arthropod samples were identified mainly for the adult specimens. Albeit, number of immature stages, larva or nymph, was included in the data analysis.

Our results showed clear and biologically meaningful patterns of the parataxonomic sorting of insect specimens into determined orders and morphospecies; knowing that weak or no detectable patterns may easily be caused by errors in sorting (Krell, 2004).

Abundance Level Determination

Overall, 3,356 arthropods (as adult and immature) were collected during the 6 sampling periods from 198 samples in 12 sites having 33 traps. A total number of 1831 insects and 1525 arthropods (other than insects), had been distributed in the four habitats during the experimental period. Nine focal insect orders represented 1,831 individuals and 129 morphospecies; eighty morphospecies were sorted from these focal taxa and identified into 25 families (Table 2). Our study examined the effects of a wide anthropogenic gradient of disturbance on a range of focal insect taxa that represent diverse taxonomic and functional guilds (Table 2). Forty two morphospecies were singleton species (32.5% out of 129) and 57 morphospecies (44.2% out of 129) were unique species. On the other hand, among the arthropod groups (other than insects), the order Araneaea was the most abundant group (1502) in all habitats of the coastal sites (98.5%) followed by the isopods, centipedes, millipedes and scorpions of 15, 4, 2 and 2 specimens, respectively.

Our data analysis indicated that there was significant difference in number of insects collected per trap ($F = 10.512$; $df = 5, 482$; $\alpha = 0.000$) among different sampling dates, but for arthropods (other than insects), there was no significant difference in number of specimens per trap among different sampling dates (App. B: Table B.1). It seems that the peak of insects' emergence in the four habitats was on the sampling date, S4 (23/8/2020), during the summer of this study. However, there was no significant difference in number of specimens ($\alpha > 0.05$) for insects or arthropods (other than insects) per trap among different habitats (App. B: Table B.2). It is important to note, that despite summer hot temperatures and the decrease in white vinegar volume in traps per 2 weeks interval up to the range of 160–300 ml (out of 400 ml), the arthropods remained well preserved in the vinegar solution. This indicated that the white vinegar is a good preservative for arthropods, and is economically feasible to be used in follow-up monitoring surveys.

Among the insect groups, the order Hymenoptera was the most abundant insect group in all habitats of the coastal sites (63.57%) followed by the orders: Diptera (9.67%), Homoptera (9.07%), and the orders Coleoptera, Orthoptera, Hemiptera, Lepidoptera, Dictyoptera and

Taxa / Order	Family	Guild[a]	No. of specimens	Morphospecies (Order)	Morphospecies (Family)
COLEOPTERA			104	28	
	Buprestidae	Wo	7		2
	Coccinellidae	Pr	1		1
	Curculionidae	Lc	1		1
	Elateridae	Lc	2		2
	Mordellidae	Fc	6		2
	Staphylinidae	Pr	12		4
DICTYOPTERA	Blattidae		2	2	2
DIPTERA			177	18	
	Asilidae	Pr	1		1
	Calliphoridae	Sc	14		3
	Culicidae	Ss	9		4
	Tipulidae	De	4		2
HEMIPTERA			66	18	
	Lygaeidae	Fs	7		3
	Pyrrhocoridae	Ss	5		2
HOMOPTERA			166	20	
	Aphididae	Ss	111		8
	Cicadellidae	Ss	17		5
	Membracidae	Ss	1		1
HYMENOPTERA			1164	30	
	Apidae	Po	132		10
	Braconidae	Pa	1		1
	Formicidae	An	1027		16
	Sphecidae	Pr	1		1
	Vespidae	Pr	3		2
LEPIDOPTERA		Ph, Po	27	7	
	Pieridae	Lc	2		1
ORTHOPTERA			82	5	
	Acrididae	Lc	10		2
	Gryllidae	Lc	72		3
THYSANOPTERA	Thripidae	Ss	1	1	1
IMMATURE INSECTS			42		

Table 2. Focal taxa of insects sorted by parataxonomists in four habitats at selected coastal sites. a: Guilds include: An = ants, De = Decomposers, Fc = Flower chewer, Fs = Fallen seeds, Lc = leaf-chewers, Pa = parasitoids, Ph = Phytophagous, Po = Pollinator, Pr = predators, Sc = Scavenger, Ss = sap-suckers, Wo = wood-eaters (Moran & Southwood, 1982).

Thysanoptera which were less than 9% (Table 3; App. C: Fig. C.1). The number of Hymenopterans sampled was the highest (1164) with high taxa diversity of 30 morphospecies in 5 families followed by 28 and 18 morphospecies in the Coleoptera and Diptera orders, respectively (Table 2).

In our study, the biweekly catch rate was in the range of 12.56 and 27.69% insect specimens for S1 and S5, respectively (App. B: Table B.3) with an average biweekly catch rate of 16.67% for insects. For collected arthropods (other than insects), the biweekly catch rate was in the range of 5.77 and

25.70% specimens for S1 and S4, respectively. Furthermore, total non-flying arthropods (including insects) were 1839 versus 1517 flying arthropods (insects); with highest numbers of non-flying and flying arthropods being in H3 followed by H4, H2, and H1.

Biodiversity level determination

There is no single indicator for biodiversity in an ecosystem or eco-habitat. The choice of indicators depends on the aspect or entity of biodiversity to be evaluated and is guided by a specific value system based on particular motivation/s. Each biodiversity index (BI) for a system should consist of a group of methods with one or several consistent indicators (Duelli & Obrist, 2003).

In our study, according to Simpson's index (D), the highest diversity in numbers of insect orders among all habitats had been observed in field crops H1 of 0.64, followed by H3 of 0.58, H2 of 0.49 and H4 of 0.44 (Table 4). For comparative issues, the Shannon-Weiner Index (H') also indicated the diversity level to be in the following order (H1>H3>H2>H4), similar to Simpson's index (Table 4). In our study, we emphasized the Simpson index which is a dominance index because it gives more weight to common or dominant species whereas the Shannon index assumes all species are represented in a sample which is not applicable to all insect orders and morphospecies determined in our study. Thus, the determined diversity level (D) of insects in the four habitats of the selected sites on the coastal area of Lebanon was medium of 0.51 (Table 4). Similarly, the highest (D) of morphospecies among habitats had been observed in H1 of 0.91, followed by H3, H2, and H4 of 0.87, 0.78, and 0.77, respectively (Table 4) with (D) value of 0.83 for the coastal area (Table 5). The Shannon-Weiner Index (H') also indicated the diversity level of morphospecies to be in the following order (H1>H3>H2>H4), similar to Simpson's index (Table 5).

The evenness index (J) and (D) can be used as measures of species dominance in a community. In our study, the Simpson's Dominance index indicated that the most dominant insect order among the determined orders in each habitat for the highest abundant order (as Hymenoptera) was 2.27 (68.66%), 2.05 (67.49%), 1.72 (60.43%), and 1.56 (50.49%) in H4, H2, H3, and H1, respectively (Tables 2, 4). In terms of morphospecies, the highest number of Hymenopterans among all other morphospecies per habitat was in H3 followed by H2, H1, and H4 of 63.33, 53.33, 43.33, and 36.67%, respectively (Table 6). Thus, there was a high number of Hymenopteran morphospecies in H3 which is the

Number of specimens belonging to different insect taxa per habitat											
Order[a] / Habitat[b]	**Co**	**Dic**	**Di**	**He**	**Ho**	**Hy**	**Im**	**Le**	**Or**	**Th**	**Total[c]**
H1	42	0	36	20	10	175	2	5	22	1	313
H2	18	0	8	27	115	409	10	7	12	0	606
H3	24	1	102	10	22	339	7	11	45	0	561
H4	20	1	31	9	19	241	23	4	3	0	351
Total[d]	104 (5.68)	2	177 (9.67)	66 (3.61)	166 (9.07)	1164 (63.57)	42	27 (1.47)	82 (4.48)	1	1831

Table 3. Abundance of sampled insects in different terraces habitats along the selected coastal sites. a: Co=Coleoptera; Dic=Dictyoptera; Di=Diptera; He=Hemiptera; Ho=Homoptera; Hy=Hymenoptera; Im= Immature insects; Le=Lepidotera; Or=Ortoptera; Th=Thysanoptera; b: H1=Intensive production irrigated field crops; H2=Protected agriculture habitat; H3= Natural habitat; H4=Low input production olive orchards; c: Total number including insects' numbers per habitat type; d: Total number including insects' numbers per insect order.

Habitat type[a]	Simpson's D (0-1)	Simpson's index (1-D)	Simpson's Dominance Index (1/D)	Shannon's diversity index (H')	Evenness Index (J) (0-1)
H1	0.36	0.64	1.56	0.61	1.00
H2	0.51	0.49	2.05	0.44	0.72
H3	0.42	0.58	1.72	0.54	0.89
H4	0.56	0.44	2.27	0.43	0.70
Coastal sites[b]	0.21	0.51		0.64	

Table 4. Biodiversity level of insect orders at different terraces habitats of the selected coastal sites in Lebanon; a: H1=Intensive production irrigated field crops; H2=Protected agriculture habitat; H3= Natural habitat; H4=Low input production olive orchards; b: Coastal sites cover the four selected habitats.

Habitat type[a]	Morphospecies No. per habitat	Simpson's D (0-1)	Simpson's index (1-D)	Simpson's Dominance Index (1/D)	Shannon's diversity index (H')	Evenness Index (J) (0-1)
H1	101	0.09	0.91	1.10	0.61	1.00
H2	91	0.22	0.78	1.28	0.44	0.76
H3	100	0.13	0.87	1.14	0.54	0.86
H4	85	0.23	0.77	1.31	0.43	0.74
Coastal sites[b]	129	0.17	0.83	1.20	1.90	

Table 5. Biodiversity level of Morphospecies at different terraces habitats of the selected coastal sites in Lebanon; a: H1=Intensive production irrigated field crops; H2=Protected agriculture habitat; H3= Natural habitat; H4=Low input production olive orchards. b: Based on number of Morphospecies in 9 insect orders determined in four habitats.

Order[a]/ Habitat[b]	Co	Dic	Di	He	Ho (% MP out of total MP per order)	Hy (% MP out of total MP per order)	Le	Or	Th	Total MP per habitat
H1	16	0	11	12	5 (25%)	13 (43.33%)	4	4	1	66
H2	13	0	5	12	9 (45%)	16 (53.33%)	3	3	0	61
H3	12	1	9	7	6 (30%)	19 (63.33%)	4	3	0	61
H4	10	1	7	6	9 (45%)	11 (36.67%)	1	1	0	46
No. of MP per insect order	28	2	18	18	20	30	7	5	1	

Table 6. Distribution of number of insect Morphospecies (MP) at different terraces habitat of the selected coastal sites in Lebanon; a: Co = Coleoptera; Dic = Dictyoptera; Di = Diptera; He = Hemiptera; Ho = Homoptera; Hy = Hymenoptera; Im = Immature insects; Le = Lepidotera; Or = Ortoptera;Th = Thysanoptera. b: H# Habitat types: H1=Intensive production irrigated field crops; H2=Protected agriculture; H3=Natural habitat; H4=Low input production olive orchards.

least disturbed habitat represented by scrublands and least number of these was in H4, the olive orchards that were usually managed by removal of the vegetative cover among trees and were treated with pesticides for olive pests. However, in terms of dominant morphospecies, the most dominant morphospecies number represented mainly by the 3rd abundant insect order Homoptera among all other morphospecies per habitat was 1.31 (45%), 1.28 (45%), 1.14 (30%) and 1.10 (25%) in H4, H2, H3, and H1, respectively (Tables 5, 6). Thus, there is high dominance of Homopteran morphospecies in H4 and H2 which are considered to be disturbed habitats that are usually managed with pesticides for olive and vegetable/ornamental plant pests, respectively; knowing that in H3 usually lower number of Homopteran pests are expected and in field crops (H1) a limited number of pest spp. are associated with mono-cultured crops. Furthermore, (J) was high in all habitats of 1, 0.89, 0.72, and 0.70 for H1, H3, H2, and H4, respectively (Table 4) indicating that most insect orders are dominating these habitats; i.e. H1 had more even distribution of numbers of species in different insect orders followed by the other 3 latter habitats. Similarly, there was high even distribution of morphospecies per habitat in H1 followed by H3, H2, and H4 consecutively (Table 5).

According to Sorenson's Coefficient (CC), these 4 habitats had much overlap or similarity in terms of determined insect orders, as the range of this coefficient among habitats was 0.89–1; the minimum CC was among H1 versus (H3 and H4) and the maximum CC was among H3 versus H4, respectively. However, these habitats had low overlap or similarity in terms of morphospecies, as the range of this coefficient among habitats was 0.24–0.33; the minimum CC was among H2 versus H4 and the maximum CC was among H1 versus H3, respectively.

Furthermore, our regression analysis indicated that the highest positive regression coefficient of 1.006 was correlated with detection of Lepidopteran specimens in the 4 habitats from H1 to H4 (Fig. 1; App. B: Table B.4). This positive correlation became weaker with the order Hymenoptera, followed by the orders: Coleoptera, Dictyoptera, and Diptera, but this correlation was negative with the orders: Hemiptera and Homoptera particularly through H3 and H2 (Fig. 1; App. B: Table B.4; App. C: Fig. C.2). However, this analysis indicated high negative correlation with regression coefficient of -1.071 between sampling number and insect order Hymenoptera followed by Coleoptera, Diptera, Dictyoptera, and Lepidoptera, in a decreasing order, particularly in S3 and S4 (Fig. 2; App. B: Table B.5;

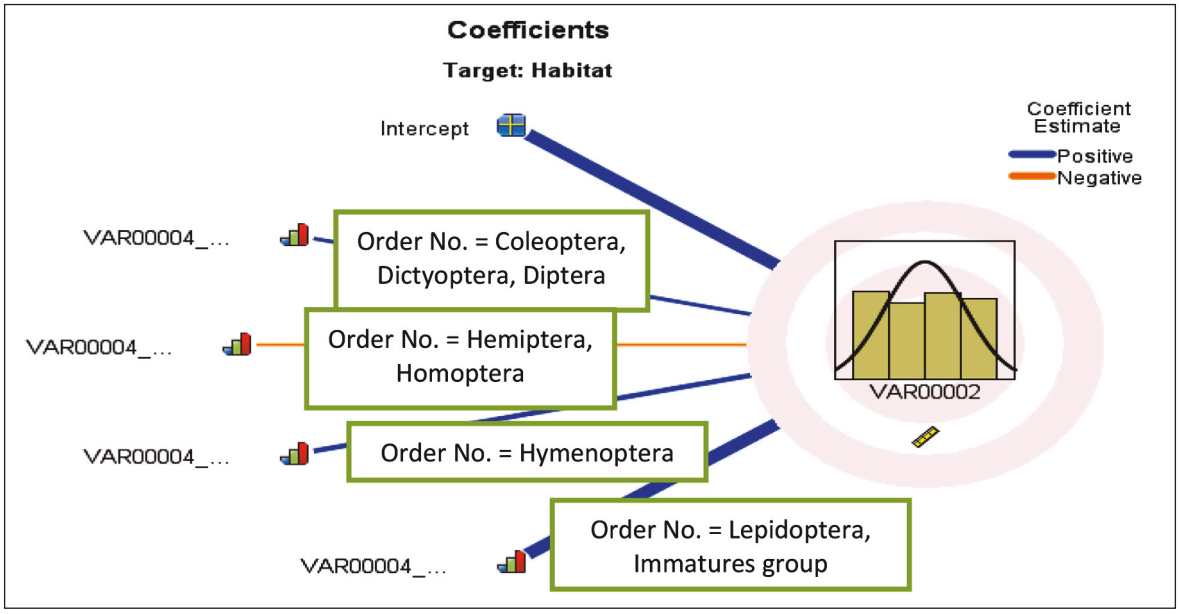

Figure 1. Correlation among insect orders in different habitats through regression analysis, with the target being habitat type (VAR00002).

App. C: Fig. C.3), but a positive correlation with regression coefficient of 0.053 was detected between number of insect specimens collected through these sampling dates during the experimental period (Fig. 2; App. B: Table B.5). Specifically, there was a positive correlation with regression coefficient of 0.968 between number of insect specimens and the order Hymenoptera, but there was high negative correlation with regression coefficient of -3.774 between number of collected insects and the order Lepidoptera followed by Hemiptera, Homoptera, Coleoptera, Diptera, and Dictyoptera, consecutively (Fig. 3; App. B: Table B.6). It is important to note that SPSS excluded certain dependent variables as Orthoptera, Thysanoptera, and Lepidoptera as one variable showed a linear dependency to another variable during the analysis; this is represented by the regression coefficient being set to 0 by SPSS analysis (Tables B.4; App. B: B.6). Thus, changes in the selected habitats would be associated significantly ($p < 0.05$) with changes in the population of insects in the order Lepidoptera (Table B.4; App. B). Furthermore, changes in the sampling process (during the experimental period) in the selected habitats would be associated significantly ($p < 0.05$) with changes in the population of insects in the orders: Coleoptera, Dictyoptera, Diptera, and Hymenoptera (App. B: Table B.5).

DISCUSSION

Based on this study, it is clear that there was significant diversity of insect orders along the selected coastal area. There was also considerable diversity of morphospecies belonging to these determined insect orders (Table 2); with medium proportion of singleton (32.25%) and unique (44.2%) morphospecies. Unique species are very common in biodiversity studies; for example, it was found that for morphospecies and species, Malaise traps produced a high proportion of unique species (55–60%), whereas this was lower for Pitfall traps of 19–26%, in a tropical landscape (Missa et al., 2009). On the other hand, it was found that Pitfall traps and Yellow Pan Traps (YPTs) were most efficient when considering catch rates per trap-day of 21.7 and 19.5% arthropod specimens, respectively with YPTs having the lowest coefficient of variation in catches per trap-day in a tropical landscape. Thus, our yellow-white pitfall-pan trap seems to combine the effects of the latter 2 trap types efficiently with arthropod catch rate of 16.67% per trap at a biweekly interval in our selected coastal temperate sites.

In our study, the order Hymenoptera was the most abundant with highest morphospecies diversity followed by the orders Coleoptera and Diptera (Table 2). Similarly, in a study of two distinct habi-

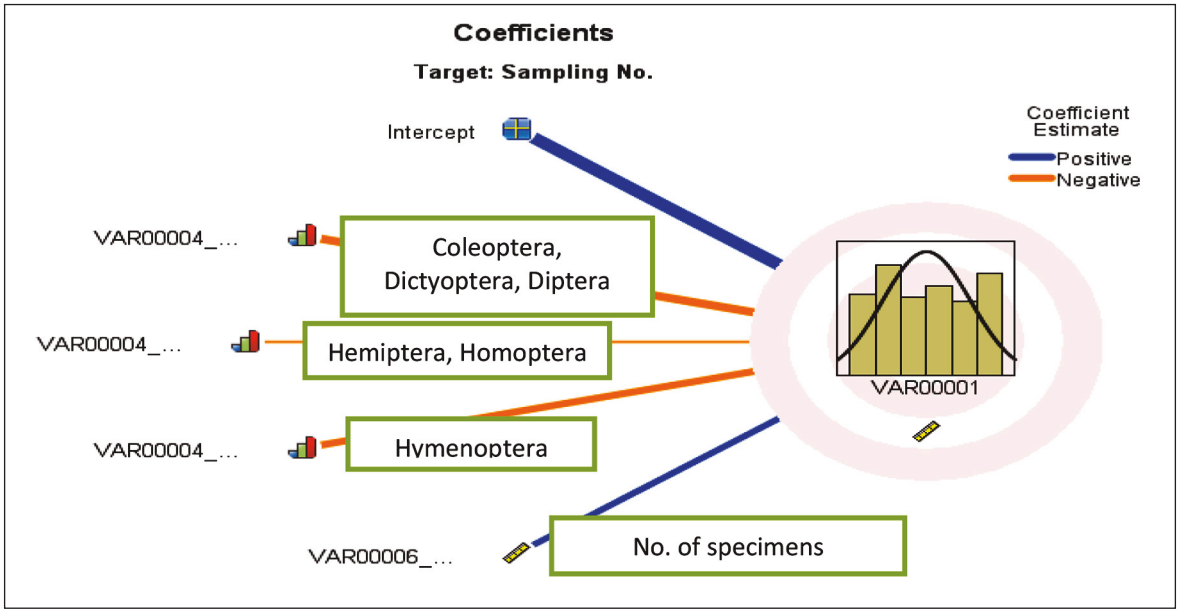

Figure 2. Correlation among insect orders and number of specimens in different habitats through regression analysis, with the target being sampling number (VAR00001).

tat types at Ghana in Africa: riparian forest mosaic and woodland savannah with some rocky outcrops at a village; it was found that Hymenopterans were the most abundant (3229) while the Dipterans were the most diverse with 39 families, followed by the Coleopterans with 21 families (Kyerematen et al., 2014). Hymenopterans as bees, ants and other spp. had been found to be useful as ecological and biological indicators (Lobry de Bruyn, 1999; Andersen et al., 2002; Ghini et al., 2004; Urbini et al., 2006; Coelho et al., 2009; Rabea et al., 2010; Pereira et al., 2010; Herrera et al., 2023). On the other hand, it was found that the diversity of coastal environmental insects from a sandy beach in India to be partitioned as follows: Coleoptera (26%), Lepidoptera (24%), and other orders: Diptera, Heteroptera, Hemiptera, and Orthoptera that were less than 20% (Balakrishnan et al., 2014). This trend had also been recorded in the mangroves islands of India, with the following abundance results: Lepidoptera (50%), Coleoptera (20%), Hemiptera (15%), and the orders: Diptera, Hymenoptera, Orthoptera, and Thysanoptera that were less than 5% (Veenakumari et al., 1997). The latter two studies reflect on absence or low abundance of hymenopterans, respectively which could be related to the topography of the selected sites along the coastal areas in the tropics.

As for land use, it was found that the highest numbers of flying and non-flying arthropod groups were observed in the natural habitat terraces (H3) and lowest numbers of these two groups were found in intensive production irrigated terraces of field crops (H1). This result correlate directly with higher human intervention in the habitats H1, H2, and H4 versus that of natural habitats as scrublands.

Furthermore, both the Simpson's index (D) and Shannon-Weiner Index (H') indicated the diversity level of insect orders and morphospecies to be higher in H3 compared to the other habitats, except for H1 (Tables 4, 5). However, (H') for insect orders and their morphospecies in our studied coastal area were of 0.64 and 1.90, respectively. Balakrishnan et al. (2014) also found in different coastal habitats of Tamil Nadu, Southeast coast of India, H' to be high and varied from 3.692 to 4.950; the minimum H' was determined in Station III during summer and in Station II during premonsoon, respectively, with low species diversity.

Furthermore, these four habitats had much overlap in terms of determined insect orders, but low overlap in terms of morphospecies. Hence, there was least overlap among morphospecies attacking crops planted in greenhouses and those attacking olive trees which is related mainly to the different pests of vegetable/ornamental plants and olive trees

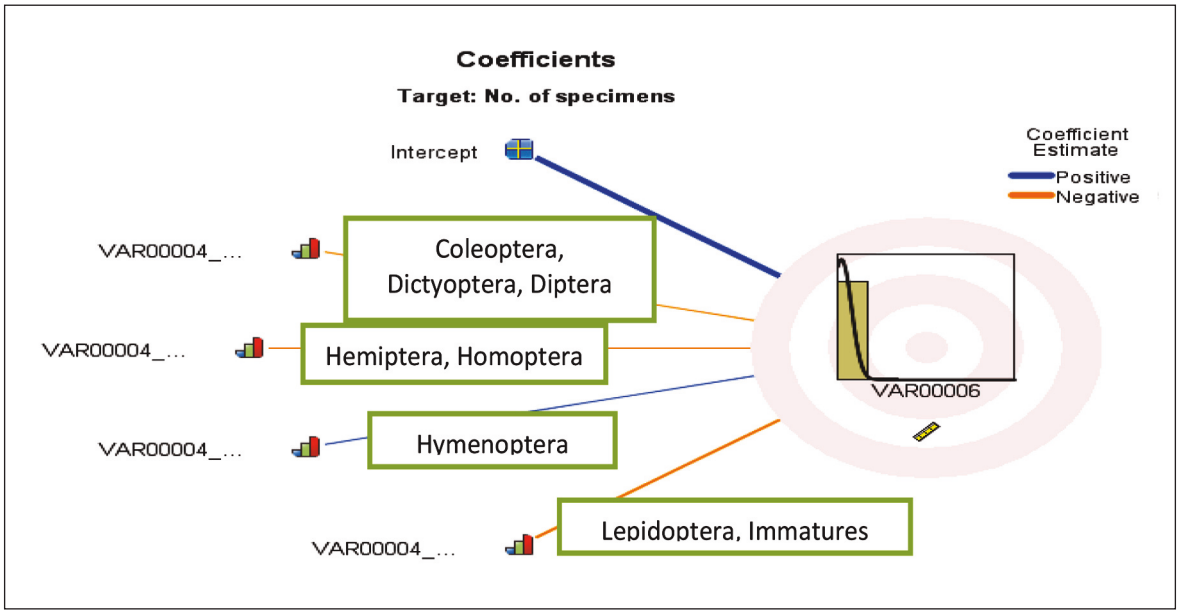

Figure 3. Correlation among insect orders and number of specimens (VAR00006) in different habitats through regression analysis.

with their corresponding natural enemies, respectively. However, the highest overlap in morphospecies was among field crops and scrublands; knowing that the field crops were originally initiated from relatively adjacent scrublands in the selected coastal sites.

Hence, the analytically deduced five insect orders: Lepidoptera, Coleoptera, Dictyoptera, Diptera, and Hymenoptera can be selected as biodiversity indicator/s in the selected Lebanese coastal area; especially as the diversity indices were of the medium level in the four habitats. This was based on description of a species-richness gradient, from the group comprising most species (as high biodiversity), to the group with a medium number of species (as medium biodiversity), and the group that included the fewest species (as low biodiversity) (Velázquez & Bocco, 2001). In another study, seven taxa were selected as potential bioindicators of species richness of semi-natural grassland habitats; ten combinations of taxa were found to have significant positive correlations with the remaining species richness, of which sedges and carabids (Order: Coleoptera) combined showed the strongest correlation (Hayes et al., 2015).

In our study, unexpectedly the field crops (H1) had the highest diversity and number of morphospecies (Tables 4, 5) due to the decrease in farming practices, such as pesticides application, weeding and others, for economic reasons in the country during the period of the study in 2020. However, the scrubland habitat (H3) was expected to have the highest BI, but the index level was medium (0.58) at this habitat; this would be due to the location of these habitats near urban areas with a high density of human structures such as houses, commercial buildings, roads, facing pollution challenges of air, water, and soil. In terms of morphospecies, these habitats H1 and H3 had similar numbers of 101 and 100 morphospecies, respectively (Table 5), but only the number of Hymenopteran and Homopteran morphospecies were higher in the natural habitat (H3) compared to those in H1; other determined morphospecies in the other 7 insect orders were higher in H1 which might indicate that a lower fraction of the fauna was sampled in H3 than in H1 (Table 6).

As for (H2), BI was low (0.49); due to pesticides application that was intensive (every 5 days) during the sampling period. However, farmers changed their practices by the end of August in form of preparing most of their greenhouses for soil solarization practices and thus decreased their pesticides use at end of season. Similarly, the olive orchards (H4) showed a low BI (0.44) due to the use of pesticides every 21 days and due to repetitive soil plowing and continuous weeding. Thus, the latter 2 habitats seem to have contributed to lower biodiversity level at the coastal side. Furthermore, the scrubland habitat seems to be highly disturbed by human intervention whereas the field crops habitat seem to contribute to high biodiversity level of the coastal side at that experimental time, at the expense of deteriorating Lebanese economic status in 2020. Thus, repeating the same experimental study along the coastal sites of the selected habitats after a period of time depend mainly on detection of the classified insect orders and morphospecies with a comparable number of the collected specimens using the combined trap type.

The scope of this study in terms of diversity of habitats surveyed, the combined sampling method, sample size, replication, and taxonomic coverage allowed us to discuss some issues which may be important for designing monitoring programs assessing the effects of ecosystem changes on multiple assemblages of arthropods in a temperate region. When selecting an appropriate sampling method, considering the design of the respective sampling tools as well as the ecological traits and habitat conditions is a must. Utilization of yellow-white pitfall pan traps was a simple and cost-effective method to collect insects having different living habits. In this context, the sampling method used in this study is tested for being suitable for biological monitoring, for revealing relative efficiency (in terms of abundance and species richness) and potential to collect rapidly baseline information; the relative effects of our sampling method and habitat types on the composition of trap catches are basic in our data analysis.

It is well known that the development of a biodiversity assessment and monitoring study is a task that increases people's skills, knowledge and awareness about their natural heritage. Development of databases usually helps inform the management teams of the protected areas as the national coastal areas on the available key species and habitats and on how, where and when to monitor them, appreciate them and use them as an effective tool of con-

servation (Ramadan-Jaradi et al., 2004; Samwaysa et al., 2020).

The world is currently facing its greatest ever biodiversity crisis. Insects and plants are becoming extinct because of habitat loss, overexploitation, pollution, human overpopulation, and the threat of global climatic changes (Shivanna, 2022). It is recommended to invest more efforts for conservation of the arthropods (as insects) biodiversity along the coastal areas so that the diversity indices would not reach a lower level and consequently pass through having locally endangered and extinct species as time evolves. It is essential to preserve the abundance of the determined bioindicator insect orders: Hymenoptera, Diptera, Coleoptera, Lepidoptera and Dictyoptera to ensure ecological schemes for various local insect and plant species along the Lebanese coast.

For eco-habitat monitoring, insect species as biological indicators are essential. Human intervention on the coastal landscape of a country has positive and negative attributes on the different habitats present. Terraces system is one main example of positive attribute in terms of preserving soil and water since long time ago, but implementation of intensive agriculture practices as use of pesticides and repetitive cultivation has contributed to negative effect on insect biodiversity in agroecosystems. Determined insect biodiversity indicators can specifically be monitored and be highly useful as indicator species for any changes in the latter systems in comparison to natural habitats that are being geared by humans for their living needs. These bio-indicators will be helpful to manage habitat loss and limit human intervention towards a sustainable living future.

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Appendix A

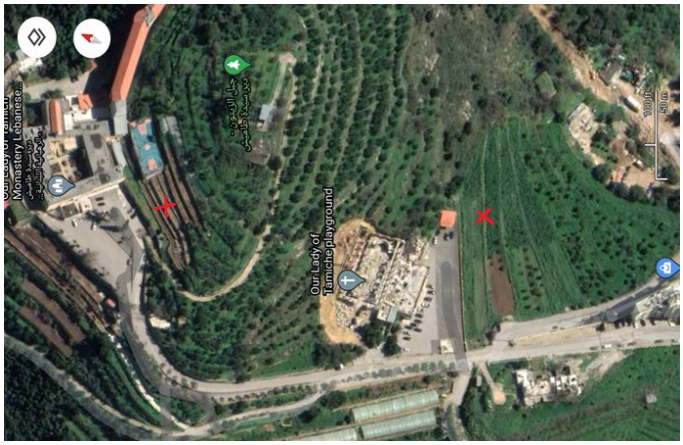

Figure A.1. Two Pitfall Pan traps (PPTs) placed in one site of Tamish Monastery, with field crops habitat (H1). x denotes trap location.

Figure A.2. Three PPTs distributed among greenhouses (H2) in one site of St. Roukoz Monastery. x denotes trap location.

Figure A.3. Three PPTs placed in one site of Tamish Monastry, scrubland habitat (H3). x denotes trap location.

Figure A.4. Two PPTs placed at one site of St Roukoz Monastry, olive orchard habitat (H4). x denotes trap location.

Figure A.5. Two PPTs placed at one site of Edde Jbayl, Field crops habitat (H1). x denotes trap location.

Figure A.6. Three PPTs placed among greenhouses (H2) at one site in Jbayl. x denotes trap location.

Figure A.7. Four PPTs placed at one site of Ghazir, scrubland habitat (H3). x denotes trap location.

Figure A.8. Two PPTs placed at one site in Jbayl, olive orchards habitat (H4). x denotes trap location.

Figure A.9. Two PPTs placed at one site in Batroun, field crops habitat (H1). x denotes trap location.

Figure A.10. Three PPTs placed among greenhouses (H2) at one site in Batroun. x denotes trap location.

Figure A.11. Four PPTs placed at one site in Batroun, scrubland habitat (H3). x denotes trap location.

Figure A.12. Three PPTs placed at one site in Koubba, olive orchards habitat (H4). x denotes trap location.

Appendix B

Table B.1. Arthropods sampled in all habitats at different sampling dates along the selected coastal sites.

S#[a]	Ave. no. of insect specimens per trap	Ave. no. of arthropods (other than insects) per trap[b]
S1	1.27 ± 0.14 b[c]	1.77 ± 0.34
S2	2.22 ± 0.41 b	1.81 ± 0.30
S3	2.85 ± 0.98 b	1.31 ± 0.20
S4	11.60 ± 2.65 a	1.33 ± 0.22
S5	3.30 ± 0.61 b	1.50 ± 0.31
S6	1.82 ± 0.19 b	1.10 ± 0.07

Values are Mean ± Std. Error
[a]: S# = Sampling number include: S1 = 12/7/2020, S2 = 26/7/2020, S3 = 20/6/2023, S4 = 23/8/2020, S5 = 5/9/2020, and S6 = 20/9/2020.
[b]: There was no significant difference in number of specimens ($\alpha > 0.05$) among different sampling dates.
[c]: Means within column followed by different letters are significantly different at $\alpha \leq 0.05$.

Table B.2. Arthropods sampled in different terraces habitats along the selected coastal sites during the experimental period.

	Ave. no. of insect specimens per trap[a]	Ave. no. of arthropods (other than insects) per trap[a]
H#[b]		
H1	3.17 ± 0.53	1.00 ± 0.00
H2	4.86 ± 1.84	1.19 ± 0.18
H3	4.00 ± 0.71	1.55 ± 0.26
H4	3.25 ± 0.60	1.77 ± 0.17

Values are Mean ± Std. Error
[a]: There was no significant difference in number of specimens per trap ($\alpha > 0.05$) among different habitat types.
[b]: H# Habitat types: H1=Intensive production irrigated habitat as field crops; H2=Protected agriculture habitat; H3= Natural habitat; H4=Low input production olive orchards.

Table B.3. Abundance of sampled insects at different sampling dates along the selected coastal sites.

	Number of specimens belonging to different insect groups										
Order[a] / S#[b]	**Co**	**Dic**	**Di**	**He**	**Ho**	**Hy**	**Im**	**Le**	**Or**	**Th**	**Total[c] (% of insects per S#)**
S1	22	0	7	14	12	147	11	7	10	0	230 (12.56)
S2	21	1	16	18	7	199	17	6	8	0	293 (16.00)
S3	18	0	24	10	12	174	3	1	17	0	259 (14.15)
S4	21	0	50	6	8	142	4	2	11	0	244 (13.33)
S5	3	1	45	7	107	321	4	2	17	0	507 (27.69)
S6	19	0	35	11	20	181	3	9	19	1	298 (16.28)
Total[d]	104	2	177	66	166	1164	42	27	82	1	1831

[a]: Co = Coleoptera; Dic = Dictyoptera; Di = Diptera; He = Hemiptera; Ho = Homoptera; Hy = Hymenoptera; Im = Immature insect group; Le = Lepidotera; Or = Ortoptera;Th = Thysanoptera. [b]: S# is Sampling date: S1 = 12/7/2020, S2 = 26/7/2020, S3 =9/8/2020, S4=23/8/2020, S5 = 5/9/2020, S6 = 20/9/2020. [c]: Total number including insects' numbers per sampling date. [d]: Total number including insects' numbers per insect order.

Table B.4. Parameters related to insect orders in different habitats through regression analysis, with the target being habitat type (in Fig. 1 of text). [a] corresponds to orders: Orthoptera and Thysanoptera.

Coefficients
Target: Habitat

Model Term	Coefficient ▶	Sig.	Importance
Intercept	2.220	.000	
VAR00004_transformed=0	0.246	.175	1.000
VAR00004_transformed=1	-0.113	.599	1.000
VAR00004_transformed=2	0.343	.050	1.000
VAR00004_transformed=3	1.006	.000	1.000
VAR00004_transformed=4	0[a]		1.000

[a] This coefficient is set to zero because it is redundant.

Table B.5. Parameters related to insect orders and number of specimens in different habitats through regression analysis, with the target being sampling number (in Fig. 2 of text). [a] corresponds to order Lepidoptera and immature insects group.

Coefficients
Target: Habitat

Model Term	Coefficient ▶	Sig.	Importance
Intercept	3.715	.000	
VAR00004_transformed=0	-0.894	.003	0.772
VAR00004_transformed=1	-0.190	.462	0.772
VAR00004_transformed=2	-1.071	.006	0.772
VAR00004_transformed=3	0[a]		0.772
VAR00006_transformed	0.053	.018	0.228

[a] This coefficient is set to zero because it is redundant.

Table B.6. Parameters related to insect orders and number of specimens in all habitats through regression analysis, with the target being number of specimens (in Fig. 3 of text). [a]: corresponds to orders: Orthoptera and Thysanoptera.

Coefficients
Target: Habitat

Model Term	Coefficient ▶	Sig.	Importance
Intercept	5.000	.017	
VAR00004_transformed=0	-1.747	.442	1.000
VAR00004_transformed=1	-2.856	.227	1.000
VAR00004_transformed=2	0.968	.668	1.000
VAR00004_transformed=3	-3.774	.143	1.000
VAR00004_transformed=4	0[a]		1.000

[a] This coefficient is set to zero because it is redundant.

Appendix C

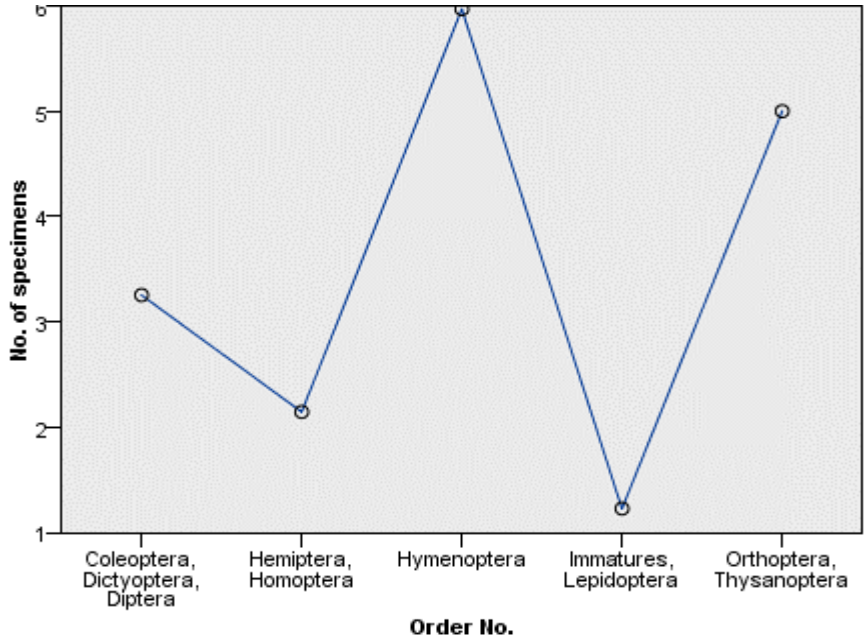

Figure C.1. Abundance of insects per order/group in the four selected habitats; based on estimated means for the top 10 significant effects ($p < 0.05$), with the target in analysis for number of specimens.

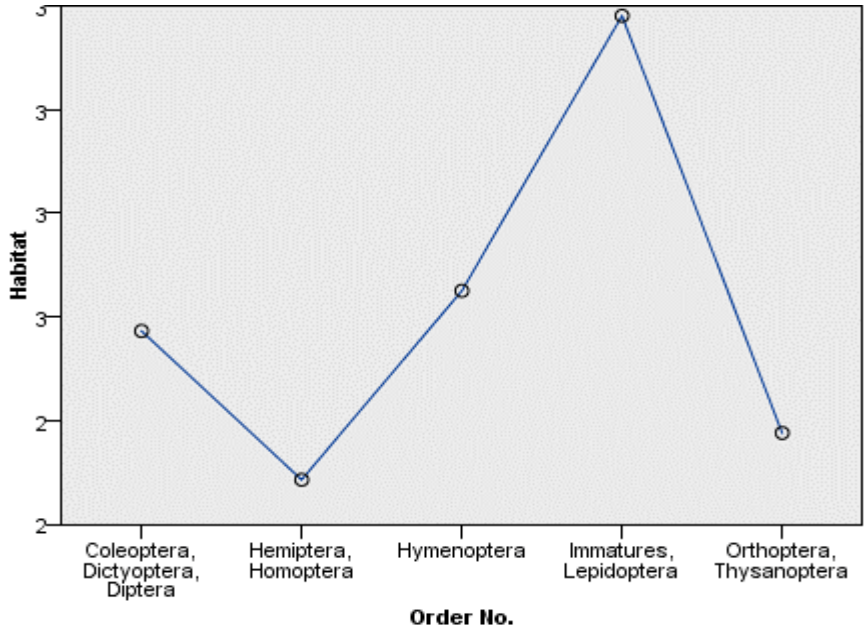

Figure C.2. Distribution of insects per order/group per habitat; based on estimated means for the top 10 significant effects ($p < 0.05$), with the target in analysis for habitat type. **Habitat** types: H1=Intensive production irrigated field crops; H2=Protected agriculture; H3=Natural habitat; H4=Low input production olive orchards.

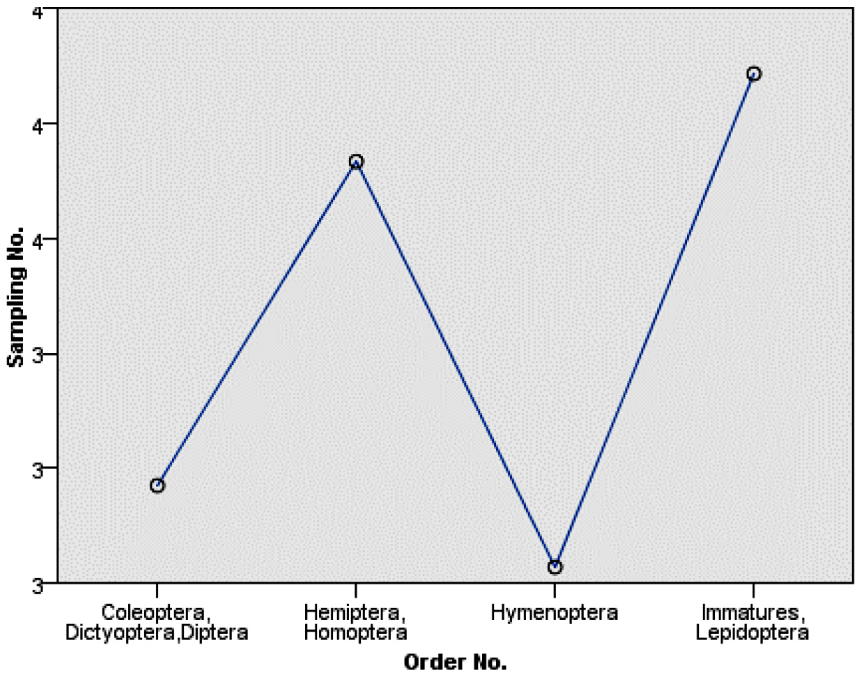

Figure C.3. Distribution of insects per order/group per sampling date; based on estimated means for the top 10 significant effects ($p < 0.05$), with the target in analysis for sampling number. Sampling No.: S1 = 12/7/2020, S2 = 26/7/2020, S3 =9/8/2020, S4=23/8/2020, S5 = 5/9/2020, S6 = 20/9/2020.