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Biodiversity of the Aquatic Entomofauna at St. Katherine Protectorate and Wadi Feiran, South Sinai, Egypt

[1]Mohamed M. Tawfik, [2]Fayez M. Semida, [3]Rowaida S. Saleh Ahmed and [4]Gamal M. Orabi

[1]Department of Zoology, Faculty of Science, Port Said University, Port Said, Egypt
[2]Department of Zoology, Faculty of Sciences, Suez Canal University, Ismailia, Egypt
[3]Department of Zoology, Faculty of Science, Suez Canal University, Ismailia, Egypt
[4]Department of Zoology, College of Science, King saud University, P.O. Box 2455, Riyadh, 11451, Kingdom of Saudi Arabia

Corresponding Author: Rowaida S. Saleh Ahmed, Department of Zoology, Faculty of Science, Suez Canal University, Ismailia, Egypt Tel/Fax: 00201000102539/00201000015130

ABSTRACT

Aquatic biodiversity is one of the most essential characteristics of the aquatic ecosystem for maintaining its stability and a means of coping with any environmental change. South Sinai is one of the most ecologically important regions in Egypt. The location of the peninsula of Sinai makes it one of the most characteristic of the Egyptian faunistic regions and it contains very different geomorphological units. It lies at the confluence of three zoogeographic regions (Afrotropical, Palaearctic and Oriental), which makes its fauna and flora special. Twenty nine species, in 24 genera, belonging to 16 families were collected. Species richness, species evenness, Simpson diversity index, Shannon diversity index and species composition were assessed using different statistical methods. There is a high significant difference obtained in aquatic insect's diversity and their richness between the two studied localities. Habitat heterogeneity within a locality may also affect aquatic insects' diversity. The diversity of aquatic insects between natural and artificial pools showed a significant difference in the Simpson diversity index as it was 0.889 for natural pools and was 0.701 in the artificial pools. Also, there is a significant difference in the Shannon diversity index, as it was 2.418 for natural pools and was 1.6 in the artificial pools. Similarity among drainage systems graphed by DCA (detrended correspondences analysis) and cluster analysis showed discrimination of three drainage systems within the locality of Saint Katherine from the remaining two drainage systems within wadi Feiran. Moreover, the Jaccard's similarity index was measured among different localities in the study area.

Key words: South Sinai, St. Katherine protectorate, entomofauna, biodiversity, aquatic insects

INTRODUCTION

Fresh water must be recognized as the blood of society (Wetzel, 2000). Despite the extensive discussion and evolution of human needs for water of reasonable quality, it is essential to know how aquatic ecosystems function to manage them successfully (Sharma *et al*., 2007). Aquatic biodiversity is one of the most essential characteristics of the aquatic ecosystem for maintaining its stability and a means of coping with any environmental change (Sharma *et al*., 2004).

The majority of the 126,000 freshwater animal species are insects (60.4%) (Balian *et al*., 2008). They make up only 3-5% of all insect species, but are very taxonomically diverse (Daly *et al*., 1998). The aquatic insects are an extremely important part of the ecosystem in any body of fresh water. The diversity of insect species is particularly important in aquatic systems due to the large and varied role they play in aquatic food webs, freshwater insects play an important role in ecosystem functioning (Yen and Butcher, 1997). Aquatic insects are also often used to determine water quality. Many aquatic insects of the order Diptera, such as mosquitoes, blackflies and biting midges, are biting pests to both humans and other animals (Daly *et al*., 1998).

South Sinai covers an area of above 70,000 km^2. Most of the interior of the peninsula is bare and rugged, the mountains gradually ascend to the Mount Sinai massif (Saint Katherine mountain), with peaks rising to a height of 2642 m above sea level (m.a.s.l.) (Perevolotsky, 1981). South Sinai consists of different drainage systems made up of a number of connected wadis with very different microclimatic condition (Semida *et al*., 2001). The Saint Katherine protectorate contains one of the most spectacular and resource-rich areas in the Middle East. It includes Egypt's highest mountainous peaks, which support a unique assemblage of high altitude ecosystems with a surprisingly diverse fauna and flora and a relatively high representation of endemic species. It is the only protectorate in Egypt with a sizeable resident population and a significant urban development within its limits, a situation that presents management (Grainger, 2003).

The water resources in Saint Katherine can be classified mainly into two categories: Renewable resources from rain and underground water (Rayan *et al*., 2001). Water supplies are very limited for both wildlife and people. These supplies were traditionally exploited by Bedouins digging wells and require local precipitation for replenishment. Recent tourism development has resulted in a serious depletion of this limited ground-water (Grainger, 2003).

In spite of the considerable attention has recently been given to animals in these areas, the study of aquatic insects in Saint Katherine has received little attention over the years. This study aimed to point out Biodiversity of the aquatic insects as well as to estimate and assess the temporal and spatial biological diversity of aquatic insects in South Sinai. Moreover, the study aimed to investigate the role of different ecological factors such as altitude, water bodie's volumes and human activities on the temporal and spatial distribution of these aquatic insects.

MATERIALS AND METHODS

The Saint Katherine Protectorate extends over virtually the entire mountain massif of southern Sinai, an area of 4350 km^2. It lies in the arid North African belt and is characterized by a Saharan-Mediterranean climate. Saint Katherine's has an arid climate with a mean annual rainfall of about 60 mm $year^{-1}$, compared to 13 mm $year^{-1}$ at El Tor some 50 km away on the western coastal plain. The rainfall is sporadic but usually falls between October and May (Grainger, 2003). The study was conducted in the Saint Katherine protectorate, the drainage systems have been sampled bimonthly from March 2005-2006.The selection of the localities and sites depends upon different issues as the following: (1) the man made pools (artificial sites) or natural pools, (2) the elevation gradient (altitude) from medium range in Wadi Feiran to high range in Saint Katherine and (3) the drainage of the hydrographic basins of the south Sinai considered as important factor in the selection of the sites as the drainage systems receive water from different resources with different properties. The drainage systems were sampled bimonthly from March 2005-2006 at two widely separated localities within the protectorate, Wadi Feiran and

St. Katherine (Fig. 1). The studied localities were represented by five wadis or drainage systems: (1) Wadi Al-Alarbaeen, (2) Wadi Telah and (3) Wadi Gebal, (4) Feiran oasis and (5) Wadi Neddia. The first three wadis are located in Saint Katherine and the last two wadis are located in Wadi Feiran (Fig. 2).

The water was sweeped with a triangular D-framed net. The number of sweeps/pool depends on the water body volume (as one sweep/1 m^3). Identifications were mainly based on available keys; determinations arrived through the use of keys that were compared with correctly identified specimens in the different collections.

Five metrics (simpson diversity index, Shannon diversity index, species richness, species evenness and species composition) were calculated from the aquatic insect's data.

Fig. 1: Sinai Peninsula map showing the study localities; St. Katherine and Wadi Feiran

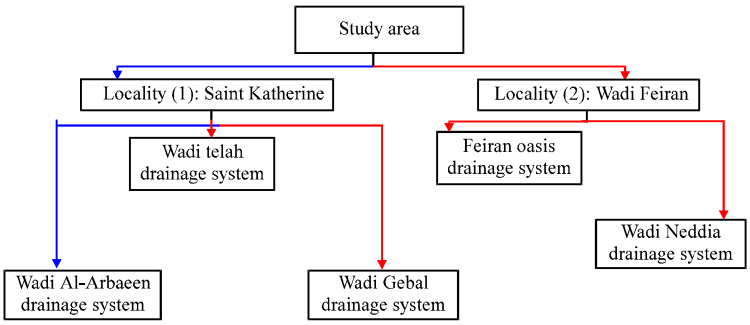

Fig. 2: The studied localities and sites

Species richness: Richness was probably the first measure used for assessing diversity. Counting the number of taxa in the sample under consideration is always the first step. Often richness or an estimate of it is the only measure available for large unexplored regions.

Species evenness: Often the individuals are not evenly distributed among species. A site containing dozens of species may not seem particularly diverse if 99.9% of the individuals belong to the same one species. Evenness is defined as the ratio of observed diversity to maximal possible diversity if all species in a sample were equally abundant.

Shannon's diversity index: The Shannon-weaver diversity index is one of a so called family of heterogeneity indices. These indices do not only take taxa richness into account but also depend on the relative distribution of individuals. The logarithm can be taken to any base but taken to the base of two gives H a special meaning: Bits per species. It is the mean number of binary decisions necessary to determine the taxum of an individual:

$$H = -\sum_{i=1}^{s} P_i \log P_i$$

Simpson's index of diversity: The Simpson's index D also belongs to the class of heterogeneity indices and is a probability measure. Therefore, it ranges between 0 and 1 but it appears in three similar formulations: D, 1-D and 1/D. Each one has its own name but often they all use the symbol D and are called simply called Simpson's index, so attention is advisable at comparisons. In the formulation of 1-D, the Simpson's index of diversity is the probability of encountering two different species when randomly picking two individuals of a sample:

$$D = 1 - \sum_{i=1}^{s} P_i$$

All data were analyzed by using programs; SPSS 11.01 (SPSS, Chicago, IL, USA) and PC_ORD 4.10 (McCune and Mefford, 1999) and differences be estimated at $p<0.05$ (one-way ANOVA).

RESULTS

The adequacy of sampling were represented by species effort curve (Fig. 3) and species/sweep curves (Fig. 4). These curves resulted by plotting the cumulative number of species against the

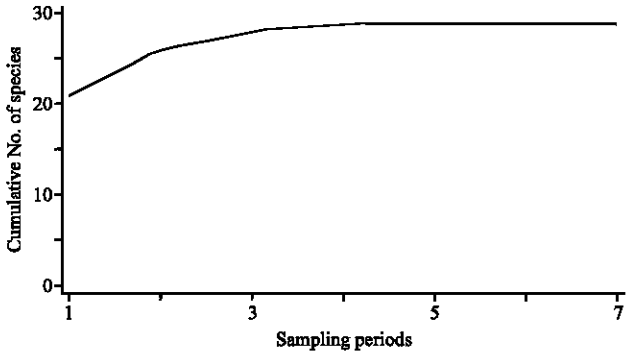

Fig. 3: The species-effort curve

area which have been sampled during the study period. Twenty one species were obtained from the first trip as is clear in the species effort curve then, the curve showed a considerable flattens after the third trip.

Figure 4 clarified all species which collected form pool T1 (13 m^3) in Wadi Telah appeared after the eighth sweep then, the curve showed a level off. That means most of the common species in the study area were sampled.

Twenty nine species in twenty four genera belonging to sixteen familie's included in sex orders were recorded. The variation of the species composition among the five drainage systems shown in Table 1. The overall pattern of aquatic insects' diversity was 0.808±0.02 (Simpson index) and 2.01±0.17 (Shannon index). Species evenness was recorded as 0.727±0.02 while species richness was 29 species.

In the current study there was a highly significant difference obtained in mean values of the aquatic insect's diversity spatially among the five drainage systems, represented Species richness (χ^2 = 13.29, df = 4 and p<0.009) and Abundance (χ^2 = 1138.07, df = 4 and p<0.00001). The global drainage system had the highest value of Species richness(24) and the highest value of abundance recorded in Wadi Al-Arbaeen (1837), while the lowest values were in wadi Neddia as species richness (7) and abundance (286), respectively (Fig. 5, 6). On the contrast hand the spatial variation of Simpson and Shannon diversity indices among the drainage systems showed no significant differences. The highest value of the Simpson diversity index was recorded in

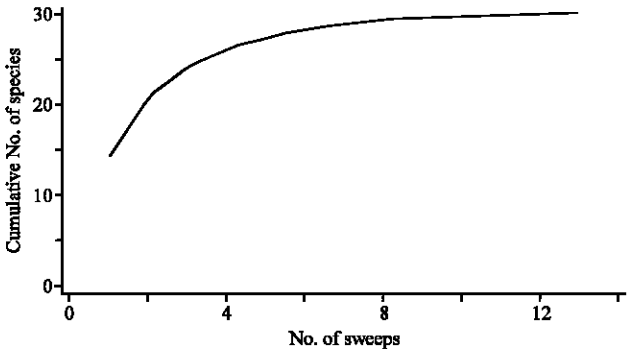

Fig. 4: The species-sweep curve

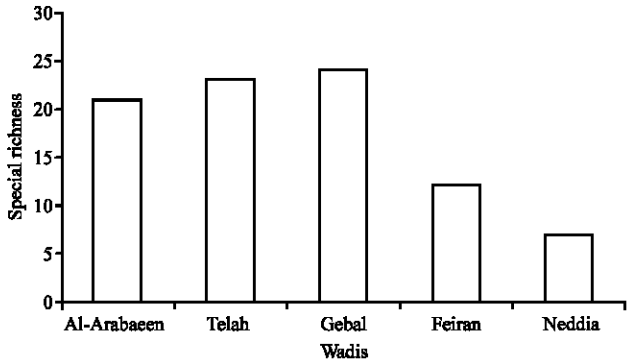

Fig. 5: The spatial variation in species richness among the five wadis drainage systems, (χ^2 = 13.29, df = 4 and p<0.009)

Table 1: The species composition of the five drainage systems

Order	Family	Taxa name	Wadi Al-Arbaeen	Wadi Telah	Wadi Gebal	Feiran Oasis	Wadi Neddia
Ephemeroptera	Caenidae	*Caenis* sp.	-	+	-	++	-
	Baetidae	*Cleon dipterum*	-	-	-	+++	-
Odonata	Coenagrionidae	*Enallagma vansomereni*	+	+	+	-	-
	Aeshnidae	*Anax parthenope*	-	+	++	-	-
	Libellulidae	*Orthetrum ransonneti*	++	++	++	++	+
Hemiptera	Veliidae	*Microvelia popovi*	+++	+++	+++	+++	++
		Microvelia macani	++	++	-	+++	-
	Notonectidae	*Anisops varius*	++	+	++	+	-
		Anisops sardea	+++	++	++	-	-
	Corixidae	*Micronecta Plicata*	++	+	+	-	-
		Micronecta scutellaris	+++	++	+++	-	-
	Naucoridae	*Heleocoris minusculus*	-	-	+++	-	-
Coleoptera	Dytiscidae	*Nebrioporus walkeri*	++	+	+	-	-
Coleoptera		*Nebrioporus insignis*	+	+	++	-	-
		Hygrotus saginatus	++	-	++	-	-
		Hygrotus confluens	-	-	+	-	-
		Eretes sticticus	+	+	-	-	+
		Rhantus includens	++	++	++	-	-
		Hydaticus decorus	-	+	+	-	-
		Derovatellus bisignatus	+	-	+	-	-
	Hydrophilidae	*Laccobius sinuatus*	+	++	+++	++	+
	Hydraenidae	*Octhebius lividipennis*	+	+	+++	-	-
Trichoptera	Limnephilidae	*Limnephilus* sp. 1	+	+	+	-	-
		Limnephilus sp. 2	-	-	++	+	-
Diptera	Tabanidae	*Tabanus autumnalis*	+	+	+	+	-
	Culicidae	*Culex theileri*	-	+++	++	-	++
		Culiseta longiareolata	+++	+	-	++	-
	Chironomidae	*Chironomus* sp.	+++	++	++	+++	++
		Pseudodiamesa sp.	++	++	++	++	++

+: 1-10 individuals, ++: 11-100 individuals, +++: >100 individuals

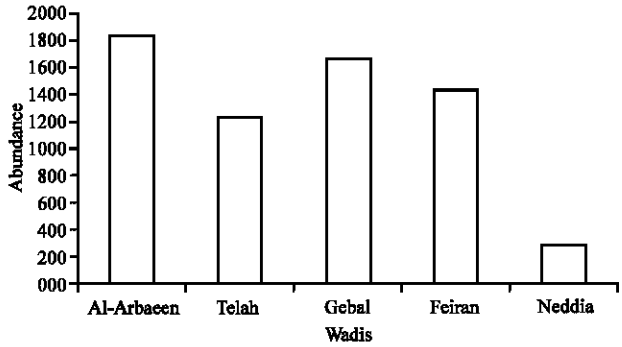

Fig. 6: The spatial variation in abundance among the five wadis drainage systems, (χ^2 = 1138.07, df = 4 and p<0.00001)

Al-Arbaeen drainage systems (0.84) while Neddia had the lowest value (0.7) ($F_{4,21}$ = 1.73 and p>0.1) (Fig. 7). Wadi gebal has the highest value of the Shannon diversity index, recorded (2.5) and Wadi

Neddia was the lowest (1.5). ($F_{4,21}$ = 3.18 and p>0.05) (Fig. 8). Also, the spatial variation of Species Evenness among the drainage systems showed no significant difference ($F_{4,21}$ = 0.20 and p>0.9) as Neddia the highest (0.77), where the lowest is Telah (0.65) (Fig. 9).

The assessment of Habitat heterogeneity's effect on the aquatic insect diversity achieved by studying the differences in the community structure between the natural and artificial habitats

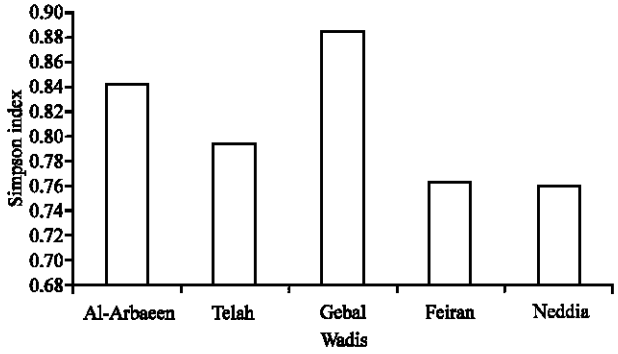

Fig. 7: The spatial variation in Simpson diversity index among the five wadis drainage systems ($F_{4,21}$ = 1.73 and p>0.1)

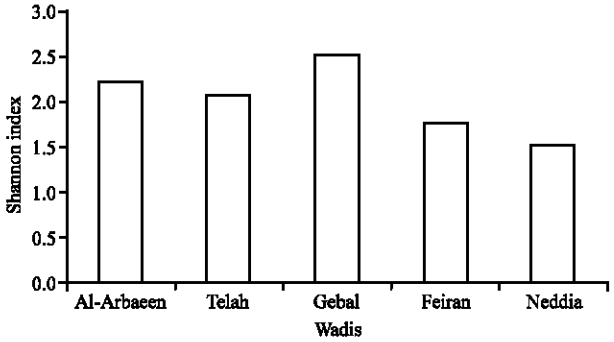

Fig. 8: The spatial variation in Shannon diversity index among the five wadis drainage systems ($F_{4,21}$ = 3.18 and p>0.05)

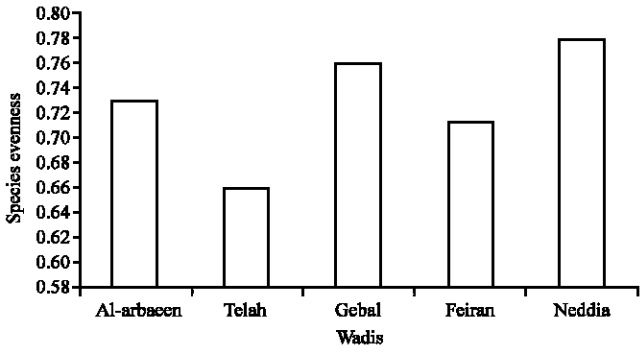

Fig. 9: The spatial variation in species evenness among the five drainage systems ($F_{4,21}$ = 0.20 and p>0.9)

of the studied sites during the study period. This study clarified a highly significant difference represented by the mean values of Simpson ($F_{1.,21} = 5.380$ and $p<0.03$), Shannon ($F_{1.,21} = 8.492$ and $p<0.009$) diversity indices and also the species. ($\chi^2 = 8.20$, df = 1 and $p<0.004$).

Figure 10 illustrates that simpson diversity index at Natural Habitats (0.889) was higher than Artificial ones (0.701). As well as, in Fig. 11 Shannon diversity index at Natural Habitats was (2.418) higher than Artificial ones (1.6). Species richness in Natural Habitats (19 species) was higher than the Artificial Habitats (11 species) (Fig. 12). Table 2 shows the effect of habitat Artificial heterogeneity on species composition of aquatic insect's composition and their abundance.

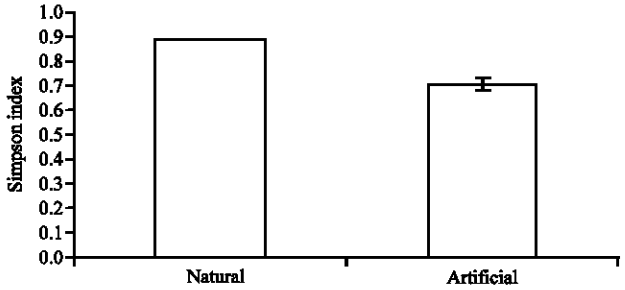

Fig. 10: The difference of Simpson diversity index between the natural and artificial habitats during the period of study ($F_{1.,21} = 5.380$ and $p<0.03$)

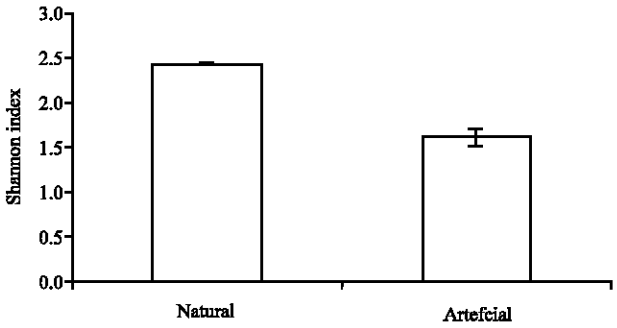

Fig. 11: The difference of Shannon diversity index between the natural and artificial habitats during the period of study ($F_{1.,21} = 8.492$ and $p<0.009$)

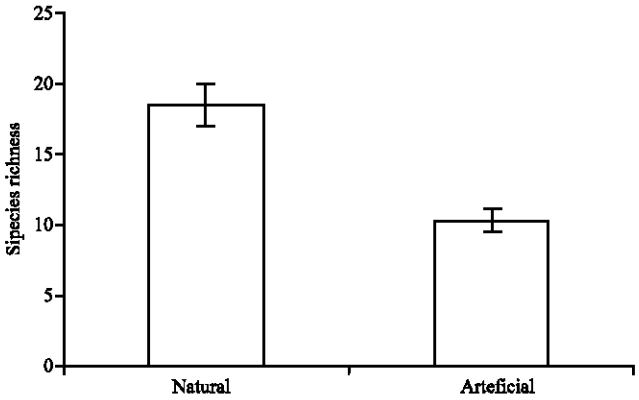

Fig. 12: The difference of species richness between the natural and artificial habitats during the period of study ($\chi^2 = 8.20$, df = 1 and $p<0.004$

Table 2: The effect of habitat heterogeneity on species composition of aquatic insect's composition

Order	Family	Taxa name	Artificial	Natural
Ephemeroptera	Caenidae	*Caenis* sp.	97	0
	Baetidae	*Cloeon dipterum*	293	0
Odonata	Coenagrionidae	*Enallagma vansomereni*	3	9
	Aeshnidae	*Anax parthenope*	9	19
	Libellulidae	*Orthetrum ransonneti*	187	18
Hemiptera	Veliidae	*Microvelia popovi*	1567	131
		Microvelia macani	201	9
	Notonectidae	*Anisops varius*	65	70
		Anisops sardea	90	123
	Corixidae	*Micronecta plicata*	17	18
		Micronecta scutellaris	298	192
	Naucoridae	*Heleocoris minusculus*	125	0
Coleoptera	Dytiscidae	*Nebrioporus walkeri*	4	53
		Nebrioporus insignis	31	40
		Hygrotus saginatus	3	48
		Hygrotus confluens	3	15
		Eretes sticticus	3	2
		Rhantus incl	128	33
		Hydaticus decorus	3	0
		Derovatellus bisignatus	17	8
	Hydrophilidae	*Laccobius sinuatus*	105	106
	Hydraenidae	*Octhebius lividipennis*	285	98
Trichoptera	Limnephilidae	*Limnephilus* sp. 1	15	11
		Limnephilus sp. 2	28	12
Diptera	Tabanidae	*Tabanus autumnalis*	7	0
	Culicidae	*Culex theileri*	350	0
		Culiseta longiareolata	610	0
	Chironomidae	*Chironomus* sp.	484	60
		Pseudodiamesa sp.	259	81

The data matrix was made for the five drainage systems. This matrix depended on species composition at the five drainage systems (Wadis) during the study period. The dendogram showed Fig. 13 illustrates that the outgroup wadi Al-Arbaeen separated on the top of the dendogram. There are node branched out of the base of the outgroup. At this node, two main clades marked as (A) and (B) were recognized. The first clade "A" represented wadi Telah and wadi Gebal. The second clade "B" was assimilated by the remaining drainage systems. This clad comprised two sub-clades marked as "B1" and "B2". The sub-clad "B1" represented Feiran oasis. The sub-clad "B2" represented wadi Neddia.

Figure 14 collected aquatic insects species. The five drainage systems are plotted along axes 1 and 2 and tend to cluster into two groups that resulted from the cluster analysis described before. The three drainage systems which located in Saint Katherine locality, wadi Al-Arbaeen, wadi Telah and wadi Gebal are shown in the first two axis of this ordination near the left-hand end of the first axis, as were the species *Hydaticus decorus*, *Anax parthenope*, *Octhebius lividipennis*, *Nebrioporus insignis*, *Enallagma vansomereni*, *Limnephilus* sp., *Anisops sardea*, *Micronecta scutellaris*, *Micronecta plicata* and *Rhantus includens*, which were mainly found at these sites. Wadi feiran drainage systems, feiran oasis and wadi Neddia lie at the opposite end of the first axis, with there characteristics species *Microvelia popovi*, *Microvelia macani*, *Orthetrum ransonneti*, *Chironomus* sp. and *Caenis* sp.

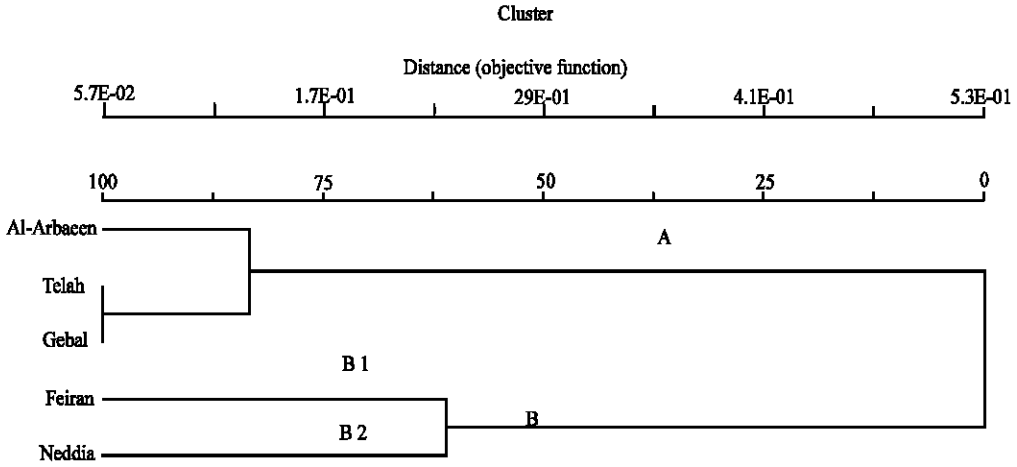

Fig. 13: The cluster dendogram for the five drainage systems depend on species composition during the study period

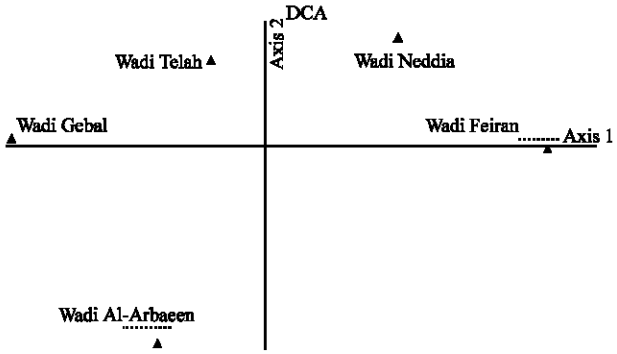

Fig. 14: The DCA of the five drainage systems at the study period

Table 3: The correlation between Simpson, Shannon diversity indices, species evenness, richness and environmental factors (altitude and water body volume)

Biodiversity indices	Altitude	Water body volume
Simpson diversity index	0.537**	0.391
Shannon diversity index	0.625**	0.421
Species evenness	0.167*	0.294
Species richness	0.675**	0.358

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level

As shown in Table 3, Simpson and Shannon diversity indices as well as species richness were significantly positive correlated with altitude. The Jaccard's similarity index was measured among the five drainage systems at the study area given in Table 4. In this table the largest values of similarity indices were between Wadi Telah and Wadi Gebal, recorded (99.4%) and between Wadi Al-Arabein and Wadi Telah, recorded (99%). On the other hand, the lowest values of similarity indices were recorded between Wadi Feiran and Wadi Gebal (97.6%) followed by that between between Wadi Al-Arabein and Wadi Neddia.

Table 4: The Jaccard's similarity index among the five drainage systems

Drainage systems	Al-Arbaeen	Telah	Gebal	Feiran	Neddia
Al-Arbaeen	1	-	-	-	-
Telah	99	1	-	-	-
Gebal	98.8	99.4	1	-	-
Feiran	97.9	98.4	97.6	1	-
Neddia	97.8	98.9	98.2	98	1

DISCUSSION

Species accumulation curves are essential tools for assessing the inventory completeness (e.g., numbers of captures) (Simmons and Voss, 1998). The results were obtained from aquatic insect's species effort curve showed the stability of the population after the third trip and that means the common species were captured which lead to a higher efficiency of the sampling times. (Hammond, 1994).

Shannon-Wiener and Simpson's diversity indices are frequently used to assess the diversity, they make no assumptions about the shape of the underlying abundance distribution of species in the community. Hence, they make no predictions concerning resource allocation or colonization. In addition, dominance indices, such as Simpson's, are unduly influenced by the most common species (Kempton, 1979) and information theory indices, such as Shannon-Wiener, are sensitive to sample size and the presence of rare species (Peet, 1974).

The theory of landscape ecology Risser *et al.* (1984) explains differences in species diversity between localities. This theory has been used to explain differences in species diversity among sites surrounded by different landuse practices (Rundle and Attrill, 1995; Tilghman, 1987). Spatial characteristics or landscape attributes (Baudry, 1989) to be the primary factors determining species diversity.

Differences in species composition reflect differences in their habitat characteristics. Species composition showed a highly variation spatially (between the localities and among the drainage systems as well as, the sites) and also over the time. Species compositions of aquatic insects were varied temporally and spatially and that agree with (Nguyen *et al.*, 2001) who stated that Species compositions of aquatic insects were somewhat different among the sites and community composition is often variable over time.

Many studies have focused on changes in species composition rather than changes in indices of diversity (Clements, 1994; Schindler, 1987), especially with regard to the effects of anthropogenic disturbances. Denslow (1985) has suggested that such antagonistic conditions may have a stronger selective force on community composition that does the physical characteristics of the habitat.

Natural and manmade aquatic ecosystems provide a wide variety of resources that have a social and economic value, calling for more attention on the importance of ecosystems to both people and biodiversity. The aquatic insect's richness and diversity showed highly significant differences between the natural and artificial pools as well as, the taxonomic composition varied between the two different habitats. Knowledge of the condition of the physical habitat is therefore a critical component, as the nature of the local habitat has a profound influence on the structure and organization of biological communities. Mugodo *et al.* (2006) stated information on habitat would also be useful for predicting or assessing the potential distribution of key aquatic organisms, such as macroinvertebrates, based on their habitat requirements. In addition, Ruggiero *et al.* (2008) suggested that because the natural wetlands were absent from the landscape (i.e., no reference conditions), the artificial ponds become so important for the settlement of aquatic communities.

The cluster and DCA analysis separated the five drainage systems in to two groups based on the variability of species presence, indicates that a highly variation in the taxonomic species composition and the studied five drainage systems provide a variety of ecological requirements for these species probably are dissimilar.

Ecologically similar species, which usually are closely related, are most likely to overlap in their critical requirements and resource partitioning is necessary for coexistence. Species will establish unique niches by partitioning resources in many ways; however, niche subdivision is limited and this then governs the number of species able to coexist in an area (Allan, 1995). The single species has numerous realized niches that change both temporally and spatially, so, it is difficult to describe a tight environmental profile for most species (Winget, 1993).

Two main clads were marked from the cluster analysis as Saint Katherine and wadi Feiran localities were recognized. The two localities have different ecological conditions which provide dissimilar eco-regions, each locality has characteristic species with special ecological requirements. Several factors are responsible to provide spatial and temporal heterogeneity in nature. Abiotic factors only or induced by organisms (Pickett *et al*., 2000) have been reported as the main causes to them. Human and natural disturbances are also important sources of heterogeneity in ecosystems, because they alter the structure of environment and the distribution of organisms (Whiter and Harrod, 1997), although, sometimes, human disturbance induces environmental homogeneity (Wiens, 2000).

The measurements of Simpson and Shannon diversity indices as well as Species richness found were significantly positive correlated with Altitude. In many cases the altitude may determine the distribution of aquatic insects since this factor sets the gradient which influences several characteristics of the aquatic environment and therefore the associated fauna (Valladares *et al*., 1990).

The biological diversity, habitat diversity, functional groups diversity and community index are among others, some of the metrics of diagnostic environmental alterations used in evaluation programs of water quality and environmental monitoring (Thorne and Williams, 1997).

CONCLUSION

The species composition and diversity of aquatic insects varied at all the five drainage systems, which demonstrated the effect of altitude and disturbances, as well as the effects of other ecological parameters on insect populations. The different sites had distinct and characteristic groups of aquatic insects responding to altitude and water body volume. Altitude has a great effect on aquatic insect's diversity and appears to have positive correlations with the diversity. Where there is slightly positive correlation between diversity and water body volume. Habitat heterogeneity within a locality may also affect aquatic insects' diversity. The diversity of aquatic insects between natural and artificial pools showed a significant difference in many different parameters.

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