

**QATAR UNIVERSITY**  
**Graduate Studies**  
**College of Arts and Sciences**

**Seasonal Changes in Biodiversity and Abundance of Invertebrates in  
Different Ecological Environments**

A Thesis in  
Department of Biological and Environmental Sciences

By

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Submitted in Partial Fulfillment  
of the Requirements  
for the Degree of  
Master of Science in Environmental Science

June 2013

## THESIS APPROVAL

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## **ABSTRACT**

Biodiversity is a natural quality that must be measured to be understood. It is the measurement of the quantity and diversity of the biota in an area. Each area of the world has its own unique biodiversity as defined by its' species diversity index number (SDIN) including the state of Qatar. This study was designed to add base knowledge of the ground fauna data of Qatar that can be used to compute this species diversity index number. The purpose of this study is to create a baseline of data of the occurrence, dominance, diversity, biomass and seasonal abundance of primarily ground dwelling invertebrates (primarily Arthropods) and to record this in different ecological habitats during ecological seasonal changes in the Northern part of Qatar. This study was conducted on samples obtained weekly from June 2012 through December 2012 in the north of Qatar. Passive pitfall traps were used and placed in three different habitats and a farm site. A total of 4953 specimens were captured. 4468 specimens were member of Class Insecta, 110 different species belonging to 10 orders and 49 families of insects. The most numerous taxa were ants (family Formicidae) 54% followed by family Tenebrionidae (darkling beetles) which is 93.5% of beetles and 28.8% of total catch invertebrate totals. Simpson diversity indexes in the sites differed among the different habitats and generally were high. The total dry biomass of all the insects caught was 226g. The most numerous taxa in terms of biomass were darkling beetles (Tenebrionidae), which made up more than 80%. It is recommended that systematic and long term collection of invertebrates in other areas of Qatar be done and the identification of some of the more difficult species is needed. This is only a beginning of the understanding the invertebrate biodiversity of Qatar. It is much more diverse that anticipated.

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### **Acknowledgment**

We are indebted to D r.Nobuyuki Yamaguchi for assistance and support in the statistical analysis and fieldwork. Dr.Ozeas Costa, for assistance in the statistical analysis, Dr. Ipek Goktepe for serving on my thesis committee, Climate Section at Civil Aviation Authority for providing weather data, Mr. Ahamed Abdelaziz for the photography of the specimens, Ms. Maureen Watson, Ms. Fatima AlKhayat, Ms. Fatma Al-Abdulla, Ms. Muneera AlMesaifri, Dr. Ekhlas Abdulbari, Dr.Nadem Hashim, Dr. Mahmoud Kardousha, Dr. Talaat Abdel-Fattah for assistance and support. Thanks to Dr. Phillip Watson for his continuous support and invaluable help in fieldwork and insects identification.



## **1. Introduction**

Biodiversity is a natural quality that must be measured to be understood. It is the measurement of the quantity and diversity of the biota in an area. Each area of the world has its own unique biodiversity as defined by its' species diversity index number (SDIN) including the state of Qatar. It is this biodiversity or species diversity index number that is used to measure any changes in an area or habitat that may or may not be human caused but that may impact the living biota of that area. To establish a Qatar Biodiversity database that can be used to compute a species diversity index number is a necessary first step to fulfill one of the national priorities according to the National Development Strategy 2011-2016 policy paper ([http://www.gsdp.gov.qa/gsdp\\_vision/docs/NDS\\_EN.pdf](http://www.gsdp.gov.qa/gsdp_vision/docs/NDS_EN.pdf)). This policy which among its many goals is the creating and establishment of a comprehensive physical and digital national biodiversity database that can be accessed as needed for evaluation purposes. This study was designed to add base knowledge of the ground fauna data of Qatar that can be used to compute this species diversity index number. The State of Qatar is the Qatari Peninsula that is geographically situated between 50°45' -51°40' E longitude and 24°27' -26°10' N latitude and is an extension of the Arabian Peninsula (Abushama, 1997 and 1999) into the Arabian Gulf. It is classified as arid subtropical (Abdu & Shaumar, 1985), characterized by very hot summers and mild (moderately warm) winters. The mean minimum temperature can reach 12°C in December and January and 42°C or higher in June, July and August. Rainfall is low and averages 77.4mm/annum (Abushama, 1999).

The Qatari peninsula is dry almost all the year (Abushama, 1999) and therefore the vegetation is known as restricted (by water) type (Batanouny, 1986). Invertebrate fauna in Qatar was believed to form the greater part of animal biomass (Abushama, 1999). Abdu & Shaumar (1985) sampled several areas of Qatar and published a list of 170 insect species in 154 genera, belonging to 63 families and pertaining to 15 orders. However, the descriptions regarding the ecology and abundance of invertebrates (arthropods) fauna and their biodiversity in Qatar is scarce and no systematic collection or biomass data was obtained (Abushama, 1997, 99). Abushama, (1999) did find that the Tenebrionidae beetle (darkling beetle) Adesmia cancellata L. and the Thysanuran (silverfish) Thermobia sp. recorded the highest dominance value in the samples but the sample size was quite small and limited in range. This dominance value computed however was not computed into species diversity or biomass accumulations.

The purpose of this study is to create a baseline of data of the occurrence, dominance, diversity, biomass and seasonal abundance of primarily ground dwelling invertebrates (primarily Arthropods) and to record this in different ecological habitats during ecological seasonal changes in the Northern part of Qatar. An additional purpose of study data is also to show the occurrence, abundance and biomass of arthropods in different ecosystems over time and different temperature fluctuations from the hot summer to the cooler winter months. These arthropods assemblages are also theorized to form the base of food chain and believed to be important to other organism development and life habits such as lizards and hedgehogs.

The term biodiversity can be defined by various things, and has many specific definitions (Jones and Laughlin, 2009) in many different aspects, according to (Reaka-Kudia, Wilson and Wilson, 1997). In this study, the working definition of biodiversity or the species diversity index number is the occurrence and abundance of ground dwelling invertebrate species and computed using the Simpson's (1948) equation for species diversity. This evaluation will be done in four different habitats which are defined by their presence or absence of vegetation.

Qatar's Biodiversity is considered as a part of Qatar's heritage and partial key to its biological future (NDS 2011-2016). The protection of Qatar's Biodiversity is therefore a part of Qatar National Vision 2030. Protection and conservation of Qatar's Biodiversity requires that the species diversity index number (SDIN) be known. Once known, this SPIN can be used to monitor the Qatar various environments for protection and preservation of its biological diversity (Qatar National Vision 2030) ([http://www.gsdp.gov.qa/portal/page/portal/gsdp\\_en/qatar\\_national\\_vision](http://www.gsdp.gov.qa/portal/page/portal/gsdp_en/qatar_national_vision)).

In general biodiversity information provides a researcher with an idea of the habitat in terms of stability. The higher the biodiversity value, the more stable and natural the habitat is considered. Biodiversity information can also have a predictive value as it may indicate over time if interactions are stable, increasing or decreasing which may for example prevent species overpopulation (Reaka-Kudia, Wilson and Wilson, 1997). Also, with knowledge of species diversity index and a base line of data, the relative abundance of unique contributors to a habitat can be monitored. Some of these unique contributors include some Coleopteran's families such as Scarabaeidae and Tenebrionidae which are valuable as scavengers and play a significant role in food web (Wilson, 2010). Moreover, the existence of many different but poorly

known species can be monitored which may keep the ecosystem functioning. Each species no matter how small may have a unique but unknown and important function or role in the habitat or ecosystem. However for Qatar to protect a resource or heritage, Qatar must have baseline knowledge in terms of its biodiversity. This study is a beginning of that base knowledge.

Biodiversity or Species diversity may also be measured at different scales. These are three indices used by ecologists to measure diversity: Alpha diversity refers to diversity within a particular area, community or ecosystem, and is measured by counting the number of taxa ( usually species )within the ecosystem ,Beta diversity is species diversity between ecosystems; this involves comparing the number of taxa that are unique to each of the ecosystems. Gamma diversity is the overall diversity for different ecosystems within a region ([http://en.wikipedia.org/wiki/M Measurement\\_of\\_biodiversity](http://en.wikipedia.org/wiki/M Measurement_of_biodiversity)).

In this study, Alpha diversity was determined as the base data of the area.

Invertebrates, mainly insects are often used in biodiversity studies due to the fact that they are the most abundant organism in most environments and that over a million species of arthropods have been described to date (STORK, N.E. 1988) This study was done to measure the terrestrial species diversity in Qatar in three different habitats weekly and over a series of months. The different habitats were defined by the presence or absence of vegetation. The quantitative assessment of species diversity at the ecosystem, habitat or community level consists of two distinct components: *species richness* or the number of different species (or genera, families, etc.) And *species abundance* or how many of each species exist in the sample. Both the species richness and abundance are important for biodiversity calculation.

## **2. Literature review**

In terms of collecting insects for biodiversity studies in the desert environments, various methods have been used. (Abdu & Shaumar, 1985) used different types of traps e.g. insect nets, aspirators, bait traps in various environments, covering the desert, wadis, plains, gardens, farms and water in Qatar. The authors published a list of 170 insect species in 154 genera, belonging to 63 families and pertaining to 15 orders. (Abushama, 1997) conducted diurnal sampling at different habitats of the Qatari desert by using wooden quadrates (m<sup>2</sup>) measurements, by hand and sweep-nets. The unfocused collections of invertebrates does not allow for quantification of presence or diversity of invertebrates.

To increase the reliability of trapping of invertebrate (Aldryhim et al., 1992) used pitfall traps to study the distribution of darkling beetles (Family Tenebrionidae) in Saudi Arabia. In further pitfall traps, the abundance and diversity of the beetles were significantly greater in uncultivated sites than that in the cultivated sites. (Faragalla & Adam, 1985) used pitfall traps to monitor darkling beetles populations (typically saprophagous) and ground beetles (Family Carabidae) (typically predators) occurrence and abundance activity in different habitats in Saudi Arabia. Results showed that darkling populations far exceeded ground beetle populations in the study. The seasonal abundance of both families decreased severely with the beginning of cold weather (Dec-Jan), gradually increasing and reaching its highest activity and abundance during the hot weather (April-May). However no species diversity calculations were determined by any of the above studies.

Using invertebrates as monitors of ecosystem function was used by (Forbes et al. 2005) who sampled arthropods living in shrub species and perennial grasses in Chihuahuan Desert grassland (USA-Mexico). Arthropod species richness was higher in the grass areas than in the shrub species. (X.R. Li *et al.*, 2011) examined in the Tengger Desert in China found that the species richness and abundance (nest density) of ants were closely associated with soil moisture, as well as topsoil temperature. (Bang and Faeth, 2011) arthropod communities in three urban habitat categories were collected and compared to arthropods in natural desert using pitfall traps in the Central Arizona USA. The results showed that the natural desert habitats had a higher diversity than urban habitats. (Roig-Juñent *et al.*, 2001) the study focuses on insect biodiversity at five natural areas in Monte Desert of Argentina. The findings indicate that the area with the highest diversity was the desert areas with the longest history of non disturbance. Due to the large diversity of invertebrate many authors use specific insects as monitors such as (Latif *et al.*, 2009) arthropod biodiversity in the Brinjal field in Bangladesh was observed over seven months, by using different collection methods including pitfall traps with the ants (Formicidae) comprised 67% of the total surface dwelling predaceous arthropod in terms of abundance . In contrast (Shalhaf *et al.*, 2012) found insect biodiversity, species richness and evenness in Karkheh Wild Life Refuge, SW Iran consisted of a total of 2207 specimens belong to 100 species, 47 families and 13 orders of insects were collected with the Coleoptera being the most diverse and abundant with 32 species. Determining biomass in terms of insect specimens has been determined by (Gilbert, 2011) and (Sample, 1993) who used both length and dry weight to calculate insect dry weight.

The references above indicate that arthropods form the bulk of the animal biomass in all environments which includes the Qatari desert. Also the use of insects as a biodiversity measurement is well established. In addition, beetles and the ants tend to be the dominant invertebrate found. Also pitfall traps are very commonly used for determining occurrence and abundance. However, there is no systematic evaluation of the diversity and biomass of insects in Qatar.

### **3. Materials and methods**

#### **3.1. Study site**

This study was conducted on samples obtained weekly from June 2012 through December 2012 in the north of Qatar Fig. 1a, sample sites were located close to Qatar University farm near Rawdat Al Faras in Qatar lying between 25°48'.069-25° 48'.899 North and 051° 20'.25-051°19'.616 East. Thirty-four sample sites were selected based upon presence or absence of vegetation Fig. 1b. Thirty sample sites were at least 50 meters away from other adjacent sampling sites to avoid trap interference. These sites were more than 100 meter from the University Farm. Foot shaped structure represents the Rawdat Al Faras Research Station farm. No samples were taken from within the managed vegetation represented on the map by dark square and rectangles. The first sets of four sample sites were at the university farm Fig.1c. They were chosen to represent arthropod diversity within a human managed vegetation (farm) zone.

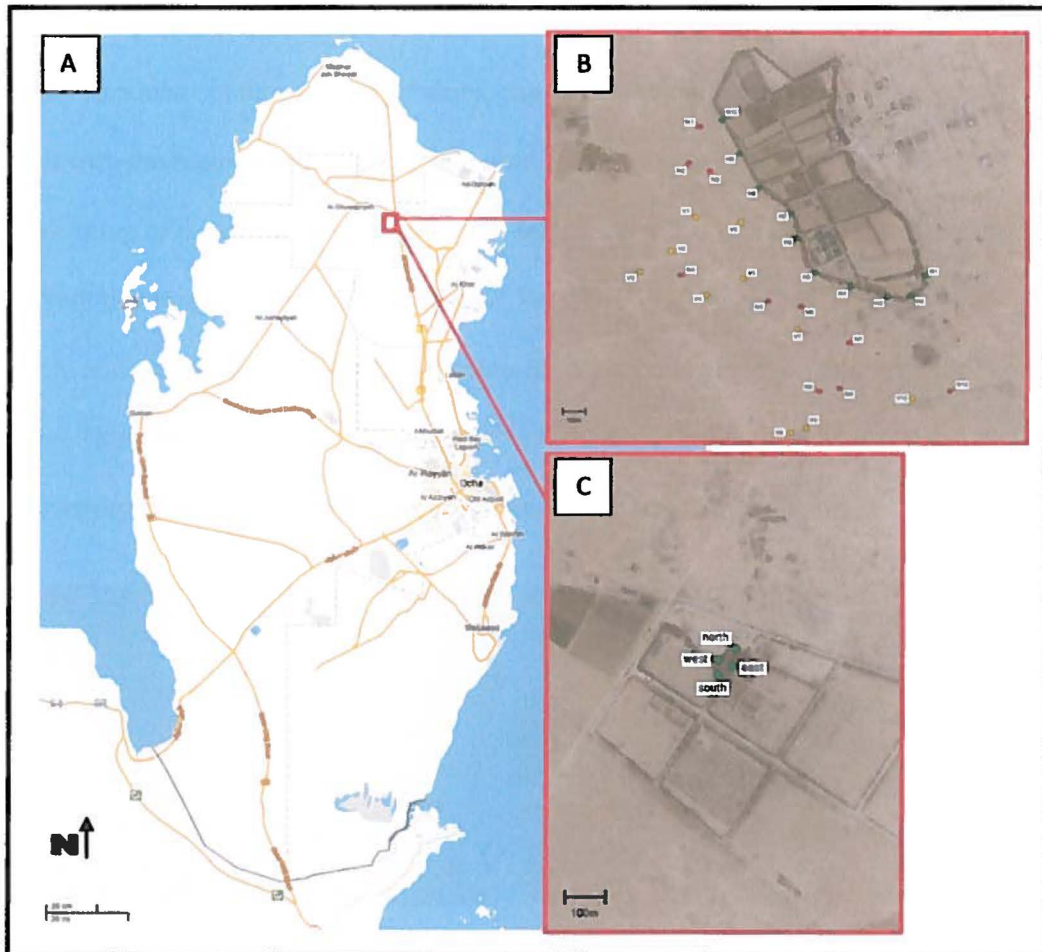


Fig.1. Map of the State of Qatar Showing the study area. (Source Google Maps).

### 3.2. Sampling techniques

Ground Arthropods in three different habitats and a farm site Fig. 2 were sampled using passive pitfall traps Fig.3. Passive pitfall traps are traps buried in the soil at ground level without any attractant. Thirty-four pitfall traps consisting of a plastic jars (Sunpet "All purpose containers" Sun Packing System) with a total volume of 400 ml were placed at each of the sites and the contained filled with 100ml of with ethylene glycol or vehicle coolant (Prestone brand pre-diluted radiator coolant). The pitfall traps were kept at ground level or with rims flush with soil surface, each trap has a plastic screw top cap. One half of the flat part of the lid was cut to allow arthropods



to fall into the trap but to prevent larger animal access to the coolant liquid. The pitfall trap also contained a plastic drink cup (First1 brand disposable plastic cups 6oz) with the bottom end cut away and used as a funnel to further restrict the consuming of the coolant solution by non-target animals such as vertebrates and to prevent the escape of trapped arthropods. Four farm traps were placed in east, west, north, and south cardinal directions within the human managed in Qatar university farm. Thirty additional traps were placed in three different habitats near Qatar University farm according to presence or absence of permanent plants.

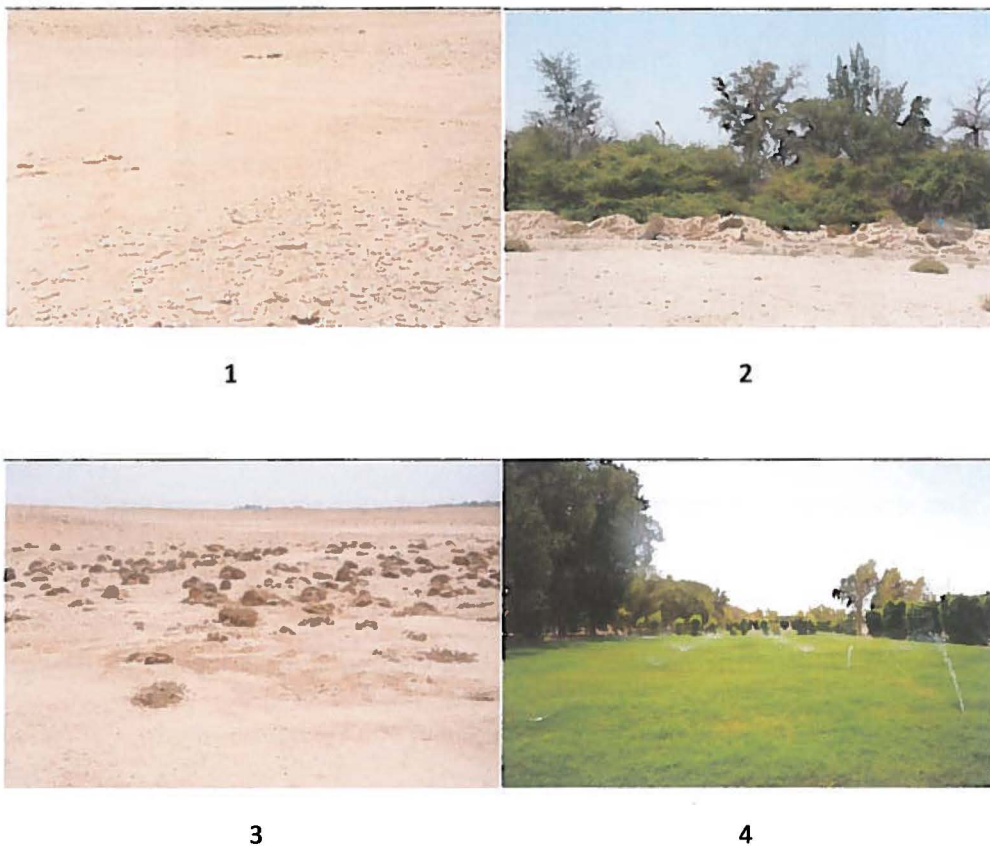


Fig. 2 Study sampling sites 1-No-vegetation (N); 2-Hedge rows (H); 3-Vegetation (V); 4-Farm (F).



**Fig. 3. Pitfall traps used in the study showing the cut lid, the cup funnel and placement in the ground.**

Ten traps were placed in hedge rows habitat (H) that was located outside of the Rawdat Al Faras Research Station farm. These traps were at the outward edge of the hedge row which formed the non planted vegetation perimeter of the farm. Ten additional traps were in isolated vegetation habitat (V) and were in areas of scattered natural vegetation. These represented habitats that were sparsely occupied by drought tolerant plants. The last ten traps were located in no-vegetation habitat (N). These were areas where no vegetation was evident within a 50 meter radius Fig.4. All traps

were serviced once a week that included emptying the traps of the arthropods ,storing the specimen in numbered vials and topping up the coolant to the 100ml mark of the trap which may have been reduced due to evaporation. The use of the coolant was due to the ability of the liquid to remain liquid even in high temperature, its low evaporation rate and its ability to preserve arthropods that fall into the traps. The traps were emptied each week and were returned to the Qatar University lab C104 (Men’s Campus) for handling and processing.

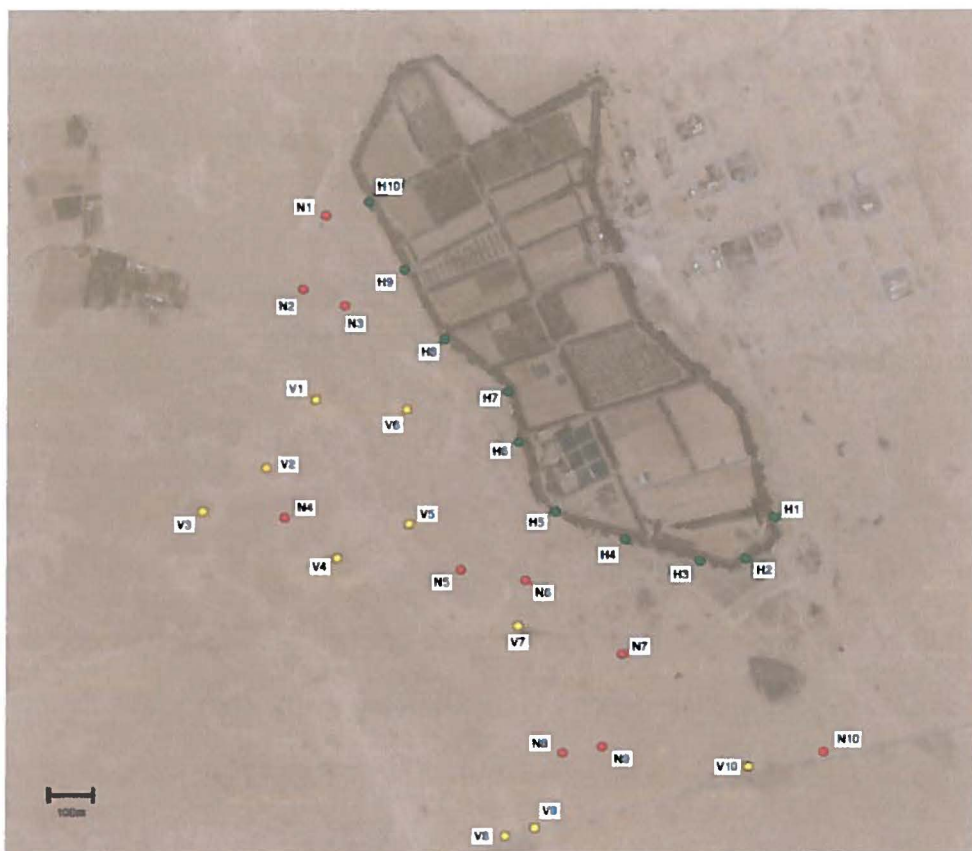


Fig.4. Sampling sites around the Rawdat Al Faras Research Station. Pitfall traps in three different habitat: hedge (H: green circles), vegetation patch (V: yellow circles) and area with no vegetation (N: red circles).

Handling and processing included emptying the traps contents and noting the quantity weight and identity of the invertebrates found in the trap. Some of the insects were pinned the insects or stored in 70% alcohol if they were small insects or multiple duplicates of pinned specimens and other invertebrates. All of the specimens that were collected were preserved, including some small reptiles and other organisms. Data was collected on an excel sheet with all available data organized for data analysis. For each unique collected specimen a number was given. Each unique number served as a Type specimen for the study. In biology, a Type is one particular specimen of an organism to which the scientific name of that organism is attached and is used as a reference for subsequent identifications. (International Commission on Zoological Nomenclature).

Adult insects were identified to the most specific name possible. Some identification was to species, genus, and family level or at least to order level. Arthropods were measured and weighted by using balance Sartorius type (Sartorius handy) for weight, and caliper for length measurements (General 6 inch dial caliper) and the data collected on a excel sheet. Identification of specimens was helped by but not exclusively using taxonomic keys (Soldati 2009, Arthropod Fauna of UAE 2008 Vol.1-4, White 1983, Slater and Baranowski 1978, Borror and White 1970, and Borror and DeLong 1971). First identified insects were used as initial types (study Types) in identification process. Reptiles were divided based on visual characteristics (morphology). All Types and duplicates collected during this study will be available for future study by either the author of this thesis or other researcher who wish to understand the arthropod diversity or identification of the crawling arthropods of

Qatar. Type specimens and duplicate will be stored in the Qatar University Department of Biological and Environmental Sciences Zoological Museum.

### **3.3. Statistical Analysis**

Statistical analyses were performed using Bio-Diversity Pro version 2, Exeter Software vers.5.1, and Primer-E version6 to calculate species richness (d), evenness (J') and diversity index. Simpson's (1-D) species diversity calculation is based upon the number of species (species richness) multiplied by the number in each species (species abundance) and is a numerical value from 0 to 1 number where 0 = no diversity and 1.0 = perfect diversity. The equation used is below

$$D = 1 - \left( \frac{\sum n(n-1)}{N(N-1)} \right)$$

Where N= Total number of individuals of all species

n= Number of individuals of a species

D = Diversity index

The equation is also commonly computed without the 1 - ( ) and the resultant D is then reported as D-1.

### **4. Results**

This study results are from June to December 2012 collections. A total of 4953 specimens were captured. 4468 specimens were member of Class Insecta, 110 different species belonging to 10 orders and 49 families of insects (see appendix plate 1). Non insects collected were 132 specimens and member of class Arachnida and

belonged to 3 orders; Araneae (spiders), Scorpionida (scorpions), and Solpugida (wind scorpions) (Plate2). There were also 143 members of the order Isopoda (Plate3a) of class Malacostraca (sow bug/ wood louse) and 35 specimens were member of Class Gastropoda belonging to one order; Stylommatophora (snails) (Plate3b). In addition 17 specimens were member of Class Chilopoda (Centipedes) (Plate4). There were 73 specimens captured from the Class Reptilia, related to order Squamata (scaled reptiles) which includes the spiny tailed lizard (Dhub) commonly found in Qatar (Plate5). The specimens were collected, identified, labeled, weighted, measurement taken and prepared for storage. The data was recorded on excel sheets with all of the data coded for analysis. Temperature and moisture data was also added that was provided by Climate Section, Department of Meteorology, Civil Aviation Authority on a weekly average basis. The data was analyzed by a variety of software programs to produce the following data analysis:

1. Species abundance per trap per week
2. Number of species per trap per week
3. Species diversity per trap per week

#### **4.1. Number of species and species richness**

Fig. 5 below summarize all the data of all sites and all months, shows the number of species (error bars =range of species richness over time).

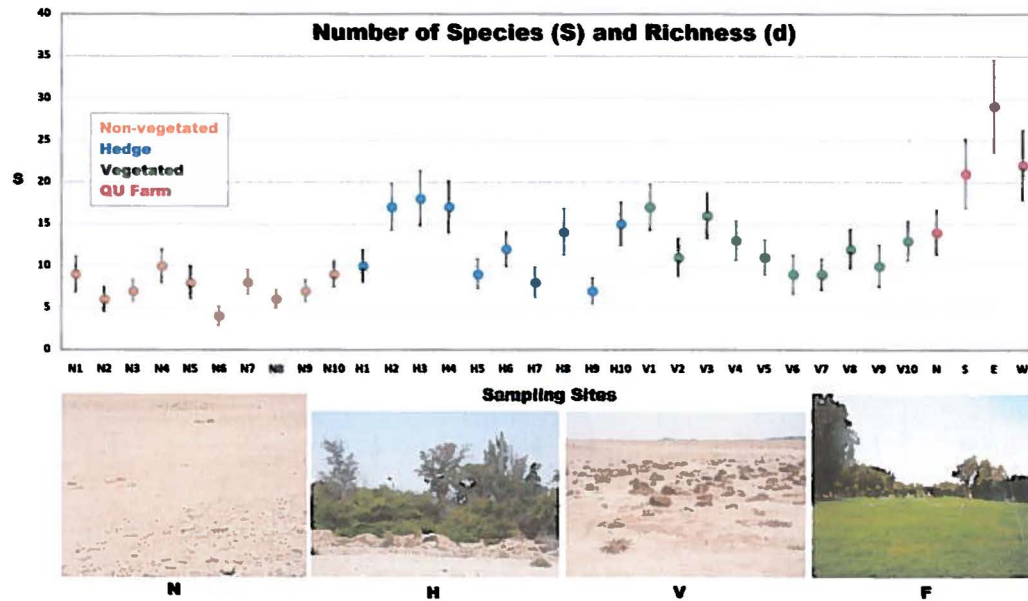


Fig. 5 Number of species (S) and richness (d) of all sampling sites during the study period.

In Fig. 4 the 34 studied sites for the sampling period are an indication of community structure within and between the four different habitats which are vegetated (V), non-vegetated(N), hedge(H), and farm(F)). The highest numbers of species (S) and the highest number of species richness (d) were found in the QU farm (F) sites with the highest number of species (S=29, d=5.4709), while the lowest number of species and species richness were found in non-vegetated (N) sites (S=4, d=1.1368) . In the hedge sites (H) number of species ranged from 17 to 18 and species richness ranged from d= 2.78 to 3.24.

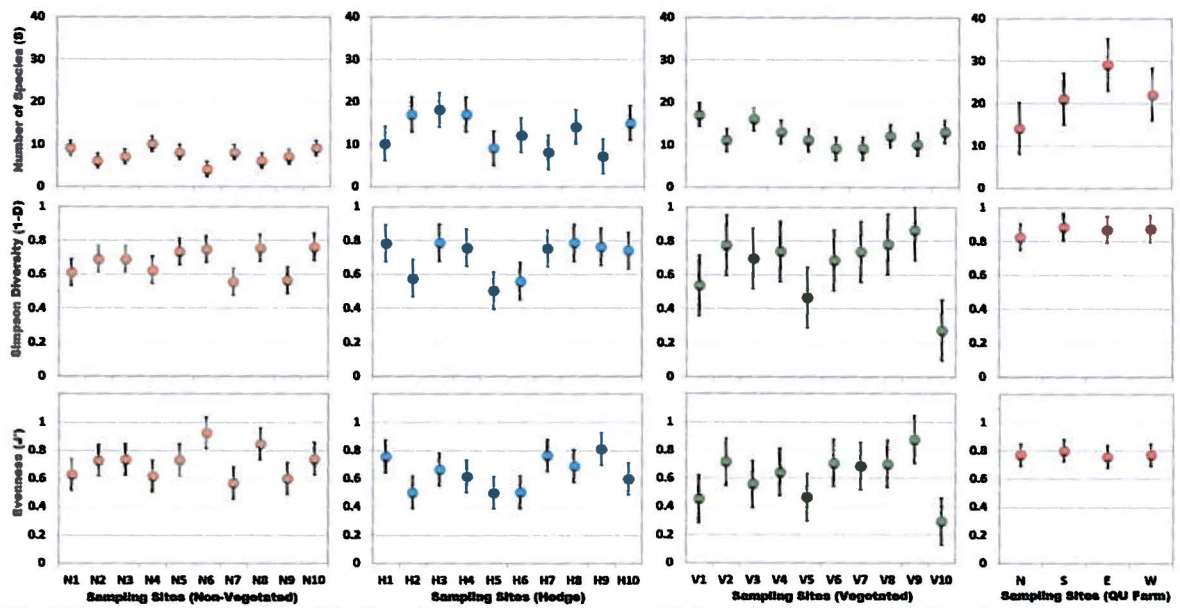


Fig.6 Total number of species (S), diversity (1-D) and evenness (J') based on data for sampling sites

during the study period.

#### 4.2. Biodiversity and Simpson diversity

The biodiversity measurement used was the Simpson's biodiversity index Fig. 6 showed that the most diverse habitat was QU farm (F) ( $1-D=.88394$ ), followed by of the isolated vegetated sites (V)( $1-D=0.86516$ ) The least diverse was (V10) of the vegetated habitat ( $1-D=.26997$ ). In terms of the diversity index most of the sample sites in the different habitats represent high values of diversity.



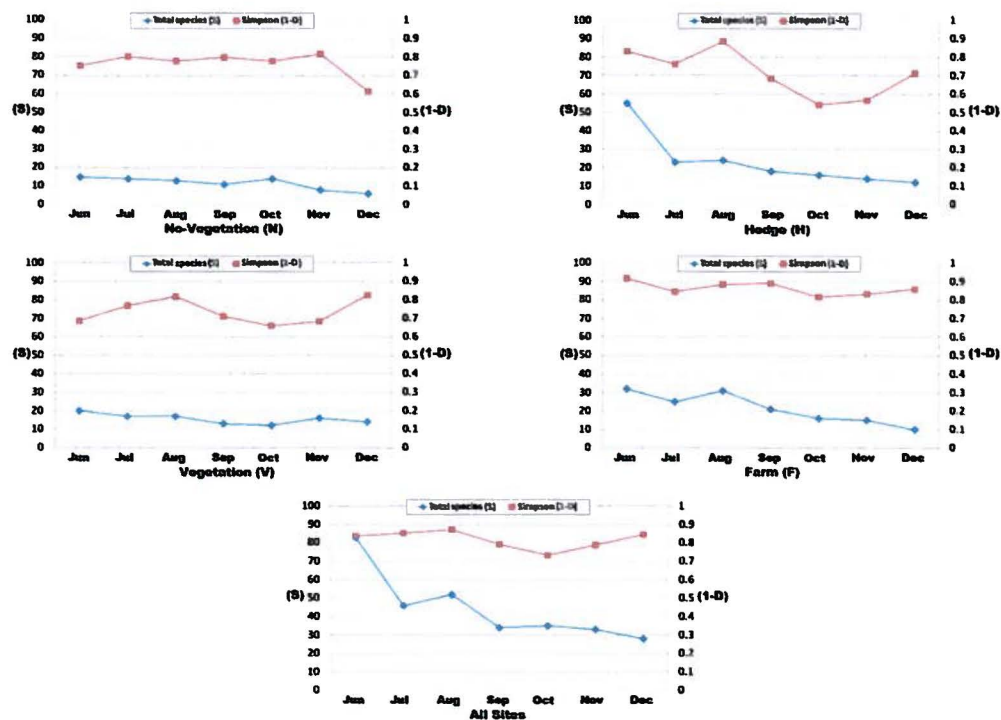


Fig.7 Total species (S) and Simpson diversity (1-D) in different traps types (N, H, V, and F) and in the all sites.

### 4.3. Simpson diversity index per time

Simpson diversity indexes in the sites differed among the different habitats Fig. 7 and generally were high which means that there is a good diversity (high number diversity). The most diverse trap type was in QU farm traps during the month June ( $1-D=0.918$  total species,  $S=32$ ), while the least diversity trap type was in hedge traps during October ( $1-D=0.543$ ,  $S=16$ ). Further there was variation in species diversity within the different traps types. In the hedge traps during June, the highest number of species was 55, In the no-vegetated traps the lowest number of species was 6 during November and December respectively and had the lowest number of species of all of

the traps during the study period. On the other hand the hedge traps showed the lowest species diversity during the entire seven month comparing to the other traps types.

The ranges of the Simpson's diversity in the locations and between the months within locations sampled at the 95% significant differences levels were quite variable (See Table 1 for details).

#### **4.4. Species diversity differences between months at same locations**

The no-vegetation (N) traps were significantly different among themselves between July and August, but during September and December they were not significant different. H traps: The Simpson's species diversity differences for all of the trapping periods. V traps: The Simpson's species diversity differences between vegetation traps were significantly different in the most of the study period, F traps: Diversity between most of farm traps was significantly different, except between June traps and between October and November traps where it was not significantly different.

Table1: Species diversity in pitfall traps in Qatar in June to December 2012.

Month	Trap Type	Total Insects	Total Species	Simpson's Diversity	95%
June	N	185	15	0.753	.726-.782
	H	656	55	0.83	.811-.848
	v	755	20	0.686	.662-.709
	farm	182	32	0.918	.905-.930
	all traps	1778	83	0.838	.829-.847
July	N	160	14	0.803	.772-.830
	H	220	23	0.762	.714-.807
	V	284	17	0.768	.741-.793
	farm	155	25	0.845	.809-.877
	all traps	815	46	0.854	.840-.866
August	N	229	13	0.779	.743-.789
	H	214	24	0.885	.803-.861
	V	256	17	0.817	.792-839
	farm	172	31	0.885	.861-.905
	all traps	1127	52	0.873	.862-.882
September	N	118	11	0.798	.76-8.29
	H	124	18	0.684	.604-.756
	V	252	13	0.711	.659-.755
	farm	55	21	0.89	.844-.924
	all traps	549	34	0.792	.766-.815
October	N	145	14	0.779	.742-.812
	H	131	16	0.543	.456-.627
	V	135	12	0.66	.59-.722
	farm	65	16	0.817	.756-.866
	all traps	476	35	0.7321	.698-.761
November	N	36	8	0.818	.748-.867
	H	63	14	0.568	.439-.686
	V	129	16	0.684	.611-.748
	farm	48	15	0.833	.75-893
	all traps	276	33	0.788	.750-822
December	N	15	6	0.613	.362-.79
	H	70	12	0.714	.645-.774
	V	81	14	0.826	.796-.853
	farm	22	10	0.861	.766-.918
	all traps	188	28	0.846	.823-.867

#### **4.5. Species diversity among traps**

Referring to (Table 1) in June, the species diversity index (1-D) was not significantly different any of the traps types. In July, species diversity index was significantly different between (N) no-vegetation and between (H) hedge traps, (V) vegetation traps, and (F) farm traps. Also it was significantly different between (H) hedge traps and (V) vegetation traps. In August, species diversity index was significantly different between (N) no-vegetation traps and between (H) hedge and (V) vegetation traps. Also it was significantly different between (H) hedge traps and between (V) vegetation and (F) farm traps. In September, species diversity index was significantly different only between (H) hedge traps and (V) vegetation traps. In October, the species diversity index was significantly different only between (N) no-vegetation traps and (F) farm traps, and also between (H) hedge traps and (V) vegetation traps. In November, the species diversity index was significantly different between (N) no-vegetation traps and between (V) vegetation and (F) farm traps. Moreover, between (H) hedge traps and (V) vegetation traps. Finally in December, species diversity index was significantly different between (N) no-vegetation traps and between (H) hedge and (F) farm traps. In addition, it was significantly different between (H) hedge traps and (F) farm traps, and between (V) vegetation traps and (F) farm traps.

#### **4.6. Biodiversity and Temperature and Moisture**

The total number of all organisms was plotted against temperature and humidity records. Table 2 below indicates the relationship between all traps and all insects caught in reference to humidity and temperature.

Table 2: Relationship of the temperature and moistures to number of insects caught in the traps.

	Temperature (°C)	Relative Humidity (%)	All Insects
JUN	34.5	34.8	1592.0
JUL	35.9	43.5	757.0
AUG	35.6	50.7	761.0
SEP	32.6	53.0	505.0
OCT	29.1	56.7	412.0
NOV	24.0	64.2	240.0
DEC	19.3	72.8	168.0
Correlation	0.703	-0.917	

There was a positive correlation (0.703) between temperature and abundance of all insects in the traps but a negative correlation (-.917) between relative humidity and abundance Fig. 8.

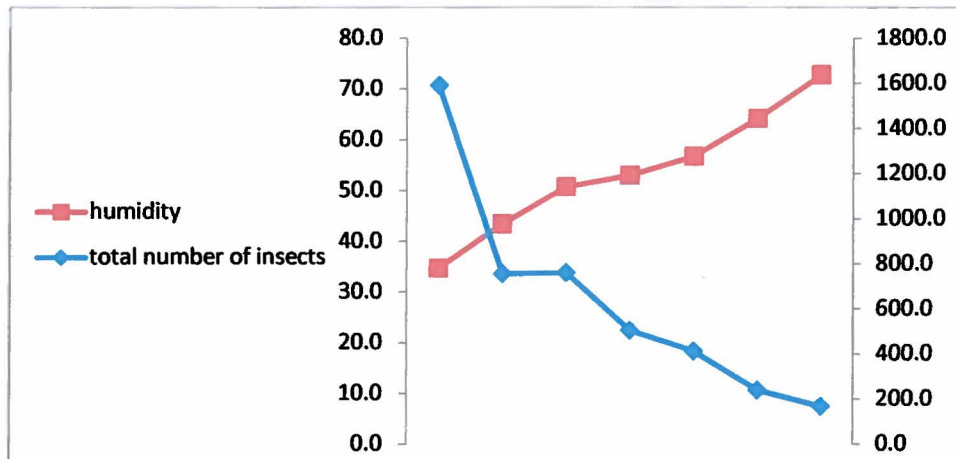


Fig. 8 Total number of all found insects against the average of humidity.

In a similar way there was a unique relationship between the two most numerous found families of the ants (Formicidae) and the darkling beetles (Tenebrionidae) and the air temperature °C relative humidity % Fig. 9 and Fig. 10. As the air temperature °C decreased the number of ants and beetles individuals decreased, further, while the relative humidity increased during the study period, the number of ants and beetles individuals (abundance) decreased. In addition there was a positive correlation

between ants and beetles with temperature (0.637 and 0.79) respectively, and a negative correlation between ants and beetles with humidity (-0.892 and -0.907) respectively Table 3.

Table 3: Correlation between the two abundance families with the air temperature and relative humidity.

	Temperature (°C)	Relative Humidity (%)	Tenebrionidae	Formicidae
JUN	34.5	34.8	513	931
JUL	35.9	43.5	291	403
AUG	35.6	50.7	341	373
SEP	32.6	53.0	161	322
OCT	29.1	56.7	61	329
NOV	24.0	64.2	29	187
DEC	19.3	72.8	31	117
correlation Tenebrionidae with Temperature			0.790280235	
Tenebrionidae with Humidity			-0.907127915	
Formicidae with Temperature				0.63762392
Formicidae with Humidity				-0.8923342

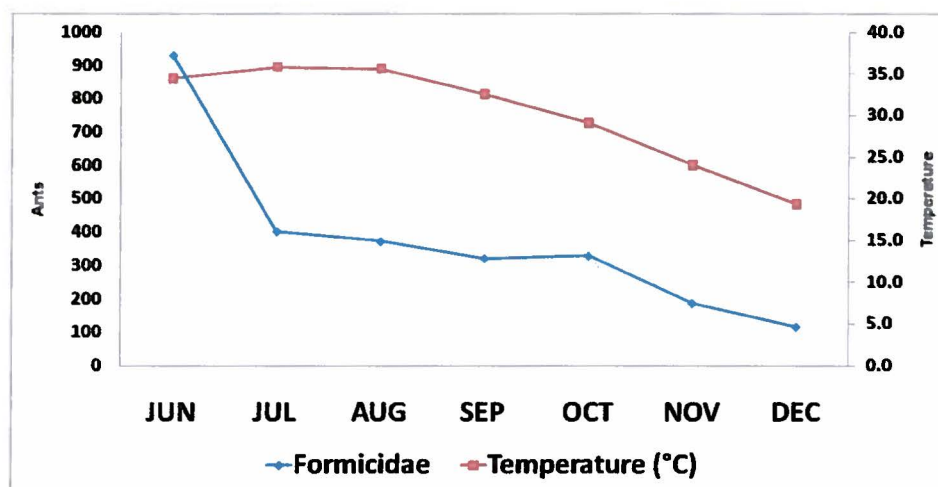


Fig. 9 Number of class Formicidae (ants) against the average of temperature.

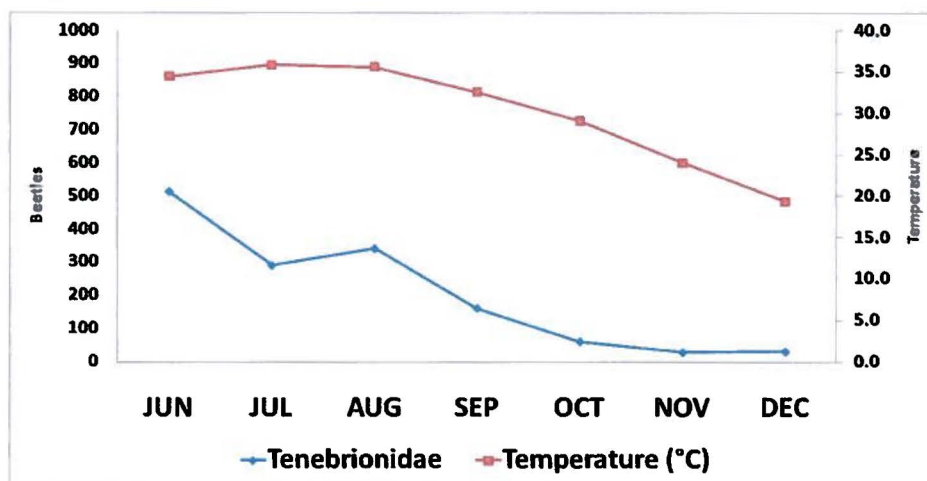


Fig.10 Number of family Tenebrionidae (beetles) against the average of temperature.

#### 4.7. Cluster analysis of data (Similarity analysis)

Hierarchical agglomerative clustering based on Bray-Curtis similarity matrices (Bray and Curtis, 1957) were used to compare the community composition between the different habitats. Multidimensional scaling (MDS) was the chosen method of ordination (Clarke and Green, 1988). Formal significance-test differences between sites (34) and habitats (4) were performed using the analysis of similarity randomization test (ANOSIM) described in Clarke and Green (1988). The results of the analysis are summarized in Fig. 11.

The differences in community patterns (diversity and abundance) between the 34 sampling sites generated four major clusters at a 53% similarity threshold. MDS ordination revealed significant differences in community structure between QU farm sites and the non-vegetated sites, as well as considerable overlap between hedge and vegetated sites Fig. 10. The cluster analysis also revealed that the patterns of diversity

and abundance at sites N6, V10, and H2 are significantly different than those observed at all other sites.

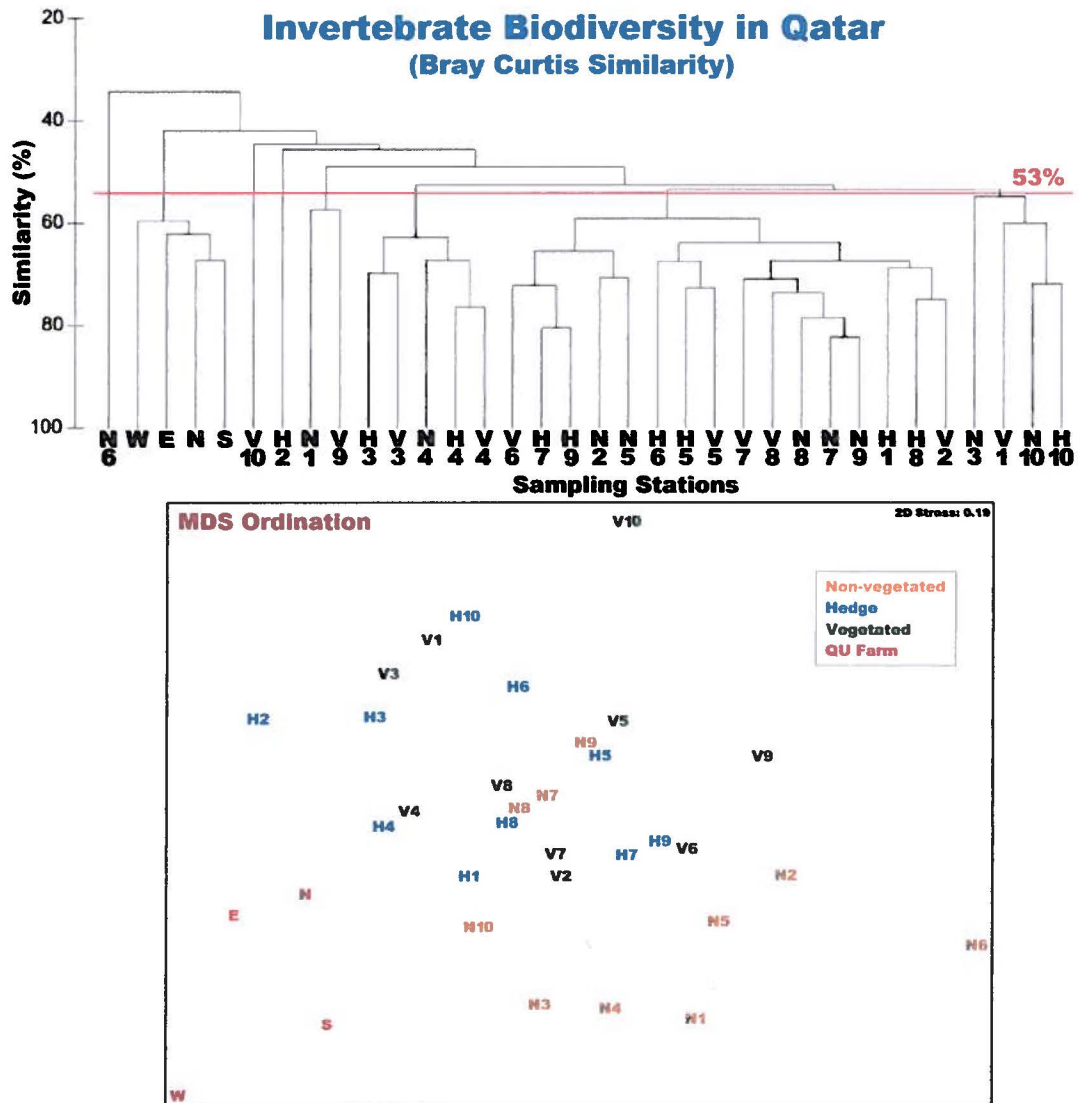


Fig. 11 Diagram of hierarchical clustering of invertebrate biodiversity (similarity threshold at 53% - based on Bray-Curtis similarity matrix) and MDS ordination.

#### 4.8. Temporal distribution

The isolated vegetated traps (V sites) in June had the highest abundance, (N=755) but the highest number of total species richness (S) were the hedge traps (H sites) also in



June (S=55). On the other hand, the low number of total insects were found in December, were found in non-vegetated traps (N sites, N=15), that number increased slightly in the farm sites (F-sites, N=22). In terms of the total number of species (S), it found that the non-vegetated sites has the lowest number of all of the sites especially in November (S = 8) and December (S = 6) and even the farm traps (F) during December (S10) were low. The isolated vegetated (V) sites in October has its lowest number of total species (S=12) Fig. 12.

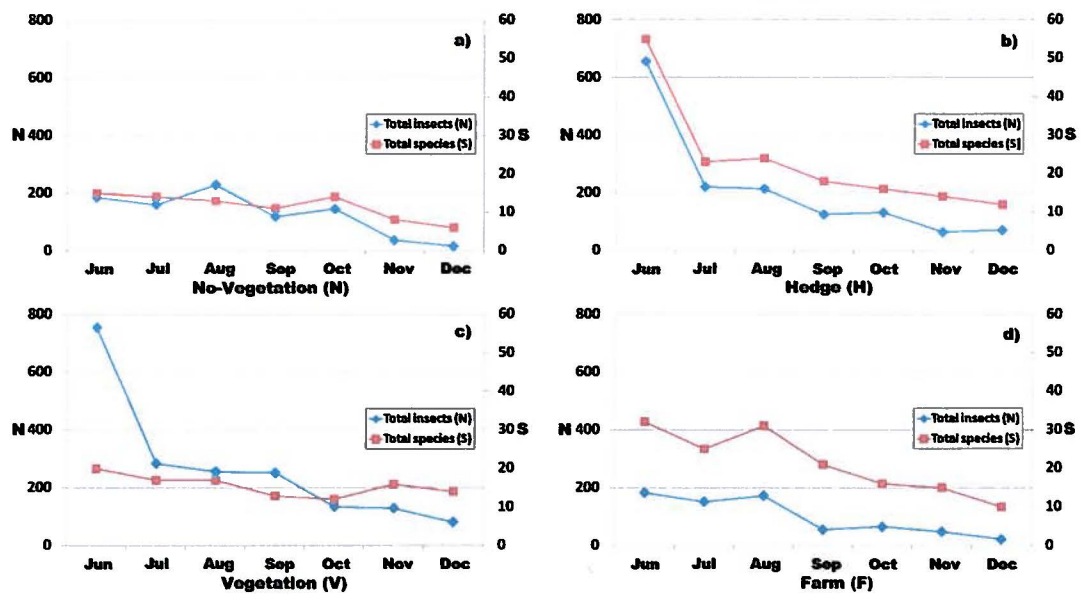


Fig. 12 showed the total insects (N) and total species (S) in each traps types among the seven months, where a is N-non-vegetated trap (site), (b) is H -hedge traps , (c) V- vegetated traps , (d) F- farm traps.

#### 4.9. Invertebrate Abundance (Total number)

A total of 4953 specimens were captured during the study period, 4468 specimens were insects Fig. 13. Of this number, 2696 were member of order Hymenoptera, the most numerous taxa were ants (plate 6) in the family Formicidae (n = 2662 or 54%). Also, 1525 specimens or 30.7% were member of order Coleoptera (beetles) Table 4

(Plate 7).Of the beetles, 1427 were member of family Tenebrionidae (darkling beetles) which is 93.5% of beetles and 28.8% of total catch invertebrate totals (plate 8). The percentage of ants and beetles captured represents 84.7% of the total specimens caught Fig. 14 showed the total number of the found individuals belonging to both families during the study period.

Table4: List of all found insects (number) per traps types and orders.

Order	Number of individual per trap type			
	No-vegetation traps	Hedge traps	Vegetation traps	Farm traps
Coeloptera	352	266	654	253
Hymenoptera	428	889	1116	263
Orthoptera	8	82	6	62
Diptera	2	8	8	7
Hemiptera	0	6	2	5
Lepidoptera	1	4	0	0
Homoptera	0	0	2	3
Thysanura	0	0	5	0
Dermaptera	0	2	0	0
Neuroptera	0	0	0	1
Total	791	1257	1793	594

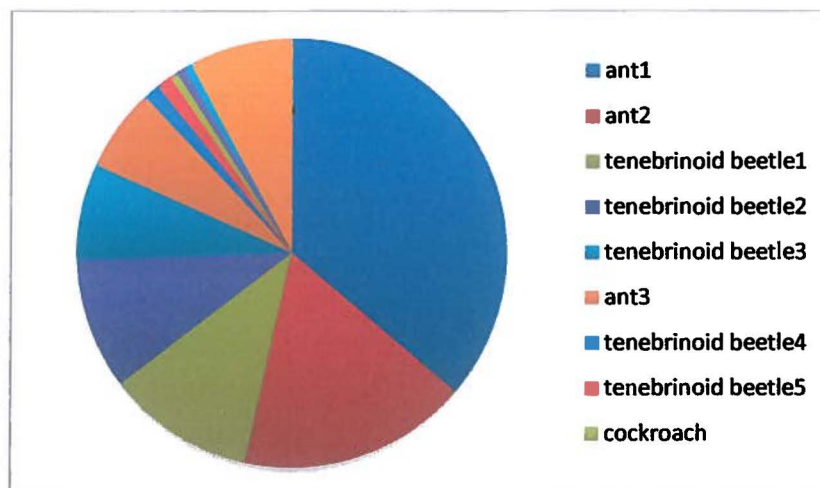


Fig. 13 Relative Abundance of the most commonly caught insects. (Each ant or Tenebrionidae type with a number represents a different species).

If we examine the total number of captured insects in the two most numerous families, the darkling beetles of the family Tenebrionidae and the ants in the family Formicidae during the study period. Fig.12 we can easily see that the most numerous species are the ants in every trapping period, this was true for all trapping periods.

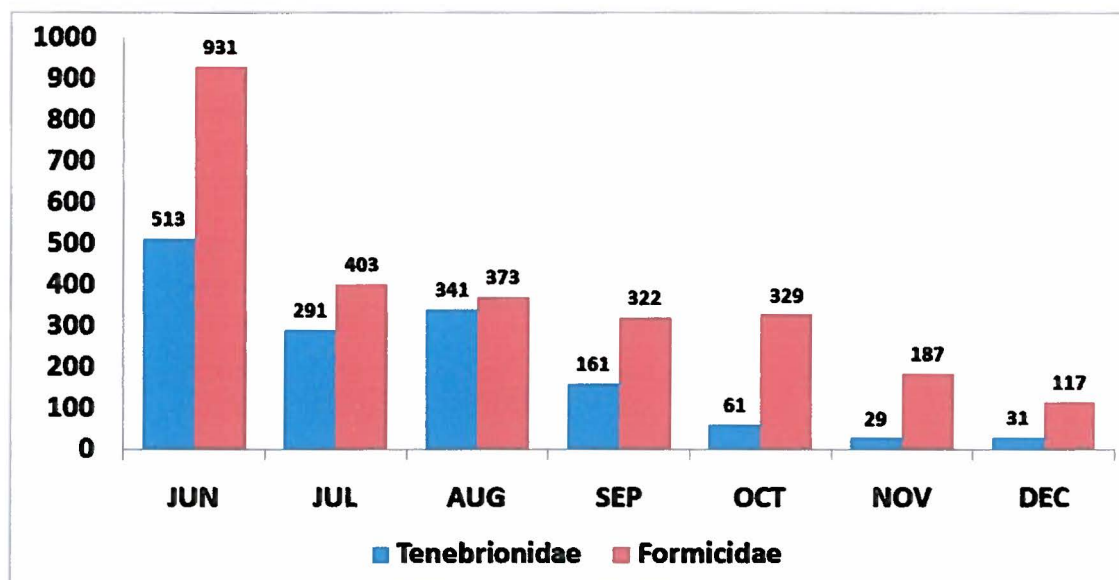


Fig. 14 Total number of the found individuals belonging to Tenebrionidae and Formicidae families during the study period.

#### 4.10. Biomass per trap and over time

Insect abundance may or may not be a relevant factor depending upon the weight of the insect. For biomass calculation we caught some very large insects up to a 5.1 cm species in size such as of the family Gryllotalpidae (mole cricket) but their abundance was not large enough to be a factor in the total biomass collected. The 20 largest species in terms of their weight are summarized in Table 5. The average of dry weights of 20 heaviest insect species that have been caught in the study area times

their abundance gave a biomass estimate for that species. This biomass estimate was used to determine the importance of the species to the ecosystem.

Table 5: Average of dry weight of largest insects.

Average dry weight* (g)	Order	Family	Genus	Species
0.356	Coleoptera	Tenebrionidae	<i>Trychyderma</i>	<i>parvicollis</i>
0.309	Coleoptera	Tenebrionidae	<i>Trachyderma</i>	<i>besnardi</i>
0.294	Coleoptera	Tenebrionidae	<i>Adesmia</i> ( <i>Macradesmia</i> )	<i>cancellata</i>
0.290	Coleoptera	Curculionidae	*	*
0.209	Orthoptera	Blattidae	<i>Phyllophaga</i>	<i>persicus</i>
0.201	Orthoptera	Blattidae	*	*
0.198	Coleoptera	Scarabaeidae	<i>Endomia</i>	<i>lefebvrei</i>
0.193	Coleoptera	Scarabaeidae	*	*
0.193	Orthoptera	Blattidae	*	*
0.186	Homoptera	Cicadidae	*	*
0.184	Orthoptera	Acrididae	*	*
0.180	Orthoptera	Blattidae	*	*
0.174	Coleoptera	Tenebrionidae	<i>Akis</i>	<i>spinosa</i>
0.167	Orthoptera	Blattidae	*	*
0.161	Orthoptera	Gryllidae	*	*
0.161	Orthoptera	Gryllotalpidae	*	*
0.160	Coleoptera	Tenebrionidae	<i>Mesostena</i>	<i>puncticollis</i>
0.157	Orthoptera	Blattidae	<i>Elachertus</i>	<i>fulvus</i>

0.153	Orthoptera	Blattidae	*	*
0.123	Coleoptera	Tenebrionidae	<i>Girardius</i>	*

(\*mean of specimens weight) (\*\* no literature for identification or confirmation is still needed)

#### 4.11. Total biomass

The total dry biomass of all the insects caught between June and December 2012 was 226g. The most numerous taxa in terms of biomass were darkling beetles (Tenebrionidae), which made up more than 80% of the entire insect biomass recorded by pitfall trapping in the study area Fig. 15.

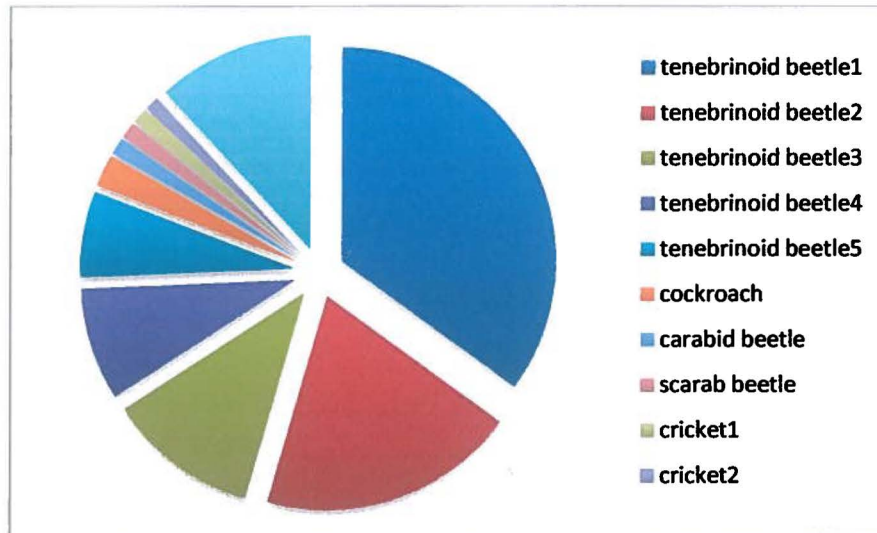


Fig. 15 Proportions of the 10 most dominant insect species in terms of their biomass in the study area based on pitfall trapping.

Biomass estimates consisted of mean dry weight times number of specimens caught of that species. The estimates of biomass show that the with the exception of the cricket 2 (mole cricket) the biomass accumulation is any of the areas is due to the darkling beetles in the family Tenebrionidae.

#### 4.12. Habitat and seasonal influence

The insect biomass decreased from June to December Fig. 17. Also, habitat types appear to influence the distribution of insect biomass in the study site. It is interesting that drier habitat types with patchy (Habitat-V) or no vegetation (Habitat-N) cover actually attract as much biomass as does a much densely-vegetated habitat (Habitat-H). There is a statistically highly significant seasonal difference in insect biomass (ANOVA (repeated measure):  $df= 6, F= 7.8, p= 0.001$ ). However, there is no statistically significant difference in insect biomass between the three habitat types (ANOVA (repeated measure):  $df= 1, F= 0.09, p= 0.78$ ).

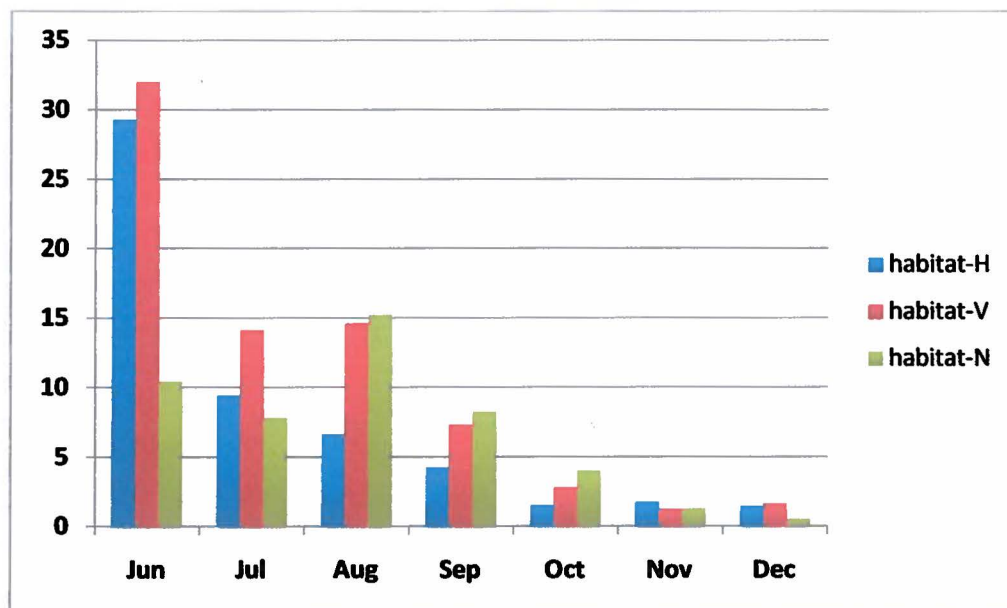


Fig.16 Seasonal changes in insect biomass (g) in the three different habitat types.

Although the insect biomass decreases from June to December in general Fig. 16 the timings of biomass peaks may differ amongst species. For example, amongst the top 10 species which were most dominant in terms of biomass Fig. 15 some Tenebrinoid beetles *Girardius persicus* and *Trychoderma parvicollis* (plate 9) seem to have their

biomass peak in July/August but other Tenebrinoid beetles *Mesostena puncticollis*, *Gonocephalum besnardi* and *Adesmia (Macradesmia) cancellata* (plate 9) had their peaks in June Fig. 17. Among these top 10 species, ground beetles (Family Carabidae) and scarab (Family Scarabaeidae) beetles also show different patterns in their seasonal changes in biomass Fig. 18. Among these top 10 species, the biomass of the cockroach, cricket-1 & -2 tended to increase during the cooler months of November and December whilst those of the beetles remain low Fig. 17 and Fig.18 suggesting the differences in natural history parameters including reproductive biology between them.

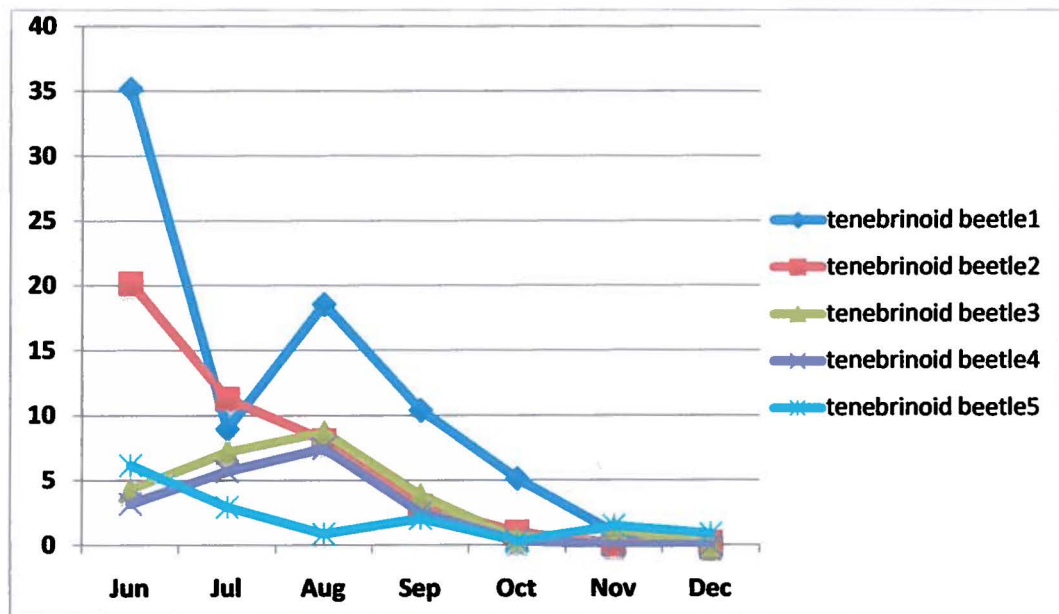


Fig. 17 Seasonal changes in biomass (g) of five species of darkling beetles (Family Tenebrionidae) with the highest insect biomass.

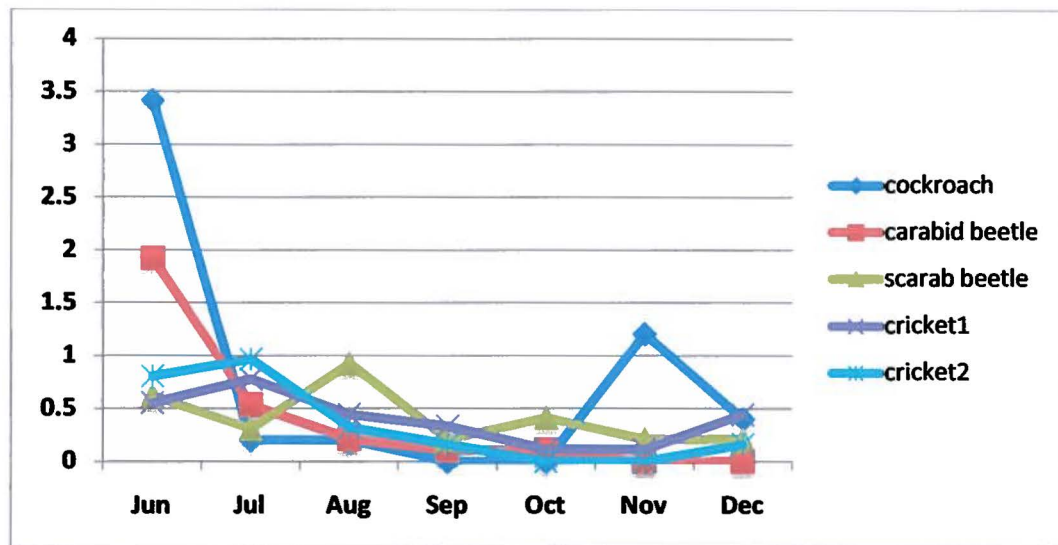


Fig. 18 Seasonal changes in biomass (g) of five insect species (except Tenebrionidae beetles) that contribute to the total insect biomass most.

## 5. Discussion

### 5.1. Number of species and species richness

The hedge (H) traps in June had the highest number of total species ( $S=55$ ). Farm (F) traps were irrigated and therefore not subject to water stress. In the traps N, V and H were not of course irrigated. In the comparison, farm (F) and no vegetation (N), we found much higher species diversity in the F traps than the N traps but the total number (abundance) of these distinct traps is not significantly different, indicating that perhaps moisture adds to species diversity more than it does to abundance. In June, all of the traps had their highest abundance and species richness values. The highest number of total species richness (S) were in the hedge (H) traps also in June ( $S=55$ ) indicating that the boom and bust cycles are not so rapid and the vegetation is not subject to the possible early succession patterns of insect colonization and is more



ecologically mature in terms of colonization in natural vegetation and invertebrate succession which would lead to a higher species richness in the hedge (H).

## **5.2. Invertebrate Abundance (Total number)**

Ground-dwelling insects represent the majority of invertebrate's fauna. A total of 4953 specimens were captured during the study period, 4468 specimens were insects Fig. 13. Of this number, 2696 were member of order Hymenoptera, the most numerous taxa were ants (plate 6) in the family Formicidae 2662 specimens. Moreover, 1525 specimens were member of order Coleoptera (beetles) of which 1427 were member of family Tenebrionidae (darkling beetles) (plate 8), which make the individuals of those two families the most numerous species of the study findings, indicating that they should play a significant role in planning for the conservation and sustainable use of worldwide biodiversity (Brown 1991; Hawksworth 1991; Kremen et al. 1993). In addition, many of invertebrate are consider as keystone species in their environment. The isolated vegetated traps (V sites) in June had the highest abundance, (N=755) which of course was a surprise. A possible reason for this is theorized that the isolated patches of vegetation go through boom and bust cycles that occur when resources suddenly become available at the beginning of a succession bloom pattern of vegetation which causes a rapid increase in the herbivores feeding upon that vegetation. Tenebrionidae beetles are primarily herbivores whose larvae and adults feed on vegetation (Smith 1970). Larvae feed below ground and adult feed above ground where mating is also possible. The exact life history of the beetles is not known in Qatar but given the above ground activity in June, it is believe that mating occurs during this time and eggs are laid and the resultant larvae are underground feeding until past December. The lowest number of total insects were found in

December in the non-vegetated traps (N sites) (N=15) could be due to the beetles larvae being underground. The farm sites (F-sites) (N=22) increased slightly, but not significantly indicating that perhaps natural adult mortality after mating in the case of the beetles or lower temperature not moisture were a factor in the abundance decline. The hedge sites (H) and isolated vegetated (V) sites also declined indicating that a general decline in vegetation in those months. The higher abundance in the less diverse vegetation areas agrees with the finding by Forbes (2005) who found more attribute this to natural vegetation and insect succession patterns.

### **5.3. Biomass**

It is interesting that drier habitat types with patchy (Habitat-V) or no vegetation (Habitat-N) cover actually attract as much biomass as does a much densely-vegetated habitat (Habitat-H).

The primary source of the biomass were darkling beetles ( Family Tenebrionidae ), which made up more than 80% of the entire insect biomass recorded by pitfall trapping in the study area. Darkling beetles are well suited to the desert environment due to their ability to eat dry vegetation and obtain metabolic water. As was stated, the life history of the beetles are unknown in Qatar, but the adults above ground , mate and lay eggs that hatch and go into the ground to feed on underground vegetation. The darkling beetles are one of most common insects in the desert environment (Soldati, 2009).

It is most interesting that the various habitats H, V and N do not significantly differ in biomass caught over time but the isolated vegetation (V) had the highest. The biomass did decline significantly from June to December in all of the traps including

F traps. This may be due to weather effects as the somewhat cooler temperature brings about less growth on the poikilothermic invertebrates or natural life history of insects that move to the more underground existence during the warmer times of the year. Although the insect biomass decreases from June to December in general Fig. 16 the timings of biomass peaks differed amongst species. For example, amongst the top 10 species which were most dominant in terms of biomass Fig. 15, some Tenebrinoid beetles *Girardius persicus* and *Trychyderma parvicollis* (plate 9) seem to have their biomass peak in July/August whilst other Tenebrinoid beetles *Mesostena puncticollis*, *Gonocephalum besnardi* and *Adesmia (Macradesmia) cancellata* (plate 9) had their peaks in June Fig. 17. The ground beetles (Family Carabidae) a predator and the scarab beetles (Family Scarabaeidae) a saprophyte show different patterns in their seasonal changes in biomass Fig. 18. This could be due to their life cycles occurring at different times to take advantage of unique unknown food supplies available during those times. Amongst these top 10 species in terms of biomass, the biomass of the cockroach, cricket-1 & -2 tend to increase during the cooler months of November and December whilst those of the beetles remain low Fig. 17 and Fig. 18 suggesting also differences in natural history parameters including reproductive biology and perhaps empty niches left vacant by the absence of darkling beetles. But the insects other than the darkling beetles never reached the level of abundance or biomass accumulation of the darkling beetles. Species activity especially darkling beetles activity was as predicted in several publications. For example, (Tigar & Osborne, 1999) found diversity and abundance were affected by the temperature and (Durrant, 2009) found that the winter season had very low beetle activity. Both of these statements were also found to be true in this study as well.

Since invertebrates are considered one of the most important food sources for hedgehogs (e.g. Reeve 1994). A greater insect biomass available in the open area (Habitats-V & N) may offer an explanation for the appearance of many hedgehogs that often appear to forage in the open areas (Yamaguchi, personal communication on unpublished data 2013). The less-dense vegetation in such open habitats may also help hedgehogs to reach insect prey more easily in comparison to the hedge habitat and since biomass production is high in the V ( isolated vegetation sites) , each site may offer more biomass to consume by a predator in a smaller physical search area than the hedge.

#### **5.4. Cluster analysis of data (Similarity analysis)**

The differences in community patterns (diversity and abundance) between the 34 sampling sites generated four major clusters at a 53% similarity threshold. MDS ordination revealed significant differences in community structure between QU farm sites and the non-vegetated sites, as well as considerable overlap between hedge and vegetated sites Fig.11. The cluster analysis also revealed that the patterns of diversity and abundance at sites N6, V10, and H2 are significantly different than those observed at all other sites.

#### **5.5. Species diversity**

In general the diversity index remains high in all sites, with few exceptions. Species diversity (SD) calculation to date show that the most diverse region of the three habitats was the hedge row (H traps) with a SD index of "between" 0.731 to 0.898 at different dates. Keeping in mind that in the Simpsons' SD index, 1.0 equal's perfect diversity and 0.0 equals no diversity. The number of the SD in those areas is

considered to be quite diverse. In the non-vegetated (N) traps the Simpson's diversity were significantly different at those same dates at 0.601 to 0.771. These diversity indexes in the non-vegetated traps were higher than anticipated indicating a previously unknown diverse assemblage of invertebrates in the desert in non vegetation plots. There was a significant positive correlation between biodiversity and temperature in the non vegetation plots, but no correlation between species diversity and temperature in the hedge row.

## **6. Conclusion**

Species diversity (SD) calculation to date show that the most diverse region of the three habitats was the hedge row (H traps) with a SD index of between 0.731 to 0.898 at different dates. Keeping in mind that in the Simpsons' SD index, 1.0 equal's perfect diversity and 0.0 equals no diversity. The number of the SD in those areas is considered to be quite diverse. In the non-vegetated (N) traps the Simpson's diversity were significantly different at those same dates at 0.601 to 0.771. These diversity indexes in the non-vegetated traps were higher than anticipated indicating a previously unknown diverse assemblage of invertebrates in the desert in non vegetation plots. There was a significant positive correlation between biodiversity and temperature in the non vegetation plots, but no correlation between species diversity and temperature in the hedge row. It is interesting that drier habitat types with patchy (Habitat-V) or no vegetation (Habitat-N) cover actually attract as much biomass as does a much densely-vegetated habitat (Habitat-H).

The ants alone represent 22 different species in the one node subgroup and 32 species in the one node subgroup (plate 6). It is hoped that the collection sites become an

ongoing data stream to further understand the dynamics of the invertebrate ground fauna. It is also suggested that the pitfall collections be supplemented by light trap data using a light trap that would passively collect flying insects that are of course an important part of the species diversity, abundance and biomass. Further studies should include the pitfall specimens already being collected from January 2013 to June 2013 some of which are being stored and waiting processing in the QU laboratory.

Finally, there is no "good" SD numbers but 0.7 is considered to be a healthy diversity. A better use of the SD values is to evaluate the present diversity against future diversity or diversity between sites.

It is also recommended that systematic and long term collection of invertebrates in other areas of Qatar be done and the identification of some of the more difficult species is needed. This will require the use of resources including time, literature resources and experts and physical comparisons with insect Types specimens in other institution in other countries. This is only a beginning of the understanding the invertebrate biodiversity of Qatar. It is much more diverse than anticipated.

### **References**

Abdu, R., Shaumar, N. (1985). A preliminary list of the insect fauna of Qatar. *Qatar University Sci. J.* 5: 215-232.

Abushama, F. (1997). Density and diversity of the desert arthropoda of Qatar. *Qatar University Sci. J.* 17(2). 359-375.

Abushama, F. (1999). Dominance value and community production of desert arthropoda in Qatar. *Qatar University Sci. J.* 18: 137-153.

Alahmed, A., Kheir, S. and Khereiji M. (2010). Distribution of *Culicoides* Latreille (Diptera: Ceratopogonidae) in Saudi Arabia. *Journal of Entomology* 7(4): 227-234.

Al-Ajlan, A. (2007). Relationship between desert locust, *Schistocerca gregaria* (Forsk.) infestation, environmental factors and control measures in Gazan and Makkah regions, Saudi Arabia. *Pakistan Journal of Biological Sciences* 10(20): 3507-3515.

Aldryhim, Y., Mills III, C., and Aldawood, A. (1991) Ecological distribution and seasonality of darkling beetles (Coleoptera: Tenebrionidae) in the central region of Saudi Arabia. *Journal of Arid Environments* 23: 415-422.

Arnett, R., Downie, N., Jaques, H. (1980) How to know the beetles. Pictured Key Nature Series, Iowa. 416 pp.

Austin, A., Yeates, D., Cassis, G., Fletcher, M., La Salle, J., Lawrence, J., McQuillan, P., Mound, L., Bickel, D., Gullan, P., Hales, D., and Taylor, G. (2004) Insects 'Down Under'-Diversity, endemism and evolution of the Australian insect fauna: examples from select orders. *Australian Journal of Entomology* 43: 216-234.

Ayal, Y. (2007) Trophic structure and the role of predation in shaping hot desert communities. *Journal of Arid Environments* 68: 171-187.

Bang, C., and Faeth S. (2011) Variation in arthropod communities in response to urbanization: Seven years of arthropod monitoring in a desert city. *Landscape and Urban Planning* 103: 383-399.

Batanouny, K.H. (1986) Environment and plants life in Qatar. Qatar University. 414 pp.

Batáry, P., Holzschuh, A., Orci, K., Samu, F., Tschardtke, T. (2012) Responses of plant, insect and spider biodiversity to local and landscape scale management intensity in cereal crops and grasslands. *Agriculture, Ecosystems and Environment* 146: 130-136.

Blanchon, D., Pusateri, J., Galbraith, M., and Thorpe, S. (2011) Sampling indigenous ground-living beetles in a stand of non-native tree privet (*Ligustrum lucidum*) in New Zealand raises new management questions. *Ecological Management & Restoration* Vol. 12 No.3 pp. 234-236.

Borror, D., and White, R. (1970) A Field Guide to Insects. Houghton Mifflin Company, Boston, NY.

Cardoso, P., Borges, P., and Veech, J. (2009) Testing the performance of beta diversity measures based on incidence data: the robustness to undersampling. *Diversity and Distributions* 15: 1081-1090.

Castner, J. (2000) Photographic Atlas of Entomology and Guide to Insect Identification. Feline Press, Gainesville. 174 pp.

Colwell, R., and Coddington, J. (1994) Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions: Biological Sciences* Vol. 345, No. 1311, *Biodiversity: Measurement and Estimation* pp. 101-118.



Durrant, B. (2009) Terrestrial invertebrate biodiversity assessment for the Gngangara sustainability strategy. Department of Environment and Conservation, Gngangara Sustainability Strategy, Australia.

Faisal, M., and Ahmed, M. (2005) Collembola diversity in changing agricultural landscapes of the Thar Desert: a case study in Sriganganagar district of Rajasthan, India. *Journal of Arid Environments* 63: 717-724.

Faragalla, A., and Adam, E. (1985) Pitfall trapping of tenebrionid and carabid beetles (Coleoptera) in different habitats of the Central Region of Saudi Arabia. *Z. ang. Ent.* 99: 466-471.

Fisher, B., and Cover, S.(2007) *Ants of North America A Guide to the Genera.* University of California Press.194 pp.

Forbes, G., Van Zee, J., Smith, W., and Whitford, W. (2005) Desert grassland canopy arthropod species richness: temporal patterns and effects of intense, short-duration livestock grazing. . *Journal of Arid Environments* 60: 627-646.

Gilbert, J., (2011) Insect dry weight: Shortcut to a difficult quantity using museum specimens. *The Florida Entomologist Vol.94 No.4, pp.* 964-970.

Gotelli, N., and Colwell, R. (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* 4: 379-391.

Hagras, A., Babiker, A., and Khalil, G. (1991). The effect of temperature and relative humidity on survival of unfed *Hyalomma impeltatum* (Acarina: Ixodidae). *Qatar University Sci. J.* 11: 269-284.

Harde, K.W. (1984) A Field Guide in Colour to Beetles. Octopus Books, London. 334 pp.

Harten, A. (2008) Arthropod Fauna of The UAE. Vol.1. Dar Al Ummah Printing, Publishing, Distribution & Advertising, Abu Dhabi. 754 pp.

Harten, A. (2008) Arthropod Fauna of The UAE. Vol.2. Dar Al Ummah Printing, Publishing, Distribution & Advertising, Abu Dhabi. 786 pp.

Harten, A. (2008) Arthropod Fauna of The UAE. Vol.3. Dar Al Ummah Printing, Publishing, Distribution & Advertising, Abu Dhabi. 700 pp.

Harten, A. (2008) Arthropod Fauna of The UAE. Vol.4. Dar Al Ummah Printing, Publishing, Distribution & Advertising, Abu Dhabi. 832 pp.

Howarth, and Gillett (2009) Increasing knowledge of the entomological fauna of the United Arab Emirates and the role of private collections. *ZooKeys* 31: 119-132.

International Code of Zoological Nomenclature. Fourth Edition International Union of Biological Sciences ISBN 0 85301 006 4.

Jones and Laughlin (2009) Learning To Measure Biodiversity: Two Agent-Based Models That Simulate Sampling Methods & Provide Data for Calculating Diversity Indices. *The American Biology Teacher* Vol. 71, 7: 406-410.

Lalley, J., Viles, H., Henschel, J., and Lalley, V. (2006) Lichen-dominated soil crusts as arthropod habitat in warm deserts. *Journal of Arid Environments* 67: 579-593.

Latif, M., Rahman, M., Islam, M., and Nuruddin, M. (2009) Survey of arthropod biodiversity in the Brinjal field. *Journal of Entomology* 6: 28-34.

Li, X., Jia, R., Chen, Y., Huang, L., and Zhang, P. (2011) Association of ant nests with successional stages of biological soil crusts in the Tengger Desert, Northern China. *Applied Soil Ecology* 47: 59-66.

Li, X., Xiao, H. Zhang, J., and Wang, X. (2004) Long-term ecosystem effects of sand-binding vegetation in the Tengger desert, Northern China. *Restoration Ecology Vol.12 No.3, pp. 376-390.*

Norfolk, O., Adbel-Dayem, M. and Gilbert, F. (2012). Rainwater harvesting and arthropod biodiversity within an arid agro-ecosystem. *Journal of Agriculture, Ecosystems and Environment* 162: 8-14.

Opatovsky, I., Pluess, T., Schmidt-Entling M., Gavish-Regev E., and Lubin Y. (2010) Are spider assemblages in fragmented, semi-desert habitat affected by increasing cover of agricultural crops? *Agriculture, Ecosystems and Environment* 135: 233-237.

Qatar National Development Strategy. (2011-2016).

Qatar National Vision 2030. (July 2008).

Reaka-Kudla, M., Wilson, D., and Wilson, E. (1997) Biodiversity II understanding and protecting our biological resources. Joseph Henry press, Washington, DC. 551 pp.

Redford and Richter (1999) Conservation of Biodiversity in a World of Use. *Conservation Biology, Vol. 13, 6: 1246–1256.*

Richardson, M., and Hari, J. (2008) Teaching students about biodiversity by studying the correlation between plants & arthropods. *The American Biology Teacher Vol.70, No.4 pp. 217-220.*

Roig-Juñent, S., Flores, G., Clavar, S., Debandi, G., and Marvaldi, A. (2001) Monte desert (Argentina): insect biodiversity and natural areas. *Journal of Arid Environments* 47: 77-94.

Sample, B., Cooper, R., Greer, R., and Whitmore, R. (1993) Estimation of insect biomass by length and width. *American Midland Naturalist* Vol. 129, No. 2 pp. 234-240.

Shalhaf, Sh., Seraj, A., Esfandiari, M., and Ramazani, L. (2012) Insect biodiversity in Karkheh wild life refuge, SW Iran. *Journal of Entomology* 9(3): 178-182.

Slater, J., and Baranowski, R. (1978) How to know the true bugs. Pictured Key Nature Series, Iowa. 254 pp.

Soldati, L. (2009) The darkling beetles (Coleoptera: Tenebrionidae of Qatar). Natura optima dux Foundation (Warszawa), Poland. 101 pp.

Tigar, B. and Osborne, P. (1999). Patterns of arthropod abundance and diversity in an Arabian desert. *Journal of Ecography* 20: 550-558.

Tigar, B. and Osborne, P. (1999). Patterns of biomass and diversity of aerial insects in Abu Dhabi's sandy deserts. *Journal of Arid Environments* 43: 159-170.

Tigar, B. and Osborne, P. (1999). The influence of the lunar cycle on ground-dwelling invertebrates in an Arabian desert. *Journal of Arid Environments* 43: 171-182.

Tylianakis, J., Rand, T., Kahmen, A., Klein, A., Buchmann, N., Perner, J., and Tschardt, T. (2008) Resource heterogeneity moderates the biodiversity-function relationship in real world ecosystems. *Plos Biology* Vol. 6, 5:0947-0956.

White, R. (1983) *A Field Guide to Beetles*. Houghton Mifflin Company, Boston, NY.

Wilson, E. (2010) *The diversity of life*. Belknap press, Cambridge, Mass. 424 pp.

## Appendix

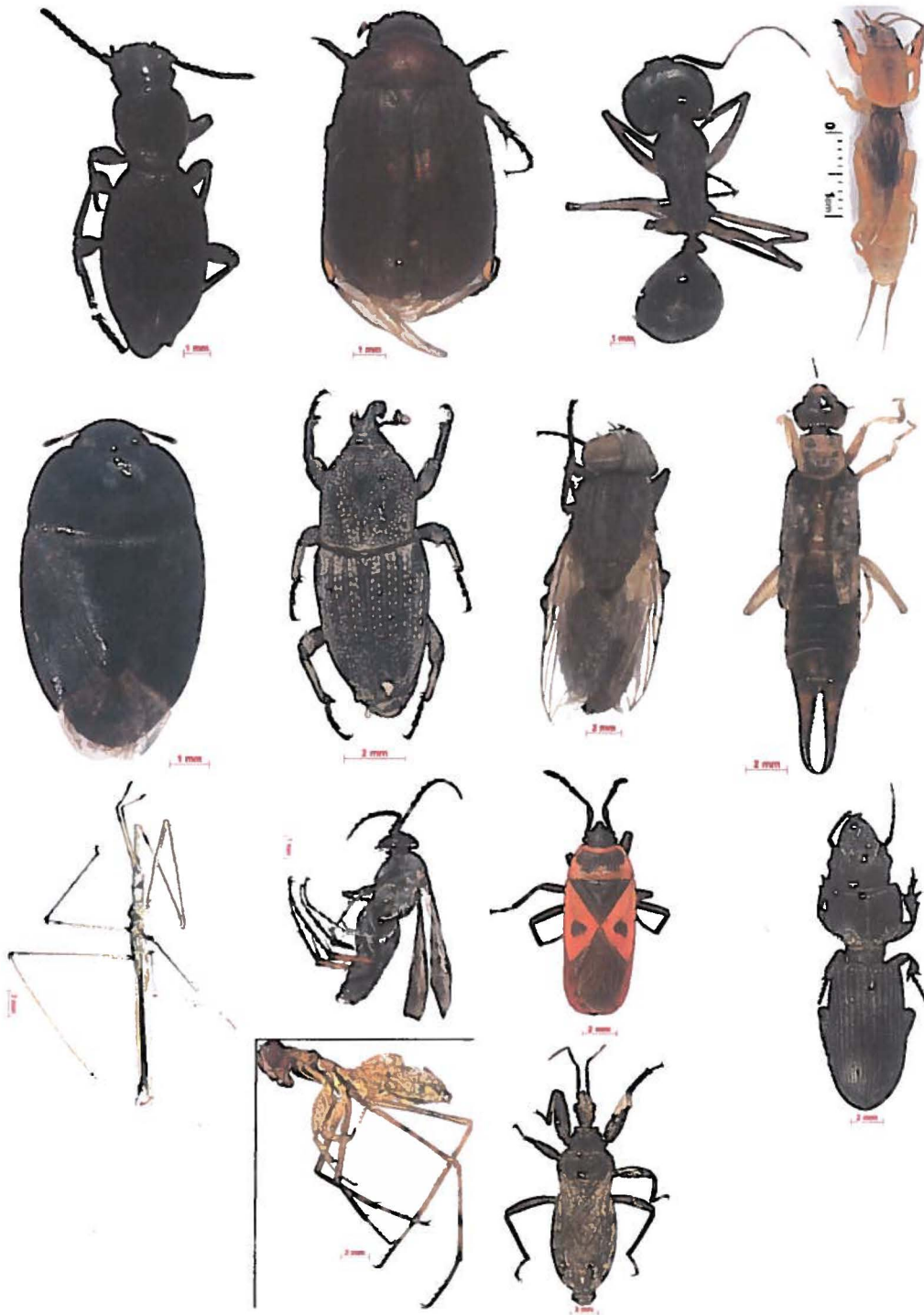


Plate1. Samples of different species belonging to class Insects of the study findings.

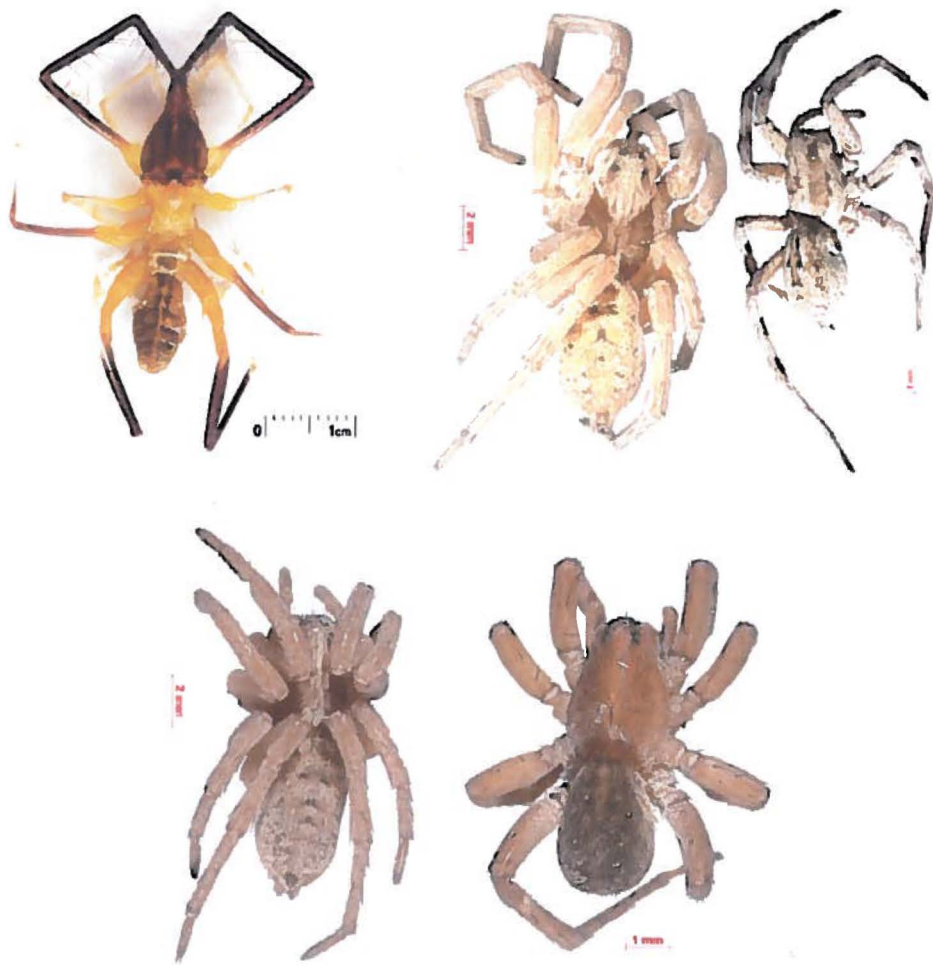
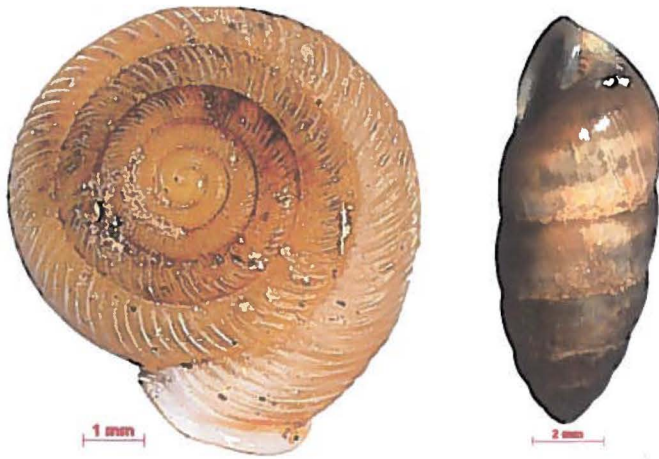


Plate2. Samples of different species belonging to class Arachnida of the study findings.



(a)



(b)

Plate3. Selective samples of (a) Isopods (sow bug/wood louse) (b) Land snails.



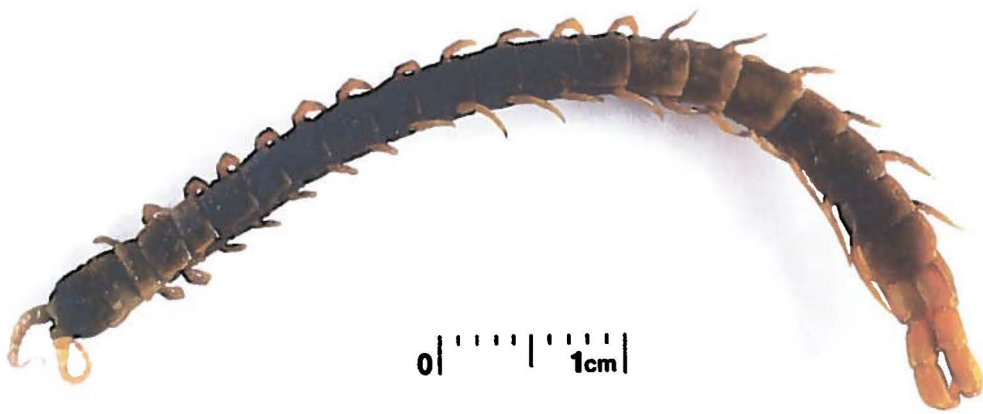


Plate4. Selective sample of Centipedes.

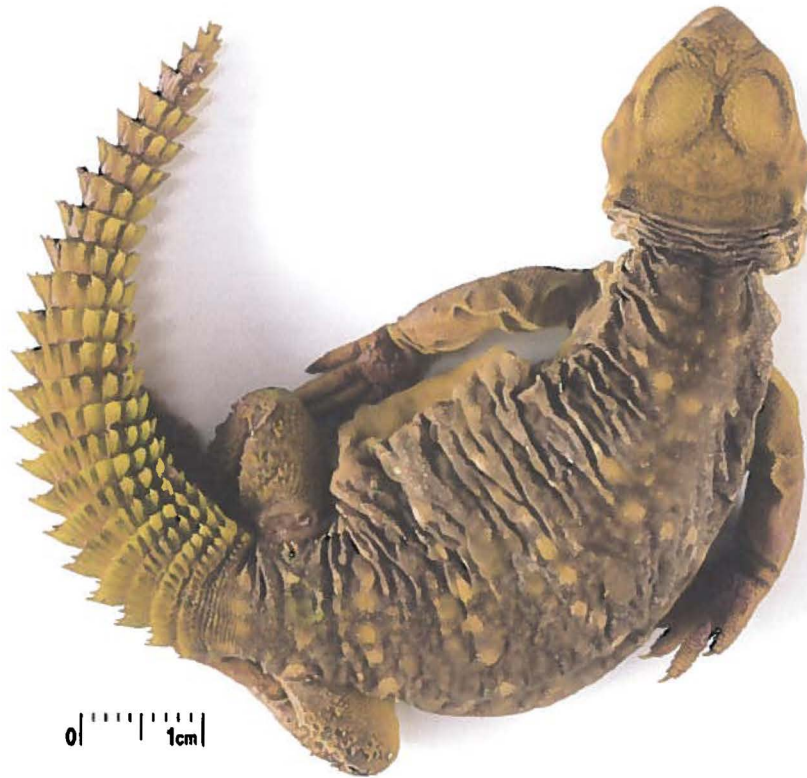
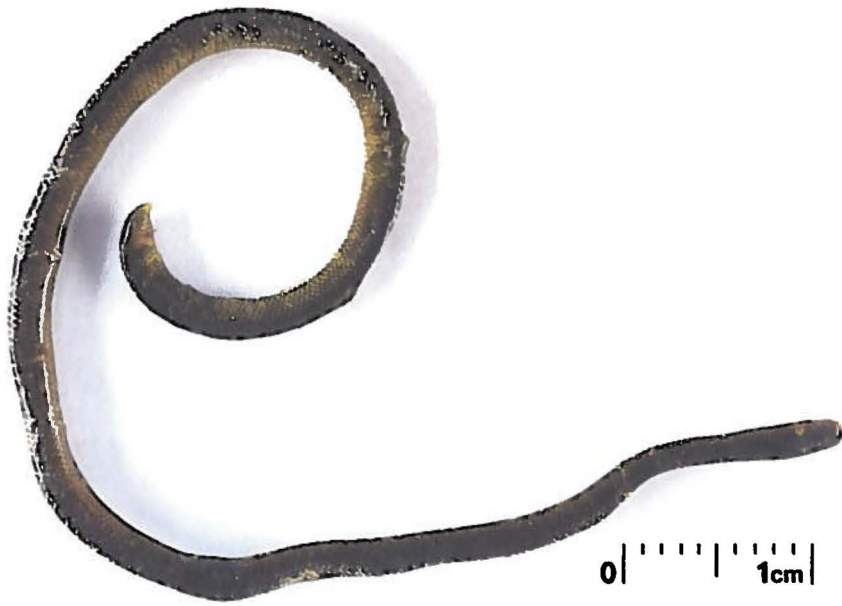


Plate5. Selective samples of scaled reptiles (above; small snake – below; Spiny tailed lizard (Dhub)).



Plate6. Selective samples of different species of ants (order Hymenoptera, family Formicidae).

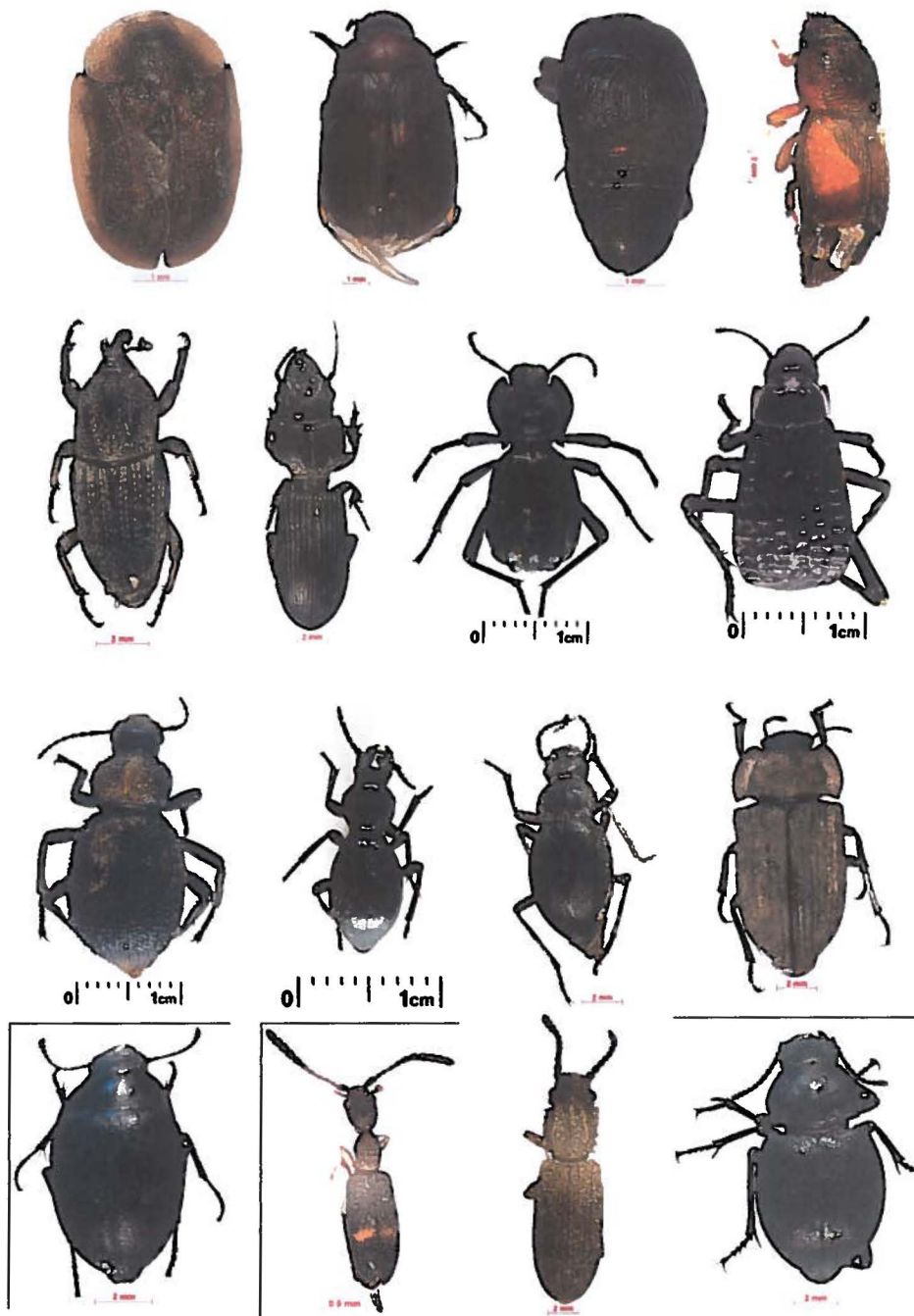
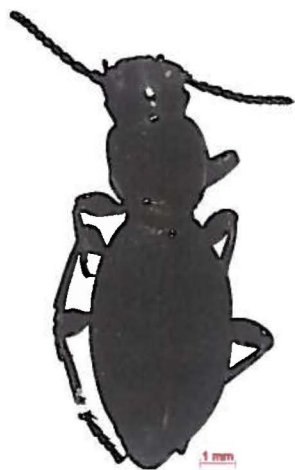


Plate7. Selective samples of different species of beetles (Order Coleoptera).



Plate8. Samples of different species of family Tenebrionidae.



1



2



3



4



5

Plate 9. 1- *Mesostena puncticollis* SOLIER; 2- *Gonocephalum besnardi* KASZAB; 3- *Girardius persicus* BAUDI; 4- *Trychoderma parvicollis* BAUDI; 5- *Adesmia (Macradesmia) cancellata* KLUG.