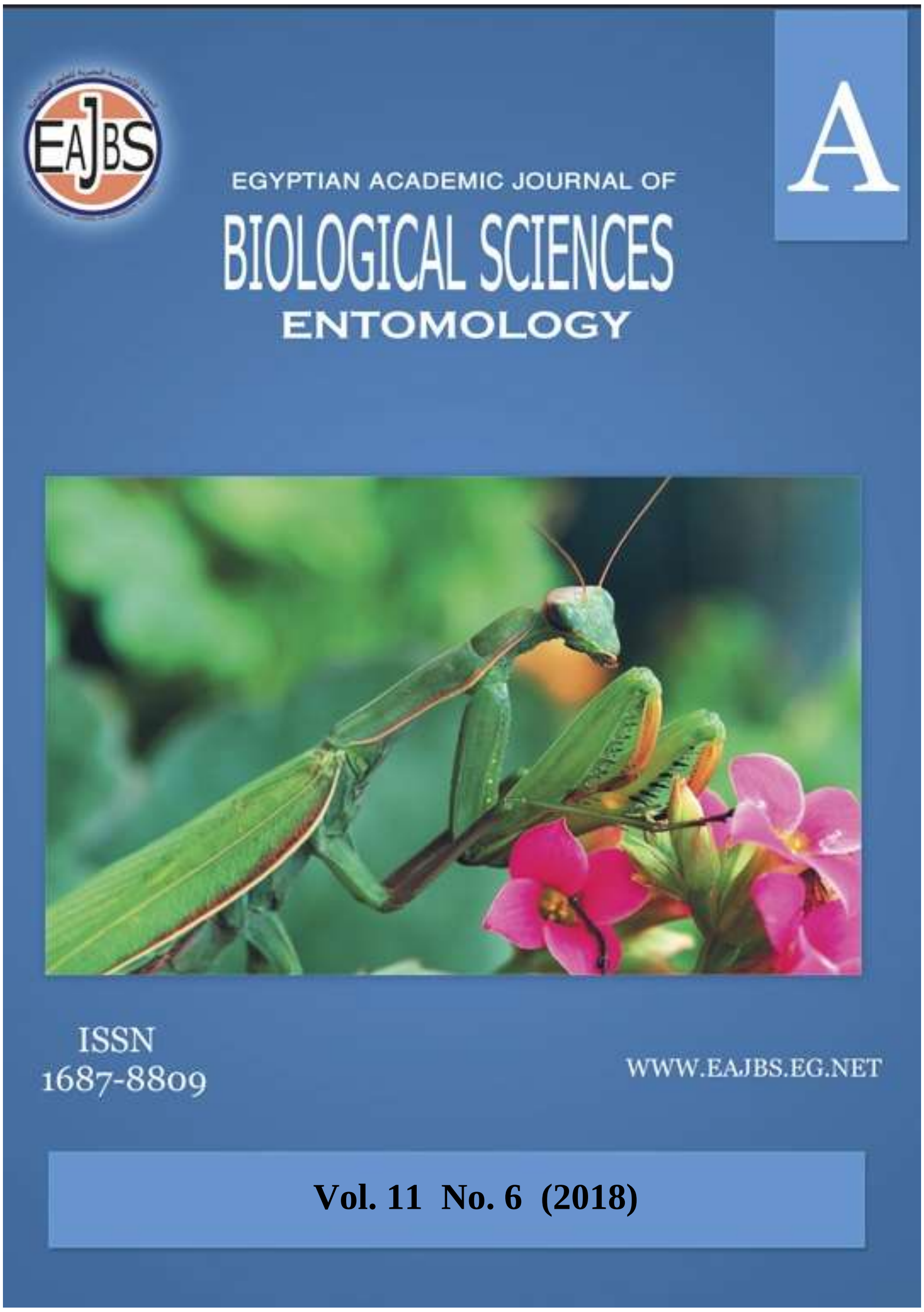

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Impact of Land Reclamation on the Diversity of Darkling Beetles, (Tenebrionidae) in Arid Ecosystem of El-Kharga, New Valley Governorate, Egypt

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ABSTRACT

The present study aimed to assess the impact of land reclamation on the distribution, diversity and monthly occurrence of darkling beetles (Tenebrionidae) in El-Kharga, New Valley Governorate, Egypt. Beetles were sampled with pitfall traps over a 6-month, from September 2015 to February 2016. Four different reclaimed sites were selected site I, site II, site III and site IV. The totals of 4725 collected beetles belong to 7 species; *Akis elevata* Solier , *Prionotheca coronata* Olivier, *Mesostena angustata* Fabricius, *Trachyderma hispida* (Forskal), *Akis reflexa* Fabricius , *Pimelia arabica* Klug and *Scaurus puncticollis* Solier. The abundance of recorded beetles differed significantly in the four studied sites. The highest density of total beetles was recorded at long period reclaimed site; the site I (1.68±1.7 individual/day*trap). *P. coronata* recorded the highest density (1.85±1.66 individual/day*trap) among the seven collected species. Results indicated monthly variations in the density of the beetles in the studied sites. *A. elevata*, *P. coronata*, *M. angustata* and *S. puncticollis* showed a significant increase in October. Canonical correspondence analysis revealed that the abundance and diversity of beetles mostly related to soil pH followed by wind velocity and relative humidity. The results indicate that land reclamation led to variations in the community of tenebrionids.

INTRODUCTION

The ground dwelling invertebrates like beetles play significant roles in most terrestrial ecosystems. Beetles are highly diverse and occupy a wide range of microhabitats and consume different food resources (Borror *et al*., 1989; Höolldobler and Wilson, 1990). Among the beetles, Tenebrionids are relatively abundant, enormous, cursorily, readily captured in pitfall traps and the most simply identified (Henschel *et al*., 2010; Saji and Al Dhaheri, 2011; Abd El-Wakeil *et al*., 2014). The Tenebrionidae (darkling beetles) is a family of beetles with some 20,000 described species worldwide. They are extremely variable in shape, size and ecological requirements.

Beetles are one of the key components of arid environments, it is important to know how they are affected by changes in the spatial heterogeneity of vegetation. This knowledge lets us expect how human activities are probable to influence diversity and distribution of beetles and in the end their impacts on a variety of ecosystem processes (Lescano *et al*., 2017). In arid ecosystems, irregular distribution of plant communities acts as biotic cores (Liu *et al*., 2016), which have important significances on arid land dynamics (Liu *et al*., 2011).

Darkling beetles are a dominant group among the invertebrate fauna of arid environments (Cepeda-Pizarro *et al*., 2005; Carrara *et al*., 2011). Tenebrionids generally feed on the material of plant origin including decaying matter, wood, leaf litter, pollen, as well as fungal and algal matter. Some are also scavengers while very few species are predatory especially of wood-boring beetles. They involved in many ecological processes, such as predation, organic matter consumption, soil nutrient cycling, pollination, seed dispersal, plant anti-herbivore defense, and food for vertebrates (Andersen *et al*., 2004; Sackmann and Farji-Brener, 2006; Lach *et al*., 2010; Lescano, *et al*., 2017).

The New Valley Governorate is located in the southwestern part of Egypt; consisting of roughly a third of Egypt's area. It is the country's largest governorate and one of the biggest on the African continent. Compared with studies done on darkling beetles (Tenebrionidae) in Egypt, Many studied was concerned with Tenebrionidae in Egypt e.g. Fakhry (1994), Fadl *et al.* (1996), Ramadan (2001), Semida *et al*. (2001) Osman (2002), El-Gohary (2004), Abd El-Moez (2005), El-Wafeef (2007), El Metwally (2008) and Ramzy (2015), there was no study on the assemblages of Tenebrionid beetles in the New Valley Governorate.

Vegetation type, cover and plant community changes can affect, directly or indirectly, the abundance, species richness and composition of beetle communities (Stapp, 1997; Schweiger *et al*., 2005; Woodcock *et al*., 2010; Pakeman and Stockan, 2014). Impacts of land use/cover variations on biodiversity well documented in many parts of the world (Perner and Malt, 2003; Koellner and Geyer, 2013; Souza *et al*., 2015; Li *et al*., 2016). New Valley Governorate, Egypt, is facing a serious challenge of landscape change due to land reclamation. Therefore, the study aimed to assess the impact of land reclamation on the distribution, diversity and monthly occurrence of darkling beetles (Tenebrionidae) in El-Kharga, New Valley Governorates, Egypt.

MATERIALS AND METHODS

Sites of Collection:

Four different reclaimed sites were selected in the experimental farm of New Vally University at El-Kharga, New Valley Governorate named site I, site II, site III and site IV (Fig. 1). They represented 4 different habitats; **the** site I is long-ago (more than 20 years) reclaimed land, site II is recently (10 to 20 years) reclaimed, the reclaimed age of site III is 5 years while site IV is not reclaimed yet.

Sampling*:*

Monthly quantitative samples were collected from the investigated sites during a period extended from September 2015 until February 2016. Pitfall traps were used for collecting samples. 4 traps were used monthly at each site. Each trap was filled with 70 ml water and 5 drops of liquid soap and sheltered by plastic sheets to prevent falling of leaf litters in the traps. The traps were evenly distributed in the site. The aggregated beetles in the traps were collected every 10-12 days. The data were standardized by the equation of N/ (d*Tr) where N = number of beetles in one sample in the investigated site, d = number of days between two sampling and Tr = number of succeed traps (some traps were excluded and replaced by effective one) (Abd El-Wakeil, 2009, Ramzy, 2015).

Fig. 1. Map showing the study sites in El-Kharga, New Valley Governorate, Egypt.

Measurement of Ecological Factors:

The following environmental factors were monthly recorded during the period of investigation for each site of collection**:** temperature (air and surface soil), soil pH, relative humidity and wind velocity.

Statistical Analysis:

The collected data were summarized and analyzed using SPSS software (Version 21) and Microsoft Excel (2010). Analysis of variance (ANOVA) was applied to study the significant differences between sites and months for different collected beetles. In case of significant differences, Duncan's Multiple Rang Test (DMRT) was selected to detect the distinct variances between means. The program Canoco 4.5 for windows was used to perform canonical corresponded analysis (CCA) as a unimodal method to analyze the response of the collected species of beetles and corresponding investigated ecological factors.

RESULTS

The Recorded Environmental Factors:

The temperature of air, soil temperature and wind velocity recorded highly amount in site VI (23.07±7.76, 18.09±0.77 and 5.72±1.18, respectively), soil pH was highest in the site I (6.59±0.40), while the relative humidity was higher in site II (45.61±9.92) (Table 1). There were no significant differences between environmental factors in the four sites. The investigated sites represented differences in the ground plants (Table 2).

Table 1. Mean ± standard deviation (SD) of investigated ecological factors at the study sites during the period of investigation and the statistical results.

Months	Site I			Site II			Site III			Site IV			F	P value
	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD		
Air Temp	22.87	±	7.76	22.52	±	7.80	22.67	±	7.76	**23.07**	±	7.76	0.017	0.997
Soil Temp	17.87	±	0.83	17.72	±	1.08	17.88	±	0.88	**18.09**	±	0.77	0.506	0.68
pH	**6.59**	±	0.40	6.46	±	0.26	6.48	±	0.31	6.44	±	0.35	0.713	0.547
R.H	43.61	±	9.93	**45.61**	±	9.92	44.61	±	9.92	41.67	±	9.98	0.517	0.672
W.V	5.67	±	1.28	5.65	±	1.22	5.66	±	1.25	**5.72**	±	1.18	0.013	0.998

Table 2.The differences among study sites in the ground plants.

Site I	Site II	Site III	Site IV
Phoenix dactylifera	*Punica granatum*	*Sesbania* aegyptiaca	*Acacia nilotica*
Beta vulgaris	*Citrus aurantifolia*	*Psium sativum*	*Ficus nitida*
Raphanus sativus	*Vitis vinifera*	*Vicia faba*	*Eucalyptus lobules*
Eruca sativa	*Hordeum vulgare*	*Allium cepa*	
Conocarpus erectus	*Triticum pyramidale*	*Allium sativum*	
Medicago sativa	*Solanum lycopersicum*		

The Collected Coleoptera:

The total number of beetles was 4725 individuals which belong to 7 species of beetles from one family, Tenebrionidae. The species were: *Akis elevata* Solier , *Prionotheca coronata* Olivier, *Mesostena angustata* Fabricius (= *Mesostena elegans* Solier; = *Mesostena punctate* Eschscholtz), *Trachyderma hispida* (Forskal) (= *Tenebrio hispida* Forskal; = *Ocnera hispida latreillei* Solier), *Akis reflexa* Fabricius , *Pimelia arabica* Klug and *Scaurus puncticollis* Solier . *A. elevata, P. coronata* were recorded in site I, *M. angustata, T. hispida* were recorded in site II, *A. reflexa* was recorded in site III, *Pimelia Arabica* was recorded in site IV and *S. puncticollis* was recorded in site III and IV (Table 3). There are highly significant differences of frequency among the collected species. The highest frequency was recorded by *A. elevata* (41.077).

Table 3.The mean values of densities (individual/day*trap) of collected beetles from the study sites during the period of investigation

Species	Site I			Site II			Site III			Site IV			F	P value
	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD		
Akis elevata	1.49	±	0.99	--------			--------			--------			41.077	<0.001
Prionotheca coronata	1.85	±	1.66	--------			--------			--------			22.440	<0.001
Mesostena angustata	--------			0.79	±	0.83	--------			--------			16.136	<0.001
Trachyderma hispida	--------			0.63	±	0.64	--------			--------			17.596	<0.001
Scaurus puncticollis	--------			--------			0.71	±	0.70**a**	0.35	±	0.42**b**	12.467	<0.001
Akis reflexa	--------			--------			0.54	±	0.49	--------			21.700	<0.001
Pimelia arabica	--------			--------			--------			0.36	±	0.29	28.387	<0.001
Total	3.34	±	2.41**a**	1.42	±	1.01**b**	1.24	±	0.90**b**	0.71	±	0.55**b**	**11.931**	<0.001

Composition and Abundance of The Collected:

Table (4) shows the mean of densities (individual/day*trap) for the collected beetles at different study sites. The highest mean density was in the site I at September (6.25±2.18), while the lowest mean of individuals was in site IV at February (0.24±0.19). In site I, the mean of *P. coronate* and *A. elevata* were higher in number of individual/day*trap in September and October, the mean of *M. angustata* recorded the highest number of individual/day*trap at October and mean of *T. hispida* was higher at November in site II, the mean of *S. puncticollis* was higher number of individual/day*trap at October in site III than at site IV, the mean of *A. reflexa* recorded the highest number of individual/day*trap at September and November in site III and the mean of *P. arabica* was higher number of individual/day*trap at September in site IV (Fig. 2).

Table 4. The mean values ±standard deviation (SD) of densities(individual/day*trap) for the collected beetles at different study sites during the period of investigation.

Months	Site I			Site II			Site III			Site IV		
	Mean	±	SD	Mean	±	SD	Mean	±	SD	Mean	±	SD
September	**6.25**	±	2.18	1.84	±	0.65	1.20	±	0.69	1.14	±	0.26
October	6.20	±	0.50	2.75	±	0.50	2.51	±	0.76	1.21	±	1.03
November	2.26	±	0.25	1.67	±	0.49	1.06	±	0.65	0.44	±	0.22
December	1.67	±	1.84	0.51	±	0.42	0.58	±	0.43	0.53	±	0.47
January	2.41	±	1.38	1.30	±	1.29	1.66	±	0.86	0.73	±	0.20
February	1.27	±	0.71	0.42	±	0.31	0.44	±	0.33	**0.24**	±	0.19

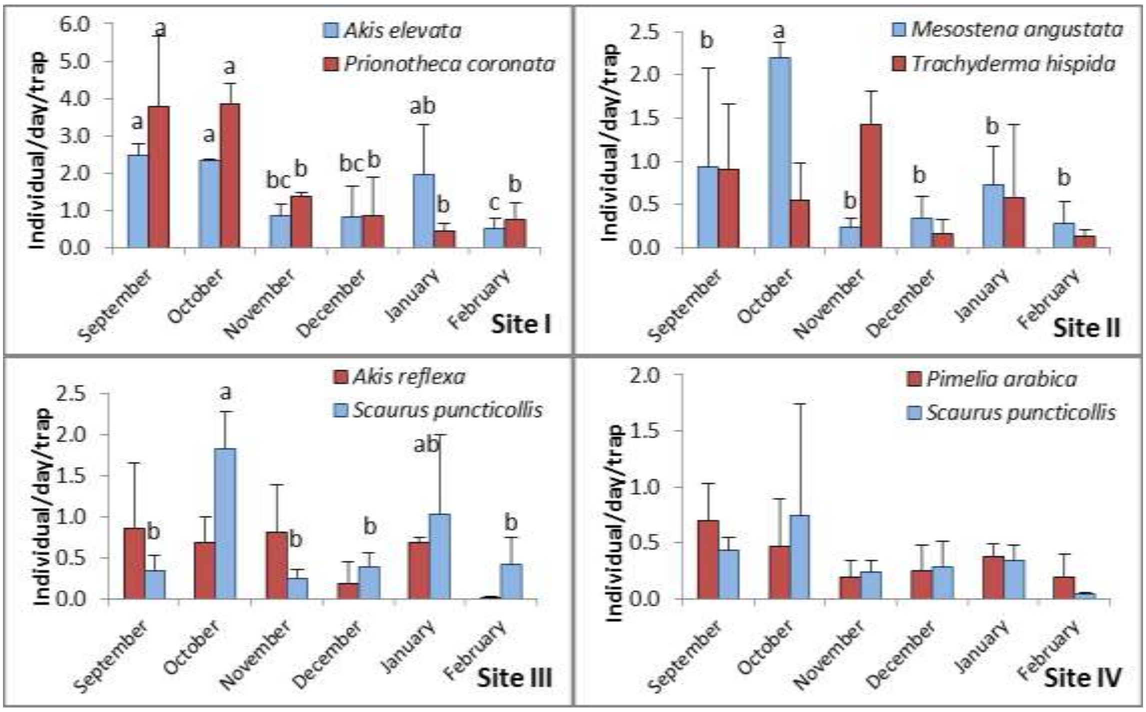

Fig. 2. Monthly variations for the mean density (individual/day*trap) of collected beetles at the studied sites during the period of investigation. (The similar characters for each species show no significant difference).

Statistical results:

Statistical test (ANOVA) was applied to show the significant differences between sites and months for different beetles species. Table (5) shows the results of this analysis, which can be summarized in the following points:

- There were significant differences in *A.elevata* at site I and *S. puncticollis* at site III.
- There were highly significant differences in *P. coronata* at site I and *M. angustata* at site II.

Canonical Corresponding Analysis (CCA) for the beetles was illustrated in figures (3); it shows that:

- *A. elevata* and *P. coronate* were positively correlated with air temperature and negatively correlated with soil pH.
- *Mesostena angustata*, *T. hispida* and *P. arabica* were positively correlated with soil temperature and wind velocity, while they were negatively correlated with relative humidity.
- *S. puncticollis* and *A, reflexa* were positively correlated with relative humidity and negatively correlated with soil temperature and wind velocity.

Table 5. ANOVA results for differences between monthly densities of collected beetle species at different study sites during the period of investigation

Sites	Source	Sum of Squares	df	Mean Square	F	P value
Site I	*Akis elevata*	11.104	5	2.221	4.916	**0.011**
	Prionotheca coronata	36.579	5	7.316	8.623	**0.001**
Site II	*Mesostena angustata*	8.356	5	1.671	5.955	**0.005**
	Trachyderma hispida	3.573	5	0.715	2.598	0.081
SiteIII	*Scaurus puncticollis*	5.622	5	1.124	5.079	**0.010**
	Akis reflexa	1.866	5	0.373	1.959	0.158
Site IV	*Scaurus puncticollis*	0.805	5	0.161	0.868	0.530
	Pimelia arabica	0.596	5	0.119	1.705	0.208

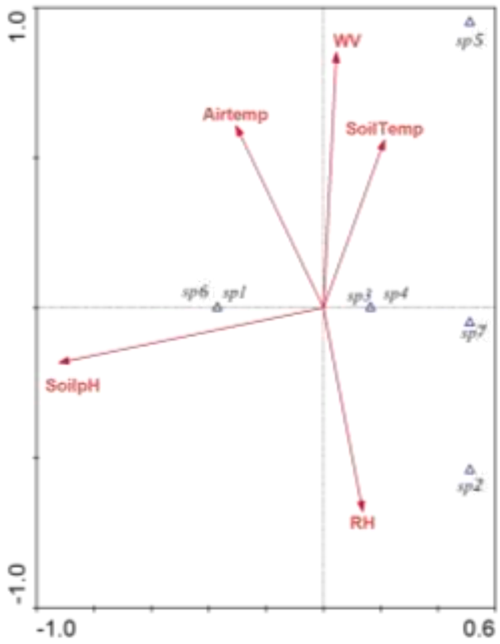

Fig. 3. Ordination diagrams of canonical correspondence analysis (CCA) of the collected species of beetles and corresponding investigated ecological factors. Species notation; sp1: *Akis elevata*, sp2: *Akis reflexa*, sp3: *Mesostena angustata*, sp4: *Trachyderma hispida*, sp5: *Pimelia arabica*, sp6: *Prionotheca coronate*, sp7: *Scaurus puncticollis*. Ecological factors notation; Airtemp: air temperature (°C), SoilTemp: soil temperature (°C), pH: soil pH, RH: relatively humidity (%), WV: wind velocity (knots).

DISCUSSION

The present results indicate that the abundance and diversity of the darkling beetles (Coleoptera: Tenebrionidae) are correlated with the site conditions. The relatively low abundance of tenebrionids (seven species) in the investigated study area may be due to the agricultural activities of this area. Aldryhim *et al*. (1992) found that cultivated area has lower tenebrionids abundance than uncultivated one. Li *et al*. (2016) noted that the beetle community is largely determined by plant cover and diversity. Similar results were observed during the current study whereas the beetle abundance and density were impacted by plant diversity. Relatively high plant diversity increase beetle densities. Plant groves may be the reason for the relatively low diversity of tenebrionid beetles in the investigated sites. Li *et al*. (2016) concluded that shrub plantations reduce beetle diversity. Many research illustrated that the main cause of reducing the biodiversity of many terrestrial ecosystem is the changes in the land use/ cover (Garnier *et al*., 2006; Krauss *et al*., 2010; Garcia-Tejero *et al*., 2013; Vergnes *et al*., 2014; Sweaney *et al*., 2015). Liu *et al*. (2015) concluded that shrub diversity and season variations are the significant factors for ground beetle assemblages in the desert ecosystem, while the responses of beetles varied among trophic and taxonomic levels.

Beetles are adept of existing in a wide range of arid environments (Marcuzzi 2005; Saji and Al Dhaheri, 2014). The thick sclerotization of body integument of adult tenebrionids helps them to be highly tolerating dry and hot conditions (Aldryhim *et al*., 1992; Piňero and Gómez, 1995; Saji and Al Dhaheri, 2011). They are able to survive under harsh environmental conditions as a result of physiological and behavioral adaptations (Cloudsley-Thompson, 2001; Carrara *et al*., 2011). Abd El-Wakeil *et al*. (2014) illustrated that Tenebrionidae escapes from tough climate by burying themselves underground to avoid the sand's very high temperatures emerging periodically each day (Seely *et al*., 1988). Many of them cover their exoskeleton by wax, which reflecting some of the sun's heat and protecting them from water loss (Chown and Nicolson, 2004).

Interaction of many environmental factors may control the variations in biodiversity; species composition, evenness and diversity indices, which include microclimate favorites, resource availability, habitat quality, grazing or the disturbance itself (Hardersen *et al*., 2014; Aldhafer *et al*., 2016). The present results indicated that species diversity of tenebrionids varied among the different investigated sites. Semida *et al*. (2001) illustrated that species diversity not only varied among the different localities but also, sometimes within localities. These differences may relate to the heterogeneous of habitat conditions which affect the spatial and temporal existence of beetles (Wiens 1976, Addicott *et al*., 1987; Niemelä *et al*., 1992; Yu *et al*., 2016). Ohwaki *et al*. (2015) mentioned that heterogeneity is a key feature determining biodiversity in agricultural landscapes (Weibull *et al*., 2000; Kato, 2001; Benton *et al*., 2003).

Several studies illustrated that seasonal fluctuation is a feature of most ecosystems, particularly in deserts, where the temperature and rainfall fluctuations affect animal productivity and activity (Ayal and Merkl, 1994; Blondel and Aronson, 1999; Miranda, 2007; Sackmann and Flores, 2009; Abd El-Wakeil *et al*., 2014; Liu *et al*., 2015; Bartholomew and El Moghrabi, 2018). Monthly variation of the recorded tenebrionid density was proved in the current study. Generally, higher densities of tenebrionids were recorded during September and October. Bartholomew and El Moghrabi (2018) recorded similar results for tenebrionids which inhabiting

Sharjah, United Arab Emirates. They recorded significantly higher beetle activity levels during the late autumn. They suggest that tenebrionid beetles prefer shrubs during hotter seasons of the year, because shrubs shelter them from extreme temperatures, not because of reduced predation risk or greater food availability. Liu *et al.* (2015) suggested that in autumn the food resources attracted beetle due to the decrease in solar radiation stress and soil temperature.

Hawkins *et al*. (2003) found a strong positive correlation between water availability and richness of a wide range of animal groups in water-limited environments. In contrasts with this the present results show negative correlation between the abundance of the collected *M. angustata, O. hispida* and *P. arabica* species with relative humidity. This is agreeing with the results recorded by Carrara *et al.* (2011). They illustrated that tenebrionid richness is significantly negatively related to water availability. The reasonable explanation of this negative relationship is that the organisms occupying a harsh environment with high energy and water availability may decrease their resource consumption rates to avoid water loss. Therefore, the relative strength of the conflicting effects of water and energy may effect on animal abundance (Mueller and Diamond, 2001; Williams and Tieleman, 2002; Carrara *et al.*, 2011). De Los Santos *et al*. (2002) showed that the beetles have the capacity to regulate haemolymph osmolarity, and reduced respiration rates for conflict to desiccation and adaptation to arid environments (Gehrken and Sømme, 1994). Soil moisture appears to be a limiting factor for the presence of tenebrionids (De Los Santos *et al*., 2002; El Surtasi *et al*., 2012).

Among the collected species, *Scaurus puncticollis* was the only species recorded in two sites (sites III and IV). Previous studies indicated that species of the genus *Scaurus* can inhabit a large variety of habitats (Mas-Peinado *et al*., 2013). This species has a wide geographic range (Löbl, *et al*., 2008). The abundance of *P. coronata* recorded the highest value (1.85±1.66 individual/day*trap) among the other seven collected species and it observed during the entire period of the study with peaks in September and October. Saji and Al Dhaheri (2011) documented that *P. coronat*a is one of the most abundant species as the most dominant in the terms of its density and monthly occurrence in the Western region of Abu Dhabi, UAE. They recorded that the highest number of this species was between October and November. The high density of this species may relate to the high rate of its mobility.

In conclusion, this work is the first to describe tenebrionid beetle assemblages in El-Kharga, New Valley Governorate, Egypt. The results indicated that the environmental fluctuations and human activities that affect vegetation structure would lead to variations in the community of tenebrionid beetles affecting the variety of ecosystem in which they are intricate. This highlights the significance of considering human activities of land reclamation for developing management policies to conserve biological diversity in arid ecosystems. The present information is vital for any future monitoring fluctuations in beetle communities and their role in biological cores within arid ecosystems.

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Compliance with Ethical Standards:

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Approval: All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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ARABIC SUMMERY

تأثير استصلاح الأراضي على تنوع الخنافس الداكنة من عائلة (Tenebrionidae) في النظام البيئي القاحل بمدينة الخارجة، محافظة الوادي الجديد ، مصر

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أستهدفت الدراسة الحالية تقييم تاثير استصلاح الأراضي على التوزيع والتنوع الشهري للخنافس الداكنة في مدينة الخارجة بمحافظة الوادي الجديد بمصر. جمعت الخنافس بواسطة المصائد الأرضية لمده ستة أشهر من سبتمبر 2015 حتي فبراير 2016 ، تم اختيار أربعة مواقع مستصلحة مختلفة. تم تجميع 4725 فرد تنتمي إلي 7 أنواع وهم : *Akis elevata, Prionotheca coronata, Mesostena angustata, Ocnera hispida, Akis reflexa, Pimelia arabica* and *Scaurus puncticollis* . كان هناك فروق معنوية بين الأربعة مواقع في تواجد الأنواع .تم تسجيل أعلى كثافة من إجمالي الخنافس في موقع تم استصلاحه لفترة طويلة ؛ الموقع الأول (1.68 ± 1.7 فرد / يوم * مصيدة). كان النوع *P. coronate* أعلي الأنواع كثافة (١,٨٥ ± ١,٦٦ فرد / يوم * مصيدة). أوضحت الدراسة أن هناك أختلاف في التوزيع الشهرى لكثافة الخنافس في المواقع محل الدراسة .أظهرت الأنواع *A. elevata, P. coronate, M. angustata* and *S. puncticollis* زيادة معنوية في شهر أكتوبر. أوضح التحليلات أن وفره وتنوع الخنافس مرتبط بقيمة الرقم الهيدروجيني للتربة وكذلك سرعة الرياح والرطوبة النسبية. تشير النتائج إلى أن استصلاح الأراضي أدى إلى اختلافات في مجتمع الخنافس الداكنة.