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Diversity Analysis of Insects of the Thorn Forest Community at Harappa Archaeological Site, Pakistan

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Abstract.- The present study was conducted to compare the insect diversity of old groves and newly rehabilitated stands of thorn forest community at Harappa archaeological site. A total of 2201 insects belonging to 136 insect species under 14 insect orders were collected from old groves while 1130 insects belonging to 76 insect species under 13 insect orders were collected from a restored site. Different diversity parameters *i.e.*, Shannon index, Simpson index, Hill diversity index and Sorenson similarity index were used to explain the insect diversity at both the sites. Results showed that only the insects belonging to orders Coleoptera and Dermaptera were significantly less in mean species number ($p< 0.05$) at the restored site while all other insect orders showed no significant difference in their mean species numbers between old groves and restored site. Diversity of all the insect orders was significantly less ($p < 0.01$) at the restored site. Termites (Infraorder Isoptera) as a group had the same diversity at both sites. Cluster analysis explained the patterns of insect plant associations. After 12 years of restoration both the sites showed 72% similarity in the insect species composition but it is expected that with the increasing age of the plant community greater habitat and food resources will be available and this will enhance the diversity of insects on the restored site.

Key words: Shannon index, simpson index, cluster analysis, ecological restoration.

INTRODUCTION

Insects are the most diverse group of animals with over a million different identified species and they can be found in every habitat except the sea (Contreras and Vlisidou, 2008). Insects are the dominant component of biodiversity in terrestrial ecosystems and play important roles in ecosystem processes (Weisser and Siemann, 2004). Insects exhibit considerable variations in their season availability, size, trophic level, life history, mobility, strategy and habitats. Insect communities constitute an integral part of terrestrial ecosystems by the diversity of both the species and life forms (Adjaloo *et al.,* 2012). Insects dominate in many food webs and food chain lengths (Sugihara *et al.*, 1997) and have a great importance because of their diversity, ecological roles and influence on the agriculture, natural resources and human health (Foottit and Adler, 2009).

Ecological restoration is a vital tool for management and conservation of the ecosystems present in the world (Burkhalter *et al.,* 2013). The success of land restoration is being evaluated by monitoring the changes in the structure of plant communities. However, because of their short life-cycles and sensitivity to the environmental conditions, insects show a rapid response to the changes created by the restoration management and therefore are considered as better indicators of success of ecosystem restoration (Mortimer *et al.*, 1998). Various studies show the use of insects as indicators of success of ecosystem restoration (Andersen *et al.,* 2003; Babin-Fenske and Anand, 2010; Fernandes *et al.*, 2010; Gould *et al.*, 2013).

The present study aimed at comparing the insect diversity of old groves and a restored site of thorn forest community at Harappa archaeological site. Harappa was the urban centre of ancient Indus valley civilization. The mound still has a cover of threatened original thorn forest community so from conservation point of view it is both an archeologically and biologically important site. The dominant vegetation consists of *Salvadora oleoides* Decne., *Tamarix aphylla* (L.) Karst., *Prosopis cineraria* (L). and *Capparis decidua* (Forsk.) Edgew. These thorn forest species are a major component of Thar Desert, Northwestern Thorn Scrub Forest and Indus Valley Desert eco-regions of Pakistan (Wikramanayake *et al.*, 2001). They are reported to be drought tolerant and salt resistant

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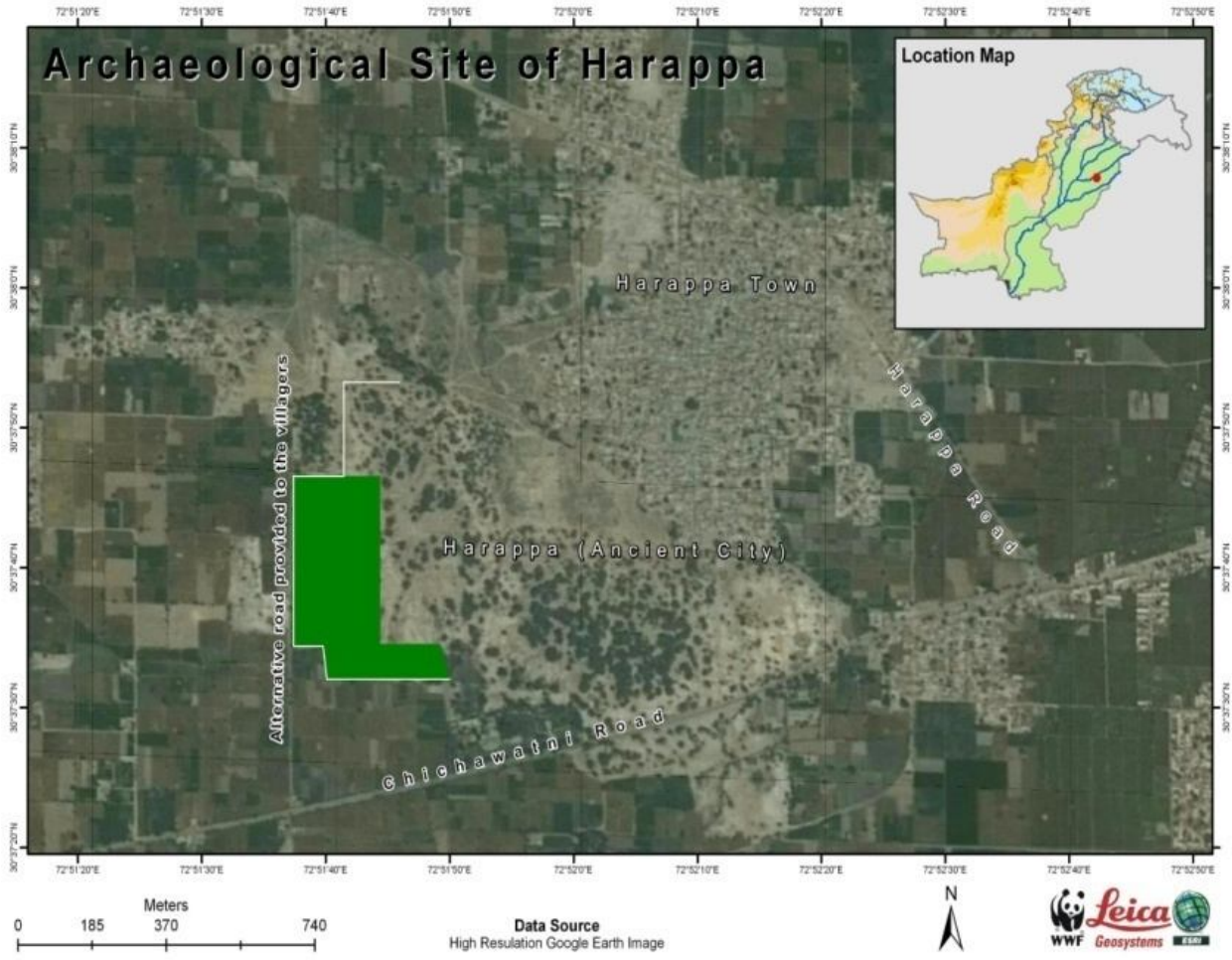

Fig. 1. Site map of Harappa archaeological site showing old groves on the mound and restored site (green shaded area).

(Sharif and Khan, 2009).The age of restored community is only 12 years but the old mound has a thick cover of thorn forest species so it was hypothesized that the former site will have less diversity of insects as compared to latter. The present study was aimed at determining the insect diversity in the old groves and restored site of Harappa.

MATERIALS AND METHODS

Description of study area

Harappa is located beside the former course of River Ravi, in the northeast of Pakistan. Indus valley civilization has its roots in ancient Harappa. Its geological coordinates are 30° 38´North and 72°52´East, respectively. Ancient Harappa is located near the modern Harappa town and is about 165 m high from the sea level (Fig. 1). The climate of Harappa is arid and the summer temperatures extend over 38°C, while the temperatures of winter season range between 10-21°C.

Sampling techniques

Two sampling sites, an old grove (53.4 ha) and a restored site (14.8 ha) of thorn forest community at Harappa mound were selected for studying the insect diversity. Twenty sampling sites of thick vegetation were selected on the old groves while twelve sites were selected on the restored site.

Both sites were sampled monthly for collecting insects for one year. Insect samples were collected in the morning, afternoon and evening. Samples were collected both from the bark and the ground near the vegetation. All the traps were installed for one week per month and then insects were collected from the traps. Frequency of sampling was increased to twice a month during flowering and fruiting seasons.

Insects collection and preservation

For trapping and monitoring a variety of insects different traps were used. For trapping the flying insects, a sweep net (32 cm diameter) was used. The sweep net was swept in an arc at the selected sampling spots. The trapped insects were killed in the killing jar containing ethyl acetate (Wickramasinghe *et al*., 2004).

For the collection of nocturnal flying insects, a bucket type light trap having 60 watt incandescent electric bulb was used. The bottom of bucket was filled with the ethyl acetate (killing agent). The traps were adjusted according to the height of trees at selected spots of both sites (Yahiro and Yano, 1997). For the collection of ground insects, pitfall traps were used. A wide mouth jar of 12 cm deep and 8.5 cm in diameter was introduced in another plastic jar whose bottom was filled with 95% ethylene glycol and few drops of detergent for killing and preservation of insects. On the selected spots of both sites, twenty traps were permanently installed at an interval of 10 feet (Paoletti *et al*., 1999).

The hard bodied insects were pinned in wooden boxes containing naphthalene balls for preservation. Soft bodied insects were preserved in the glass vials containing 70% ethyl alcohol. Insects were identified under the stereo-zoom microscope with the help of available literature and the keys.

Diversity analysis

Shannon-Weaver diversity index (H) was used to find out the diversity of insect species at both sites (Shannon and Weaver, 1963). The proportion of species relative to total number of species (pi) was calculated, and multiplied by natural logarithm of this proportion (ln pi).The results were summed across the species, and multiplied by -1.

$$H = -\Sigma\, p_i \ln p_i$$

Evenness (E) was calculated by dividing H by Hmax

$$E = H/Hmax = H/\ln S$$

where Hmax=ln S

Independent sample t-test was used to compare the diversities of two sites as given by formula (Hutcheson, 1970)

$$t = H^{1`} - H^{2`} / (Var\, H^{1`} + Var\, H^{2`})^{1/2}$$

Simpson index (λ or D) was used to provide important information about rarity (diversity) of species present on the sites (Simpson, 1949) and was calculated as

$$D=\lambda= \sum_{i=1}^{s} p_i^2$$

where pi is calculated by formula

$$pi= ni/N$$

ni shows individuals number of the species i
N shows total number of individuals of all the species

Hill diversity numbers were used to determine the number of abundant species and species which are in maximum abundance present at both sites (Hill, 1973). It was measured by using formula

$$NA= \sum_{i=1}^{s} (pi)^{1/(1-A)}$$

where pi explains the individuals proportion of ith species and A= 0, 1, 2.

The Sorensen's similarity index was used to determine the similarity between two sites. It was measured by formula

$$C_S= 2C/A+B$$

Where C_S explains the coefficient of similarity, C explains common species present in two sites, A and

B explain total species present in sample A and B, respectively (Sorensen, 1948).

For cluster analysis, STATISTICA Ver. 8 (Stat Soft, 2007) was used by analyzing chord distance as a measure of dissimilarity by following Ward's method (Ward, 1963; Sebastian *et al.*, 2005).

RESULTS

In the present study a total of 2201 insects belonging to 136 insect species under 14 insect orders were captured from old mound while 1130 insects belonging to 76 insect species under 13 insect orders were collected from restored site (Tables I, II). Overall the old groves showed high value of Shannon index and low value of Simpson index as compared to the restored site. On the basis of Sorensen similarity index, both sites showed 72% similarity. Insects in the infraorder Isoptera showed highest value of similarity index (100%) followed by the orders Coleoptera (84%), Lepidoptera (76%), Hymenoptera (74%) and Diptera (72%), Dermaptera (72%), Odonata (67%), Hempitera (67%), Neoroptera (67%), Homoptera (67%), Thysonoptera (67%), Orthoptera (60%) and Dictyoptera (60%) (Table I). Regarding mean number of species only the species of Coleoptera and Dermaptera showed significantly less number ($P< 0.05$)on the restored site while all other insect orders showed non-significant difference in their mean species numbers on old groves and restored site (Table II). On the basis of Shannon diversity index, Isoptera showed no significant difference in diversity at both sites while diversity of all other insect species belonging to various orders was significantly higher at old groves (Table III). Results of cluster analysis revealed that *S. oleoides* and *P. cineraria* have similar insect-plant associations while *T. aphylla* and *C. decidua* were found to have different insect-plant associations as compared to *S. oleoides* and *P. cineraria* (Fig. 2).

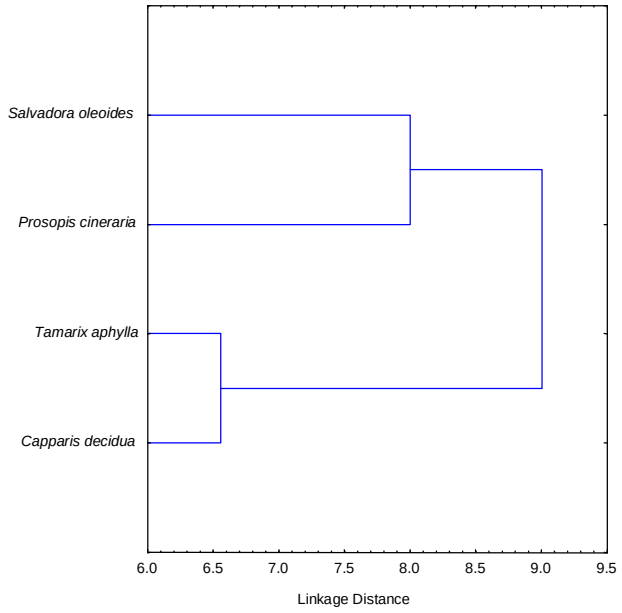

Fig 2. Dendogram showing the relationship of insect plant associations.

DISCUSSION

The present study indicated that overall old groves showed high value of Shannon index which suggested that old groves had high diversity consisting of more number of abundant species(N1= 66) in which 23 species were maximum in abundance as compared to restored site (N1= 30) where only 11 species were maximum in abundance. A low value of Simpson index of old groves as compared to restored site indicated that overall old groves consisted of less rare species because of high diversity on old groves. Due to presence of less rare species on old groves, 85% insect species were evenly distributed on old groves while only 79% insect species showed even distribution on the restored site. The similarity index indicated that both the sites were 72% similar in the distribution of insect fauna and only 28% dissimilarity was left between both sites (Table I). All the insect species present on old groves were well represented on the restored site except the species belonging to order Coleoptera and Dermaptera. The reason for this poor representation and colonization of these insects at restored site could be the presence of sparsely distributed young tree community over there as compared to the thick well established trees present on the mound. Isoptera showed equal diversity and highest similarity index (100%) between both sites while all

Table I .- Comparison of insect diversity old grove and newly rehabilitated thorn forest communities based on different diversity parameters

Insect group (Order or Infraorder)	Community	Abundance	Shannon index	Simpson index	Evenness	Hill diversity numbers		Sorensen similarity index
						N1	N2	
Overall	Old groves	2201	4.185	0.044	0.852	66	23	0.717
	Restored site	1130	3.415	0.091	0.789	30	11	
Coleoptera	Old groves	322	2.967	0.057	0.960	19	18	0.842
	Restored site	153	2.667	0.076	0.962	14	13	
Hymenoptera	Old groves	288	2.866	0.067	0.927	18	15	0.743
	Restored site	115	2.381	0.104	0.928	11	10	
Orthoptera	Old groves	265	2.885	0.063	0.948	18	16	0.600
	Restored site	105	2.165	0.118	0.985	9	8.	
Lepidoptera	Old groves	190	2.566	0.096	0.888	13	10	0.759
	Restored site	87	2.153	0.134	0.898	9	7	
Diptera	Old groves	163	2.666	0.076	0.962	14	13	0.720
	Restored site	79	2.130	0.125	0.969	8	8	
Odonata	Old groves	123	2.016	0.140	0.969	8	7	0.667
	Restored site	44	1.384	0.251	0.999	4	4	
Dictyoptera	Old groves	31	1.871	0.163	0.962	7	6	0.600
	Restored site	9	1.061	0.358	0.966	3	3	
Hemiptera	Old groves	63	1.680	0.204	0.938	5	5	0.667
	Restored site	23	1.006	0.395	0.915	3	3	
Dermaptera	Old groves	31	1.602	0.203	0.995	5	5	0.720
	Restored site	8	0.693	0.500	1.000	2	2	
Neuroptera	Old groves	47	1.337	0.272	0.964	4	4	0.667
	Restored site	17	0.691	0.502	0.998	2	2	
Isoptera	Old groves	611	0.690	0.503	0.995	2	2	1.000
	Restored site	465	0.690	0.503	0.996	2	2	
Homoptera	Old groves	35	0.643	0.549	0.928	2	2	0.667
	Restored site	17	0.000	1.000	-	1	1	
Thysanoptera	Old groves	26	0.690	0.503	0.996	2	2	0.667
	Restored site	8	0.000	1.000	-	1	1	
Collembola	Old groves	6	-	-	-	-	-	-
	Restored site	0	-	-	-	-	-	

Table II.- Comparison between old grove and new rehabilitated thorn forest communities at Harappa archeological site regarding mean number of species in each order.

Insect group (Order or Infraorder)	Site	Species richness	Mean	Standard deviation	Standard error	t-value
Coleoptera	Old groves	22	14.64	7.56	1.61	2.39*
	Restored site	16	9.56	4.52	1.13	
Hymenoptera	Old groves	22	13.09	9.17	1.96	1.51 ^{NS}
	Restored site	13	8.85	5.51	1.53	
Orthoptera	Old groves	21	12.62	7.30	1.59	0.37 ^{NS}
	Restored site	9	11.67	3.08	1.03	
Lepidoptera	Old groves	18	10.56	9.22	2.17	0.85 ^{NS}
	Restored site	11	7.91	5.70	1.72	
Diptera	Old groves	16	10.19	4.87	1.22	0.77 ^{NS}
	Restored site	9	8.78	3.35	1.12	
Odonata	Old groves	8	15.38	5.73	2.03	1.48 ^{NS}
	Restored site	4	11.00	0.82	0.41	
Dictyoptera	Old groves	7	4.43	1.81	0.69	1.26 ^{NS}
	Restored site	3	3.00	1.00	0.58	
Hemiptera	Old groves	6	10.50	5.47	2.23	0.79 ^{NS}
	Restored site	3	7.67	4.04	2.33	
Dermaptera	Old groves	5	6.20	0.84	0.37	3.51*
	Restored site	2	4.00	0.00	0.00	
Neuroptera	Old groves	4	11.75	4.03	2.02	1.07 ^{NS}
	Restored site	2	8.50	0.71	0.50	
Isoptera	Old groves	2	305.50	34.65	24.50	2.42 ^{NS}
	Restored site	2	232.50	24.75	17.50	
Homoptera	Old groves	2	17.50	7.78	5.50	0.05 ^{NS}
	Restored site	1	17.00	-	-	
Thysanoptera	Old groves	2	13.00	1.41	1.00	2.89 ^{NS}
	Restored site	1	8.00	-	-	
Collembola	Old groves	1	6.00	-	-	-
	Restored site	0	-	-	-	

NS, Non-significant (P>0.05); *, Significant (P<0.05)

Table III.- Comparison of Shannon diversity index of insect species present on old groves and restored site of Harappa.

Insect group (Order and Infraorder)	Old groves		Restored site		t-value
	H	Var (H)	H	Var (H)	
Coleoptera	2.967	0.00066	2.667	0.00106	7.23**
Dermaptera	1.602	0.00057	0.693	0.00391	-
Dictyoptera	1.871	0.00278	1.061	0.00182	11.96**
Diptera	2.666	0.00106	2.130	0.00122	11.24**
Hemiptera	1.680	0.00298	1.006	0.00654	6.91**
Homoptera	0.643	0.00252	0.000	0.00000	12.81**
Hymenoptera	2.866	0.00128	2.381	0.00237	8.02**
Isoptera	0.690	0.00001	0.690	0.00001	0.08^{NS}
Lepidoptera	2.566	0.00280	2.153	0.00399	5.01**
Neuroptera	1.337	0.00144	0.691	0.00066	23.18**
Odonata	2.016	0.00082	1.384	0.00029	27.64**
Orthoptera	2.885	0.00096	2.165	0.00039	19.59**
Thysanoptera	0.690	0.00014	0.000	0.00000	-

H = Shannon diversity index, Var (H) = Variance in diversity

other insect species showed significantly less diversity on restored site (Table II). Species of Isoptera *i.e.*, *Microtermes* sp. and *Odontotermes* sp. are the major pests of the four plant species of thorn forest community (Parihar and Singh, 1993; Orwa *et al.,* 2009). As a result of revegetation of restored site, the habitat became uniform with evenly spaced trees and homogenous ground cover that enhanced the development of one giant niche favorable for inhabitation by Isoptera (Crane and Baker, 2011).

Orthoptera and Dictyoptera showed lowest similarity index (60%). All the species of Orthoptera just visit the ecosystem for sake of food and shelter as "Visitors" and come from the nearby agricultural fields on which they act as pests (Rahman, 2001; Ahmed *et al.,* 2004; Sultana and Wagan, 2010; Sultana *et al.,* 2013). The presence of less food and shelter on the restored site could be the reason for the less diversity of these insect species on that site. All the species of Dictyopterans (*Blatella germanica* Linnaeus, *Blattid* sp. and *Periplanata* sp.) are nocturnal and homes, kitchens and sewage systems are their natural habitats (Srinivasan *et al.,* 2005; Fakoorziba *et al.,* 2010). The reason of lower similarity index of Dictyopterans on the restored site could be the greater distance of Harappa village and residential area of Harappa archaeological site from it as compared to the old groves which are closer to residential areas and are more approachable to the insects.

Species of Coleoptera (families Anthicidae, Geotrupidae and Scarabaeidae), species of Dermaptera *Forficula auricularia* Linnaeus and *Labidura riparia* Pallas, species of Hymenoptera belonging to family Formicidae (*Aenictus aratus* and *Formica exsectoides*), species of Diptera belonging to family Calliphoridae (*Calliphora vicina* Linnaeus) and Muscidae (*Anthericona soccata* Rondani, *Musca domestica* Linnaeus and *Chrysomyza demantata* Fabricius) and all the species of Dictyoptera play a vital role as scavengers in thorn forest community. Mulch, ground cover and woody debris provide habitat for other insects and are food for the scavengers (Crane and Baker, 2011). Due to presence of less mulch, less ground cover and less woody debris at the restored site these insect species were less in numbers over there.

Insects in the order Lepidoptera and Hymenoptera include many major pollinators at the sampling sites and the reason for being less in numbers on the restored site is the limited floral display and availability of nectar in the younger restored community. The availability of nest and forage sites are necessary for pollinating insects (Winfree, 2010) and low floral diversity reduces the pollinators' diversity. Plant–pollinator mutualisms are important functional relationships for the long-term success of habitat restoration. But this relationship reinstates only when resource requirements of the pollinators have been fulfilled (Cusser and Goodell, 2013).

Species of Coleoptera belonging to family Coccinellidae, Carabidae, Cicindelidae and Staphylinidae, species of Hymenoptera belonging to family Vespidae (*Polistes flavus* Cresson, *Vespa eumenes* and *Vespa orientals* Linnaeus act as predators in ecosystem. Social insects (*e.g.*, ants and wasps) are voracious predators and can consume large numbers of invertebrate prey (Wardhaugh and Didham, 2004). All the species of Neuroptera (*Ogcogaster tessellata* Westwood, *Osmylus nubeculosus* Navas, *Chrysoperla carnea* Stephens and *Dendroleon* sp.) and species of Odonata play an important predatory role in the ecosystem. Odonata are predators of dipterans *i.e.* mosquitoes (Yanoviak and Hanschu, 1997). But due to less availability of prey, all these insect species were present in less numbers at the restored site. *Haplothrips* sp. and *Thrips* sp. of order Thysanoptera, *Cicadellid* sp. and *Cicadulina bipunctella* Matsumura of Homoptera and *Bagrada hilaris* Burmeister species of Hemiptera are minor pests of thorn forest community. All the species of Orthoptera just visit the forest ecosystem for sake of food and shelter and due to less availability of food and shelter they are less in numbers on the restored site. Collembola (Spring tails) were represented by a single species on old groves while on the restored site it was completely absent. Spring tails are highly sensitive to desiccation and the climate of thorn forest community of Harappa is arid so this could be the reason of the presence of a single species on old groves and its absence on more open and exposed restored site. Moreover, springtails feed on dead decaying plant material (Zeppelini, 2009) and the

reason for its absence from the restored site could be the presence of less leaf litter and mulch at that site. Collembola had only one species which was in very less abundance so diversity analysis was not carried out for this species. Cluster analysis revealed the association of similar insect species with *S. oleoides* and *P. cineraria,* while *C. decidua* and *T. aphylla* had dissimilar insect-plant associations. The reason of having similar insect-plant associations of *S. oleoides* and *P. cineraria* may be that they constitute the climax association of the thorn forest community and have a long history of co-evolution and adaptation (Khan, 2009) therefore they share common insect species (Fig. 2).

The results of the current study showed 72% similarity in the distribution of insect species between the two sites. It is further expected that with the increasing age and complexity of the restored community the vegetation cover will become denser, and this will provide more habitat and food resources to the associated insect species and increasing insect diversity at that site.

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