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THE STEINHARDT MUSEUM OF NATURAL HISTORY
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SCHOOL OF ZOOLOGY

Long-Term Effects of Locust Pest Control on the Terrestrial Arthropod Population in the Israeli Western Negev Sands 2013-2016

Credit: Max Planck Institute for Chemical Ecology

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Abstract

- Following the infiltration of desert locust (*Schistocerca gregaria*) swarms into the western Negev in the spring of 2013, approximately 100 km^2 were subjected to insecticide spraying to control the pest.
- The effect of insecticide use on terrestrial soil-dwelling arthropods was examined 50 days post-spraying and in the following spring of 2014, 2015 and 2016.
- The sampling system comprised 16 plots, located on the northern slopes of semi-stabilized dunes, eight of which were at sites subjected to insecticide spray (treated) and the other eight at sites that had not been subjected to pest control (untreated). Sampling of arthropod populations was carried out using dry pitfall traps.
- In the spring of 2013, following the first insecticide treatment (a second intensive treatment was carried out immediately after sampling), minor variations in population structure as well as various diversity indices were found when comparing between plots at the treated and untreated sites.
- In the spring of 2014, a substantial difference between the arthropod populations at the treated and untreated sites was found. Additionally, diversity indices were significantly higher at the untreated sites compared to the treated ones.
- In the spring of 2015, while the arthropod population structure at all sites was again found to be similar, the diversity indices remained significantly higher at the untreated sites.
- In the spring of 2016, the similarity of population structures at all sites further increased, and the gap in the diversity indices narrowed substantially, with slightly higher values at the untreated sites.

> Summary: The findings of four years of monitoring revealed a broad and long-term negative effect of insecticide pest control on the arthropod populations. Three years post pest control, although a clear recovery process trend has been detected at the pest-controlled sites, those species characterized by small populations have not yet recovered.

<u>Variations in the desert ant (*Cataglyphis*) population</u>

- In the spring of 2014, the <u>*Cataglyphis*</u> population increased dramatically due to the availability of locust carcasses.

- In the spring of 2015, the *Cataglyphis* population at the treated sites decreased sharply, while at the untreated sites a gradual population size increase continued.
- In the spring of 2016, the *Cataglyphis* population size decreased at all sites, as locust carcasses were most probably no longer available and a decrease in precipitation had caused a general decrease in ecosystem productivity, reducing the availability of food sources.

Introduction

At the beginning of March 2013, desert locust (*Schistocerca gregaria*) swarms from the Sinai Desert in Egypt infested the western Negev sands located in southern Israel. In an effort to minimize damage to crops, the Ministry of Agriculture conducted mass insecticide spraying over large areas in the region. The initial pest control treatment was carried out from the beginning of March for about three weeks, and a second treatment took place from mid-April for an additional three weeks. According to estimates by the Israel Nature and Parks Authority, approximately 100 km^2 were treated with insecticide in March. The second insecticide treatment, designed to control the hatched nymphs, focused on fewer sites compared to the first treatment but was more intensive (pers. comm., Yoav Motro, Israeli Ministry of Agriculture). The insecticide Karate (Syngenta) containing pyrethroid, considered a highly effective material, was used (for details on the properties of the insecticide, see Appendix 1). Small areas (0.6 - 2.7 km^2) were either treated manually or by application from Unimog trucks. Aerial application was used for large areas (0.2 - 17.8 km^2). At several sites all three methods of application were used. The Nahal Lavan river was treated on a daily basis, and sometimes several times a day (pers. comm., Eran Haims, Israel Nature and Parks Authority; Yoav Motro, Ministry of Agriculture). The active ingredient is specific to insects, breaks down relatively quickly in the field and no secondary poisoning of vertebrates was observed.

The ecosystem of the western Negev sands is unique, differing from other sandy habitats in the Negev and from the sands of the Coastal Plain (Renan, 2007). Long-term ecological research (LTER) sampling conducted in the sands of the western Negev between 2005-2016 resulted in the identification of approximately 350 species of beetles, of which seven species are newly identified in Israel and four species are newly identified worldwide (Renan, unpublished).

The western Negev sands habitat is under increasing pressure from human impact and its natural areas are constantly shrinking. Identifying the magnitude of pest control effects on arthropod populations is important to understanding the extent of ecosystem-sensitivity to anthropogenic disturbances, and specifically pest control events, as such events will probably continue to occur in the future. Following plants, the arthropods are at the basis of the ecosystem. Consequently, the state of arthropod populations may well reflect the state of the ecosystem as a whole.

Aims

This survey sought to examine the effects of pest control on terrestrial arthropods in the western Negev sands.

Methods

From 2013 through 2016, 16 plots were sampled each spring in the southern part of the western Negev sands in Israel. Eight plots were located at sites treated by pest control (insecticide spraying), on dunes on the northern bank of the Nahal Lavan river, and another eight plots were located at untreated sites on the northern slopes of dunes with similar ecological characteristics (Figure 1, for coordinates and photos of all plots see Appendix 2). In each plot, 25 one-liter volume pitfall traps (dry, i.e., without lethal substances) were placed, totaling 400 traps. The traps were left open for 48 hours. The material (including organisms and inorganic debris) collected in the traps was sorted in the laboratory and most organisms were released back into the field. Individuals of beetles that were not identified on-site were collected for identification purposes (for the list of identified beetle species, see Appendix 3). All the collected material was transferred for preservation in the National Insect Collection at the Steinhardt Museum of Natural History at Tel Aviv University. Statistical tests for comparison of the various diversity indices (number of species, number of individuals and the Fisher-a index) in the treated and the untreated plots, were chosen after testing the assumptions of normal distribution and equalization of variances. If data did not meet these assumptions, analysis was carried out using a-parameter tests. Past ver. 3.04 software (Hemmer *et al*. 2001) was used for analysis of diversity indices. R ver. 3.2.2 (Team, 2013) software using the Vegan package (Oksanen *et al*. 2007) was utilized to create rarefaction curves, which were then compared using EcoTest ver 1.1 in the rareNMtests package (Cayuela and Gotelli, 2015).

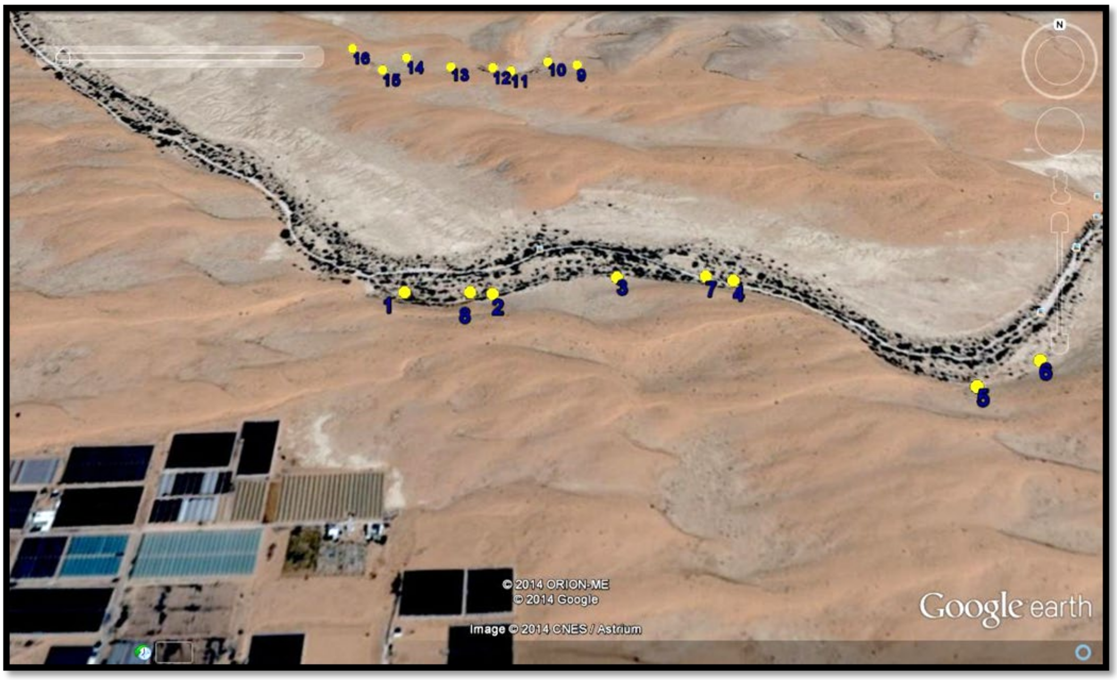

Figure 1: Map of the research area. Plots 1-8: on the slopes of northern dunes adjacent to the Nahal Lavan river – pest-controlled (treated) sites. Plots 9-16: on the slopes of northern dunes – untreated sites.

Results

During the four years of the survey, we sampled 13,001 individuals, representing 282 species and Recognizable Taxonomic Units (RTUs*) in 16 Orders (Table 1).

Table 1: Total species and individuals sampled in all years of the study

Year	Total # of individuals (w/o *Cataglyphis*)		Total # of species		Total # of *Cataglyphis*		Percentage of *Cataglyphis* out of total *(%)*	
	Treated	**Untreated**	**Treated**	**Untreated**	**Treated**	**Untreated**	**Treated**	**Untreated**
2013	633	821	78	78	62	97	9.79	11
2014	1929	1365	76	97	1267	333	66	24
2015	2501	3459	95	96	1002	1253	41	36
2016	1250	1864	83	97	589	820	47	44

*Recognizable Taxonomic Units (**RTU**) are the lowest category to which the parataxonomist researcher is able to categorize individuals based on their morphological characteristics. Precise identification of the species can sometimes be carried out only by a taxonomist specializing in a specific group. The RTU method enables quicker sorting and is both efficient and reliable. Research has found that loss of information due to sorting by RTUs is negligible for ecological studies (e.g., Ward and Stanley, 2014).

A comparison of similarity levels of terrestrial arthropod population structures in pest-controlled (treated) and untreated sites during the period of the study, reveals a significant decrease in similarity levels between 2013 and 2014, followed by a return to initial levels in 2015. In the 2016 sampling, the level of similarity had further slightly increased (Figure 2).

Low Similarity ↔ **High Similarity**

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
2016					0.56					
2015					0.55					
2014			0.32							
2013					0.52					

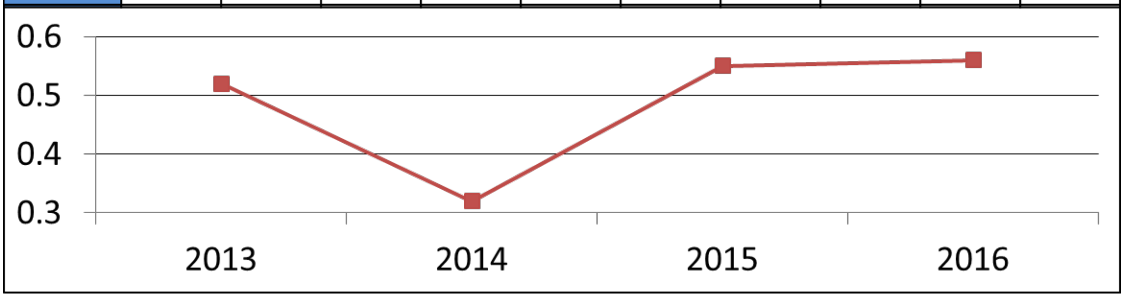

Figure 2: The change in levels of similarity between treated and untreated sites from 2013-2016 (based on Bray-Curtis similarity index).

A comparison of the ratio of the total number of species relative to the sampling effort at the treated and untreated sites, reveals the ratio curve to be almost identical in the spring of 2013, very different in 2014, again similar in 2015, and almost identical in 2016 (Figure 3).

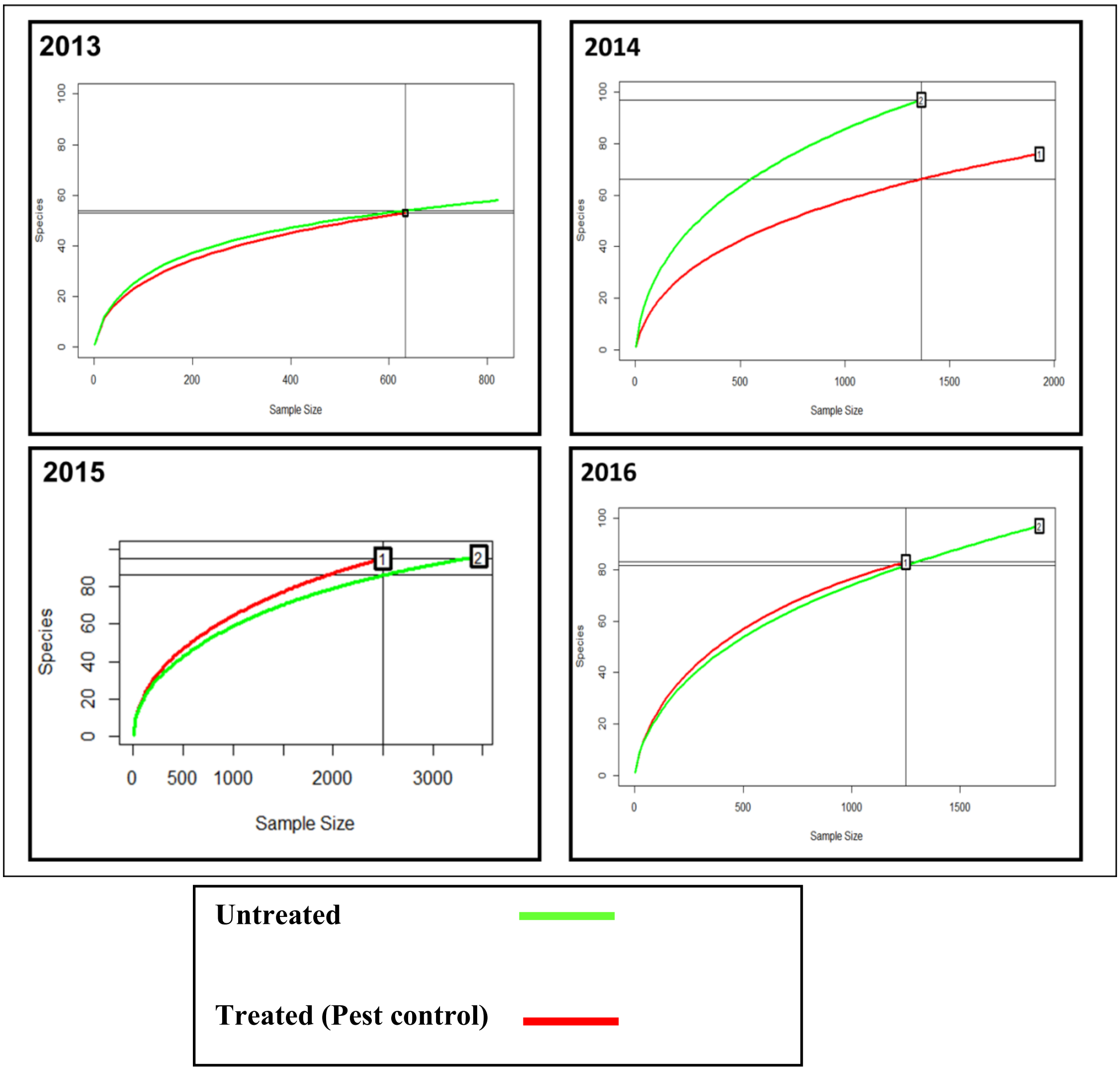

Figure 3: Rarefaction curve representing the accumulation of the number of species with an equal sampling effort between the treated and untreated sites between the years 2013-2016. EcoTest, **2013-2015**: $p<0.05$, **2016**: $p<0.01$

Three basic indices (number of species, number of individuals, and the Fisher's alpha diversity index) (Figures 4, 5, 6) display identical trends: in the spring of 2013, values are slightly higher in the untreated (control) sites in all indices. In 2014, index values are significantly higher in the untreated sites compared to the treated (sprayed) sites. In the spring of 2015, this trend remains constant, and the untreated (control) sites display significantly higher values than the treated sites. In the spring of 2016, all three index values in the untreated sites are still slightly higher than the treated sites, but not significantly so. Another trend that emerged from the results is that of a general increase in diversity indices between 2013-2015, and a decrease in the spring of 2016, which can be explained by the variation in annual precipitation in the region (see Discussion).

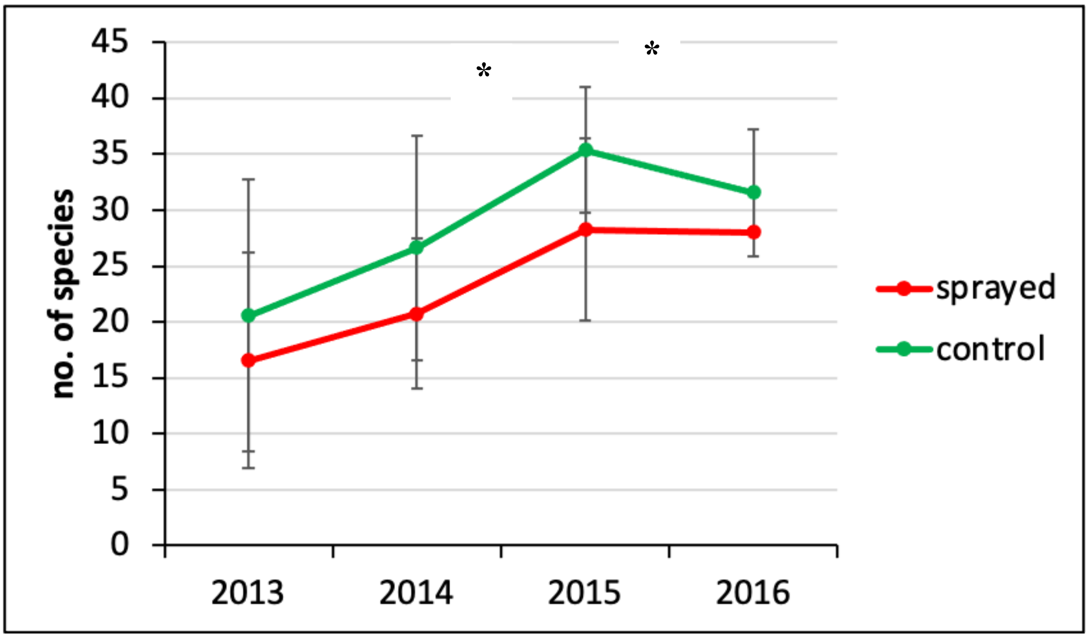

Figure 4: Average species number per plot in treated (sprayed) plots and untreated (control) plots from 2013-2016. **2013**: t-test, $t_{(7)}$=- 0.6, p=0.5, **2014**: t-test, $t_{(7)}$=0.50, $p<0.05$, **2015**: t-test, $t_{(7)}$=0.49, $p<0.05$, **2016**: t-test, $t_{(6)}$=-1.07, p=0.3.

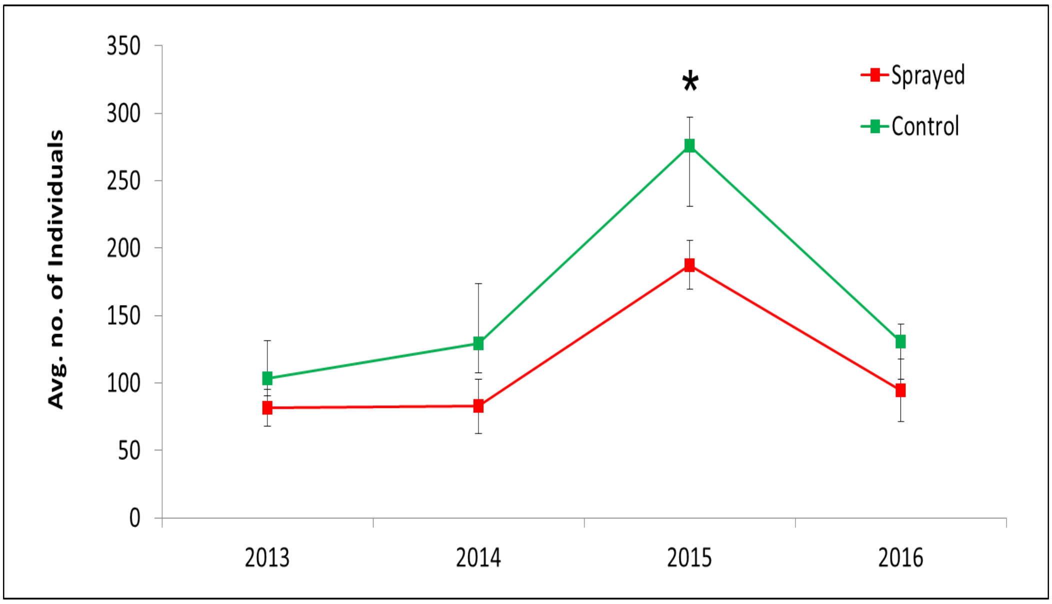

Figure 5: Average individual number per plot (without *Cataglyphis*) in treated (sprayed) plots and untreated (control) plots from 2013-2016.

2013: t-test (7,7)=-0.6, p=0.5, **2014**: t-test, (7,8)=1.6, p=0.11, **2015**: t-test (8,8)=-2.99, $p<0.05$, **2016**: t-test (7,8)=-1.08, p=0.1

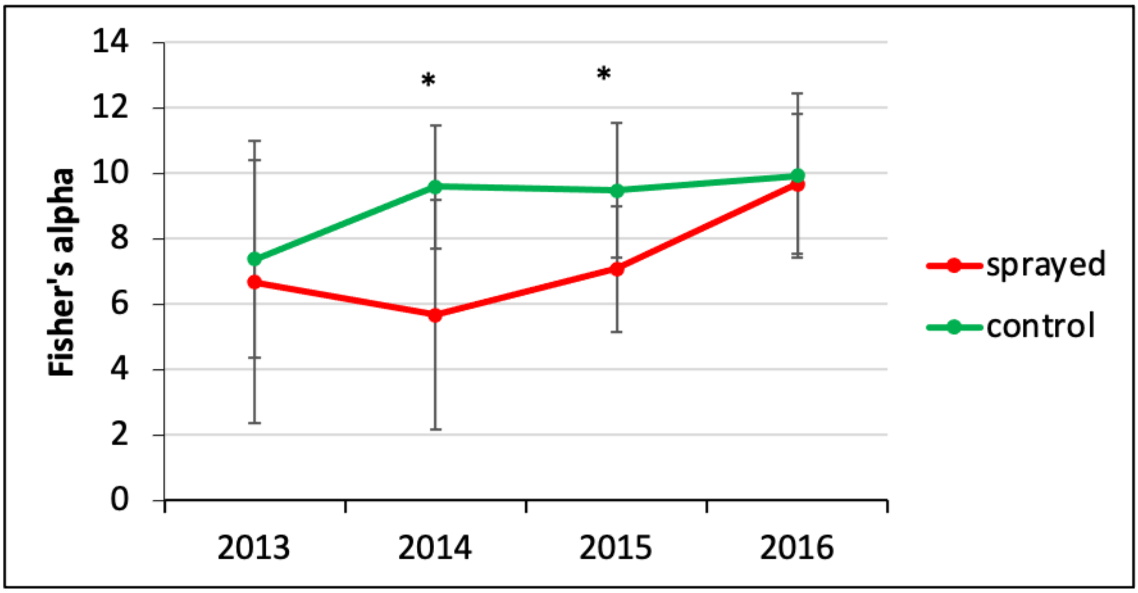

Figure 6: The average Fisher's alpha diversity index per plot in treated (sprayed) plots and untreated (control) plots from 2013-2016. **2013**: t-test, $t_{(7)}$=-0.35, p=0.72, **2014**: t-test, $t_{(6)}$=0.49, p<0.05, **2015**: t-test, $t_{(7)}$=0.50, p<0.05, **2016**: t-test, $t_{(6)}$=-0.21, p=0.8.

<u>The desert ant (*Cataglyphis*) population</u>

Examination of the change in the population size of the *Cataglyphis savignyi* species between the treated and untreated plots reveals extreme differences between years (Figures 7-8). The spring of 2014 saw a significant increase in *Cataglyphis* numbers in treated (sprayed) sites and a more moderate increase in the untreated (control/ unsprayed) sites. In the years prior to the insecticide treatment, the proportion of *Cataglyphis* numbers relative to the total arthropod population was 14.5% (Renan, unpublished). One year post-treatment, the proportion of *Cataglyphis* had increased dramatically to 66% of all arthropod individuals sampled at the treated sites. At the untreated sites there was also a significant increase in the *Cataglyphis* proportion (24%), albeit significantly lower compared to that of the treated sites (Figure 8).

In the spring of 2015, while both the proportion of *Cataglyphis* relative to the overall sample and their total number had decreased sharply at the treated sites, at the untreated sites the upward trend of both proportion and total number continued. In 2015, the differences between both parameters at the treated and untreated sites were considerably reduced. In the spring of 2016, while the size of the *Cataglyphis* population had decreased at both the treated and untreated sites, their proportion had increased relative to the other insects (a reference to this increase can be found in the Discussion in the section on the effect of precipitation on the arthropod community).

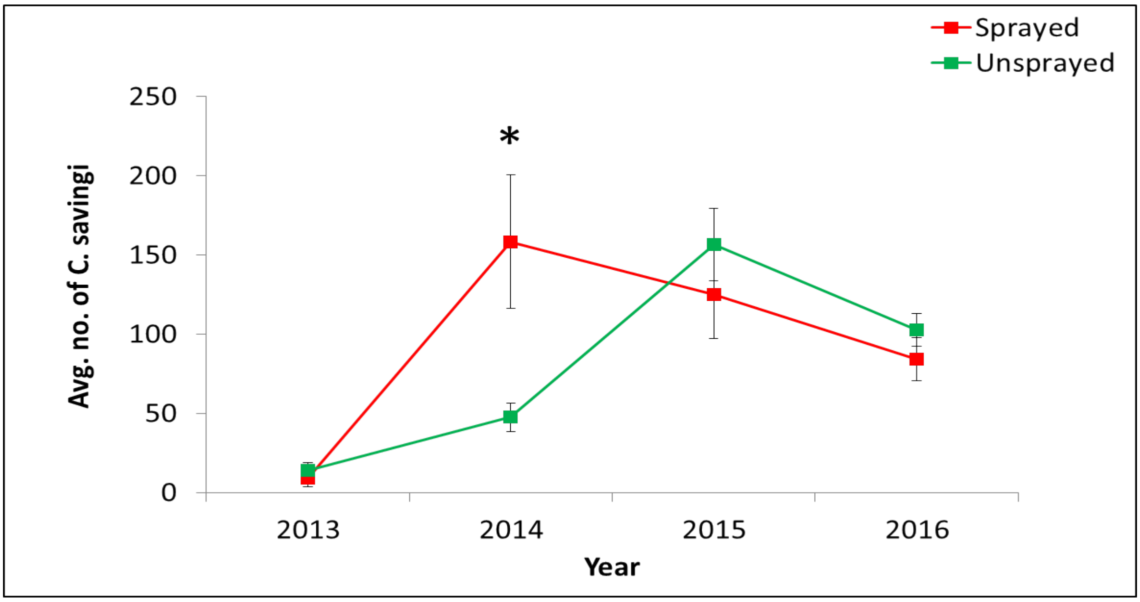

Figure 7: Total desert ant (*Cataglyphis*) numbers in treated (sprayed) plots and untreated (unsprayed)) plots from 2013-2016. **2013**: cox-box transformation, t-test , t=-1.13, p=0.27, **2014**: Mann-Whitney, U=10, p<0.05, **2015**: t-test, t=-0.8, p=0.4, **2016**: t-test, t=-1.08, p=0.2.

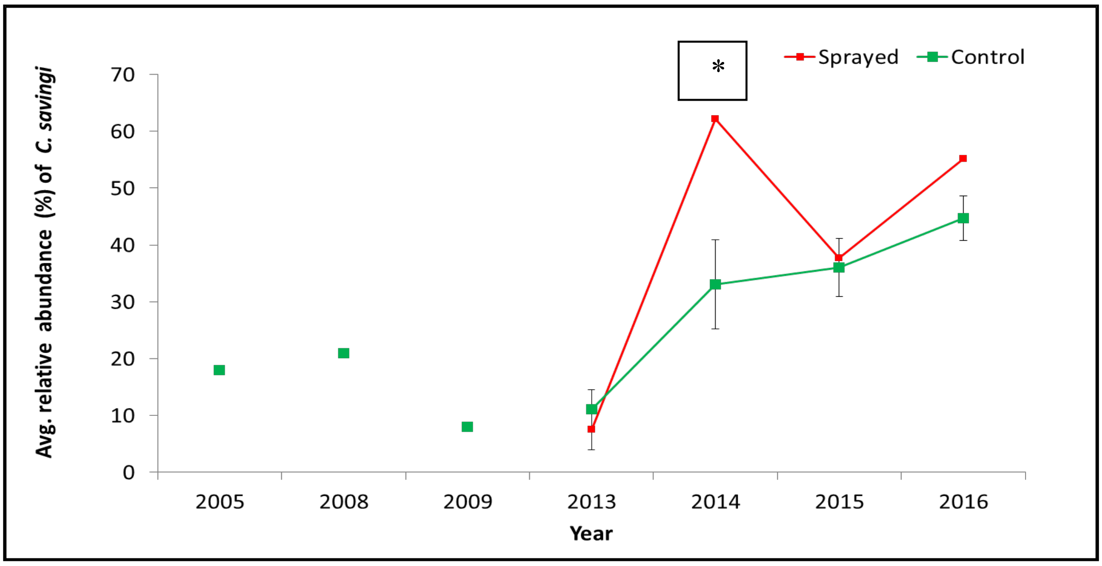

Figure 8: Average proportion of *Cataglyphis savignyi* ants relative to total population in treated (sprayed) plots and untreated (control) plots from 2013-2016 and relative to the years prior to this study.**2013**: Mann-Whithney, U=17, p=0.3, **2014**: t-test, t(8)=2.85, p<0.05, **2015**: t-test, t(8)=0.19, p=0.8, **2016**: Mann-Whithney, U=26, p=0.8.

Discussion

Recovery of the treated sites

During the spring of 2013, two intensive insecticide treatments were carried out in the western Negev sands in Israel. Each treatment period lasted about three weeks, with a two-week interval between treatments. During this period the Naval Lavan river was sprayed with insecticide, sometimes several times a day, using aerial application as well as from trucks. In order to examine the effect of the insecticide on the terrestrial arthropod population, control sites that had not been subjected to insecticide spraying were sampled in parallel to the insecticide-treated sites. The treated sites were located on the banks of the Nahal Lavan river. The control sites were chosen for their close ecological similarity to the treated sites, and served as a basis for comparison of the arthropod population structure at the treated sites. The control sites were especially necessary due to the lack of data on the arthropod population structure in the region prior to insecticide treatment. Each of the various analysis methods conducted revealed a clear and cohesive tendency from 2013-2016 – although at one year post-treatment the arthropod population had clearly suffered harm, by three years post-treatment the population had recovered almost entirely. During those years, the size of the *Cataglyphis* population changed dramatically at the treated site.

Spring of 2014, slight differences between populations

About 50 days post the initial pest-control treatment, only slight differences were found in the arthropod community structures between the treated and untreated sites. Diversity indices were only slightly higher at the untreated sites. Why no significant differences were seen 50 days post-treatment, but only the following year, is as follows: first, sampling was carried out only following the initial pest control treatment, which had focused on adults, and before the consecutive treatment aimed at eradicating nymphs, which was significantly more intense. Consequently, the changes observed in the spring of 2014 resulted from the combined effect of the two spraying events.

Second, even if only a negligible proportion of the arthropod population was lost directly after the treatment period as a consequence of pest control, the reduced contribution to the next generation of arthropods could significantly impact the population a year later. When environmental conditions are optimal (e.g. available food, high temperatures, moist soil) the arthropod population grows rapidly, with each individual contributing many offspring, as indeed is evident at the untreated sites. Although conditions were optimal during the spring of 2013, and the population located at the untreated site prospered, the population located at the treated site was impaired and fewer individuals contributed offspring for the next generation.

Only in the spring of 2014 did the difference between population sizes at the treated and untreated sites increase to such an extent that it became significant.

Site productivity effect

Whereas the number of arthropod species, and also the number of individuals, increased from 2013-2015 at all sites, in 2016 these values decreased at all sites. This trend can be explained by the site productivity, which had increased as a result of an increase in local average precipitation from 2013 to 2014 relative to previous years (Figure 9) as well as optimal rain dispersion during 2015 (Renan, pers. comm.). It should be emphasized that the distribution of rain throughout a season can be even more important than the total amount of precipitation for that season. Three consecutive years in which germination and abundant flowering took place in the sands of the western Negev, led to a gradual and significant increase in the populations of all arthropod species. The increase in the number of such species sampled in 2013-2015 was due to an increase in the populations of "rare" species (with small populations, see Figure 10), which increased the chances of sampling them.

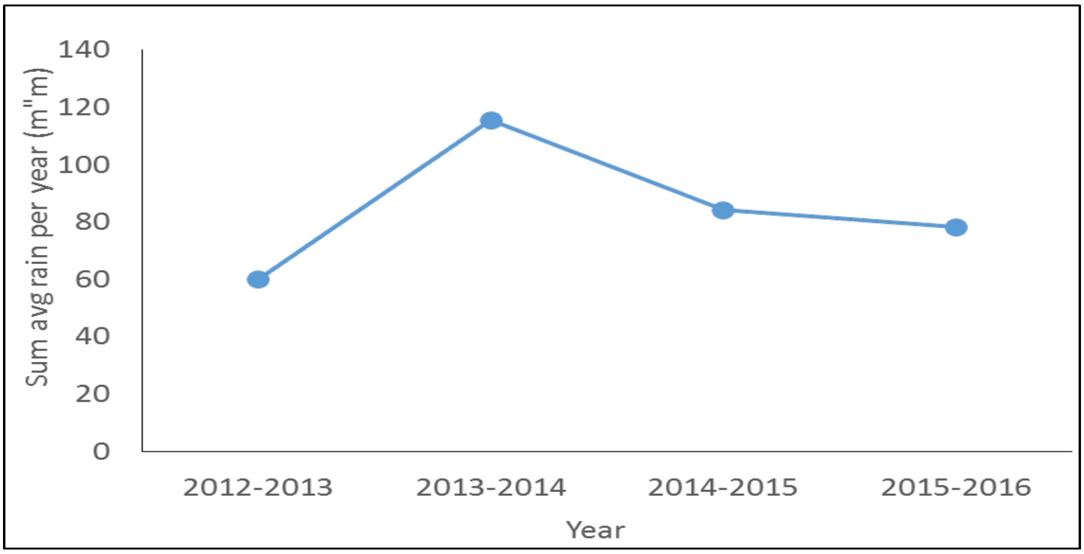

Figure 9: Precipitation in the sampled sites during research years – by winter. Data source: Kadesh-Barnea meteorological station (http://www.meteo.co.il).

Extreme fluctuations in the *Cataglyphis* populations

During the spring 2013 sampling, about 50 days post pest control, the *Cataglyphis* population was only slightly smaller in the untreated site relative to the treated site and their proportion in the overall arthropod population was below the multi-year average. It appears therefore that the treatment had had a relatively marginal effect on the *Cataglyphis* population. The success of *Cataglyphis* in agricultural areas sprayed with insecticide has also been identified in studies conducted in central Israel (Renan, unpublished, Dotan Rotem, pers. comm.).

One year after spraying, in the spring of 2014, the total desert ant (*Cataglyphis*) numbers had increased 3.5-fold at the treated site compared to the untreated site, consisting in 1,227 individuals compared to 333 individuals, respectively, and comprising about two-thirds of all individuals sampled at the treated site. An examination of the data from two previous studies that had been conducted using the same method in the western Negev sands during the spring season, reveals that on average *Cataglyphis* comprise 14.5% of the total terrestrial arthropod population (Renan, 2007; Renan *et al*., 2010). In the spring of 2014, *Cataglyphis* comprised 66% of the total arthropod population at the treated site and 28% at the untreated site. It can thus be concluded that the untreated area had also been affected by the locust events of spring 2013.

The *Cataglyphis* success can be explained by several characteristics of the species: these ants are able to thrive in sprayed areas (for example, agricultural areas) because the reproductive queen is protected in an underground nest and the effect of the insecticide on the nest population is only temporary. As long as there is food available, the queen will continue to lay eggs and the nest population will increase in proportion to the availability of food. The natural mortality of the locusts (thousands of dead adult individuals were observed in the field after laying their eggs, at the openings of rodent burrows and the base of bushes) combined with their mortality following the pest control treatment, created a vast quantity of available food for *Cataglyphis* ants, which feed on insect carcasses. The female *Cataglyphis* are able to exploit even completely dry carcasses as food for the maggots in the nest (Benny Shalmon, pers. comm.); and, consequently, even a year after the appearance of locust swarms there is still a readily available food source. Female *Cataglyphis* are aggressive towards individuals from different neighboring nests. This behavior is one of the factors limiting nest density, as well as *Cataglyphis* population size. However, when food is readily available the nest population grows and, as a result, the queen may leave the nest together with several workers and build a new nest near the original one. In such a case, which may happen several times in the mother nest, a supercolony is formed. Within the supercolony however, aggression between individuals from neighboring nests is virtually non-existent, and the density of individuals in the area may consequently increase significantly (Saar *et al*., 2014). Throughout all the years of our sampling no significant changes were detected in the populations of smaller species of *Cataglyphis,* such as *C. lividus* and *C. albicans*, which apparently, due to their size, are limited in their ability to carry locust carcasses back to the nest.

In the spring of 2015, the *Cataglyphis* population in the treated area dropped sharply. It is assumed that this decrease was due to the consumption of all the edible locust carcasses in the area. Once the ant population became larger than the natural carrying capacity of the area, it was not sustainable without the addition of locust carcasses (whereas in the spring of 2014 many locust carcasses had been observed in the area, no carcasses were observed in the spring of 2015, Renan, pers. comm.). In the 2016 sampling, the *Cataglyphis* population at the treated site continued to decrease, apparently as a result of the continuing adjustment of the population size to the carrying capacity of the area, which continued to decrease that year following a lack of rainfall (see details below) .

We assume that the increase in *Cataglyphis* population size at the untreated site in 2014 had occurred as a result of an increase in carcasses of locusts that had died naturally. It is possible that the relatively moderate increase in population size prevented its collapse following the consumption of all the locust carcasses, and in the spring of 2015 the population continued to grow. The sequence of three relatively rainy years (winters 2012/13 to 2014/15) increased the carrying capacity of the area, as is evident from the general growth of the arthropod population in those years, and enabled a continued growth of the *Cataglyphis* population. Precipitation levels during the winter of 2015/16 however, were relatively low and led to a significant decrease in the carrying capacity of the area, as is evident in the general decrease in the arthropod population size, including the *Cataglyphis* population.

<u>Are the control sites sufficiently similar to draw conclusions regarding the arthropod population in the insecticide-treated sites?</u>

In order to answer our research questions accurately, it is essential in comparative field studies to select control plots that are as ecologically similar as possible to the treated plots. In this study, we chose a close control site about 1 km from the treated site, and which to the best of our knowledge had not been impacted by insecticides. The selection of the control plots was based in this case on two essential characteristics: the degree of dune stabilization; and plant community composition - which to a large extent resembled the treated plots in Nahal Lavan (see photos of all the plots in Appendix 2).

Throughout the study we continued to question whether the ecological characteristics of the control site were sufficiently similar to those of the treated site to enable us to consider its arthropod population a suitable proxy for the intact population in the treated area.

The - positive - answer to this question was obtained in 2016, when the arthropod population in the treated site had mostly recovered. Arthropod species' richness and abundance, together with the sensitivity of many species to environmental conditions, made it possible to clearly identify the level of ecosystem similarity at the different sites. When ecological conditions differ, we would expect to observe several dominant species characterized by large populations only appearing in one of the habitats or, alternatively, to observe a large difference in numbers.

In this study, all the dominant species were sampled at both the treated and untreated sites, with the species that were found to be unique to only one site being, without exception, rare species (by the term "rare species" we refer here to species characterized by naturally small populations). During the four years of our study, we identified 79 species unique to the control site and 65 species unique to the treated site. From the number of individuals sampled from each of these unique species, they appear to be rare species: 71% and 66% of all the unique species sampled at the control site and the treated site, respectively, were represented by only one individual, while 17% and 20% of unique species sampled at the control site and the treated site, respectively, were represented by two individuals (Figure 10).

Hence, the differences observed in the number of species at the control and treated sites during the spring of 2016 do not indicate that these are different habitat types, but rather indicate a low sampling likelihood of rare species whose populations in the treated area are particularly small. When those species characterized by a sparse population were affected by pest control, their population dwindled further, reducing the likelihood of sampling them. Species with small populations recover at a significantly slower rate than species with large populations. Population growth rate in insecticide-impacted areas largely depends on the reproduction rate, and in rare species it may also be influenced by the likelihood of encountering the opposite sex for mating. It should be emphasized that despite the intense sampling effort made, we do not claim to have sampled all the different species present in the field.

The above data substantiate our conclusion that, three years post pest control, the arthropod community in the treated area is at an advanced stage of recovery. However, the abundance values of both individuals and species, which remain slightly higher in the untreated area, indicate that the restoration process is not yet complete and that at least the rare species populations in the treated area are still undergoing recovery. It is thus possible that other (as yet undetermined) factors in the ecosystem have not yet fully recovered, either following direct impact by pest control or indirectly as a result of damage to arthropod functioning within the system.

In addition, it can be assumed that desert species, which are adapted to survival during a succession of dry years and extreme changes in the environment, are also able to cope with an extreme decrease in population size and can re-establish themselves in rainy years.

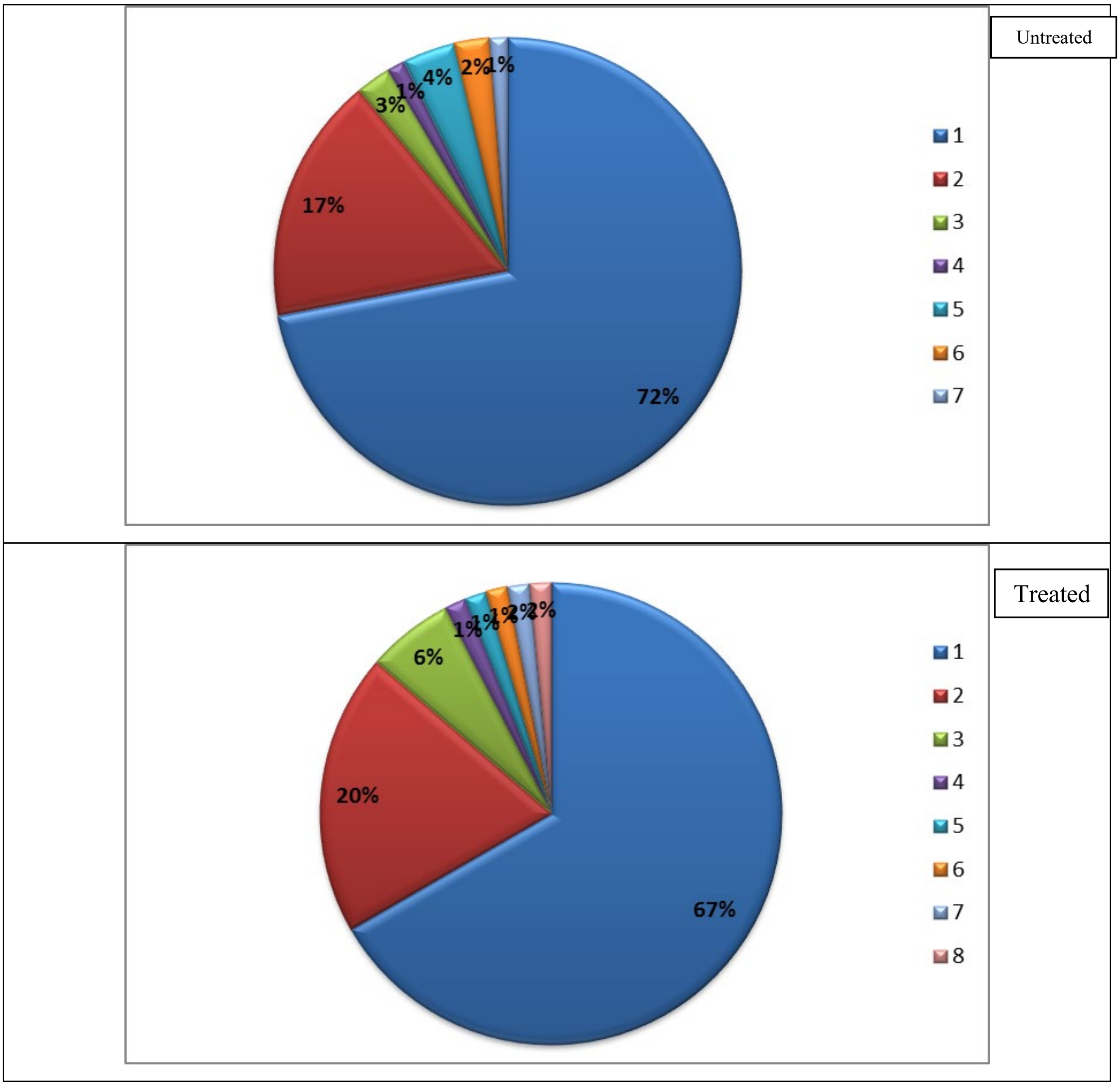

Figure 10: Distribution of the number of individuals sampled from all unique species per treatment.

Summary and Conclusions

This study presents the recovery and rehabilitation process of an arthropod community that was impacted as a result of pest-control treatment carried out in the western Negev sands in the spring of 2013. In the damaged ecosystem, the various recovery processes that took place included a gradual population growth of most of the terrestrial arthropod species; a rapid growth of the *Cataglyphis* population followed by a collapse; and long-term damage to species with small populations. Three years after the significant damage inflicted upon the ecosystem, we found that the arthropod overall population is on a clear path to recovery, which is predicted to continue into the near future.

Due to the significant and complex role of arthropods in desert ecosystems, we conclude that the changes observed in the population structure at the treated site would have affected the entire ecosystem to some degree. Although the full extent of the impact of pest control on the ecosystem is unknown, monitoring the arthropod community enabled us to identify a certain widespread effect.

As concluded from this study, extreme disturbances to the ecosystem, such as chemical pest control, may have long-term effects that are difficult to predict. Consequently, long-term monitoring is crucial to understanding the ecosystem in general, and its functioning following disturbances in particular. In light of this, and due to the clear recovery process, as reflected in the monitoring results, we recommend continuing to monitor the effects of insecticide treatment on the arthropod communities in the western Negev sands over periods of three years.

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Appendix

Appendix 1: Basic data on the insecticide

The insecticide Karate (Syngenta) sprayed on the locust swarms, and conducted by the Ministry of Agriculture, is based on the active ingredient lambda-cyhalothrin, belonging to a class of synthetic insecticides called pyrethroids. These are organic compounds that disrupt the function of the nervous system in insects directly exposed to the substance, causing paralysis and subsequent death (Environmental Health Criteria, 1990). The effectiveness of the substances increases in correlation with outside temperature increase (Toth and Sparks, 1990). The substance degrades in the field within hours or a few days, depending on concentration and climate conditions (Environmental Health Criteria, 1990). Its effect on vertebrates is negligible both following direct exposure to the substance and following ingestion of a large amount of the substance, making direct or secondary poisoning of vertebrates therefore unlikely (Environmental Health Criteria, 1990; Pesticide Tolerances Federal Register, 1998). The insecticide is not only used for pest control but also as an insect repellent (A World Compendium: The Pesticide Manual, 1997).

Appendix 2: Coordinates and photos of the 16 plots on the sampling day in spring 2015.

Plot no.	Location	Coordinates	Photo
1	Untreated	30.945405,34.423647	
2	Untreated	30.944832,34.426375	
3	Untreated	30.931593,34.432506	
4	Untreated	30.944878,34.432414	
5	Untreated	30.944286,34.435814	

6	Untreated	30.944731,34.438907	
7	Untreated	30.945003,34.440698	
8	Untreated	30.945733,34.421880	
9	Treated – Pest control	30.930582,34.429407	
10	Treated – Pest control	30.930961,34.430698	
11	Treated –	30.930981,34.433697	
12	Pest control	30.930980,34.434321	

13	Treated –	30.931047,34.435200	
14	Pest control	30.928673,34.439488	
15	Treated –	30.929593,34.441931	
16	Pest control	30.930712,34.427717	

Appendix 3: Species and genus list for beetles (Coleoptera) identified in this study.

Tenebrionidae	**Carabidae**	**Chrysomelidae**
Adelostoma sp.	*Amara* sp.	*Entomascellis sacra*
Adesmia dilatata	*Atlantomasoreus groneri*	*Chrysolina bicolor*
Adesmia metalica	*Cymindis sp.*	*colaphus palestinus*
Arthrodeis rotundatus	*Colosoma olivery*	**Buprestidae**
Blaps bifurcata	*Discoptera arabica*	*Acmaeoderella maculipennis*
Blaps judaica	*Dromius sp.*	**Coccinellidae**
Blaps nitens	*Graphiterus serrator*	*Coccinela septempunctata*
Catomus acutipennis	*Graphiterus multyguttatus*	*Lithphilus ovipennis*
Catomus sp.	*Heteracantha depressa*	**Anobiidae**
Cyptus aegyptiacus	*Platyderus* sp.	*Pleurophorus anatolicus*
Erodius dejeani	*Microlestes* sp.	*Ptinus variegatus*
Erodios gibbus	*Scarites eurytus*	*Ptinus* sp.
Erodios hebraicus	*Sphodrus leucophthalmus*	**Cryptophagidae**
Erodios puncticollis	**Curculionidae**	*Atomaria gibbula*
Eurycauaus henoni	*Ammocleonus hieroglyphicus*	**Scarabaeidae**
Eutagenia sp.	*Brachiserus spinicollis*	*Aphodius* sp.
Eutagenia cribricollis	*Brachypera isabellina*	*Hemichaetoplia gossypiata*
Gonocephalum sp.	*Borborocoetes sp.*	*Paratriodonta olivieri*
Machlopsiscre crenatocostata	*Conorrhynchus mimosa*	*Pleurophorus anatolicus*
Mesostena angustata	*Conorhynchus palumbus*	*Tropinota squalida*
Omophlus ocularis	*Ceutorhynchus chobauti*	**Glaphyridae**
Pimelia angulata	*Ceutorhynchus sp.*	*Eulasia dilutipennis*
Pimelia bohemi	*Eremiarhinus guyoti*	**Dermastidae**
Pimelia canescens	*Eremobaris picturata*	*Attagenus lobatus*
Pimelia mitteri	*Eremiarhinus* sp.	*Attagenus leprieri*
Pimelia orientalis	*Larinus siculus*	*Attagenus obtusus*
Pimelia theveneti	*Larinus* sp.	*Thorictus foveicollis*
Prionotheca coronata	*Lixus rosenschoeldi* (?)	*Thorictus orientalis*
Pseudoseriscius maculosus	*Lixus nubianus*	
Pterolasia squalida	*Lixus* sp.	
Tenterina orbiculata	*Maximus mimosae*	
Trachyderma philistina	*Porocleonus candidus*	
Thriptera asphaltidis	*Rhytideres plicatus*	
scaurus puncticollis	*Theanellus* sp.	
Scleron sp.	**Elateridae**	
Stenosis sp.	Cardiophorus negevensis	
Trachiderma sp.	*Isidus letourneuxi*	
Zophosis complanata	*Lacon candezei*	
Zothosis pharaonis		
Zophosis punctata		
Zophosis sp.		