Long-Term Species Diversity and Climate Change: An Intimate Relationship Over the Last Ten Decades : Case Study in Egypt

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Contents

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Abstract

Egypt belongs to drylands of N. Africa, including the semiarid province in its Mediterranean coastal belt. Generally, arid land is the most vulnerable to climatic changes. The future vegetation trend in such arid land can be achieved through scenarios based on the long-term field observations of certain geographic regions. The current work is dealing with the current floristic composition compared to that of the last successive ten decades in the Egyptian desert, to elucidate the spatial distribution of some indicator species to demonstrate its response to the climatic changes. The results revealed a poleward shift of some indicator Mediterranean and SaharoSindian species, in addition to the decline in Mediterranean species number and evenness and notable number and evenness increase in the SaharoSindian species. Genetic flexibility in response to the climatic change of some indicator species (the shrubby *Retama raetam* and annual *Vicia monantha*) using ISSR during the last four decades will also be presented. The retrieved molecular variations revealed that the shrub species *R. raetam* has higher genetic variation than the annual *V. monantha* in response to the in situ climate change during the period 1976 to 2018. Such a study provides a case study for the effect of climatic changes in arid land vegetation, to support the future climatic scenarios.

Keywords

Mediterranean vegetation · Climatic change · Poleward shift · Arid land vegetation · Genetic flexibility

Introduction

The Mediterranean coastal land is one of the richest phytogeographical territories in Egypt. It extends 970 km from Sallum on the Egyptian-Libyan border in the west to Rafah on the Egyptian-Palestine border in the east with an average coastal belt of 15–20 km, in a north-south direction (El-Hadidi 1980). Sallum site, representing the most western limit of the Mediterranean coastal land of Egypt, is characterized by attenuated desert climate.

The phytogeographic position of this site lies within the Mediterranean/Saharo-Arabian regional transition zone, and accordingly its floristic elements comprised both the Mediterranean and SaharoSindian elements. The vegetation and floristic composition of the Mediterranean coastal belt in Egypt was subjected to earlier studies such as Täckholm and Drar, Montasir and Hassib (1956), Täckholm, El-Hadidi (1980, 2000), Boulos (1999, 2000, 2002), Cope and Hosni (1991), Boulos and El-Hadidi (1994), and El-Hadidi and Fayed (1994/95). Kamal (1988), Fakhry (1994), and Shaltout et al. (2015) studied selective in Mareotis sector.

Climatic factors are the master of all environmental factors that control not only the growth of plants but also the development, distribution, relative abundance, and densities of the vegetation of the earth (Cramer et al. 2001; Booth and Grime 2003; Scholze et al. 2006). Plant populations can respond to climate change in three ways:

by avoidance/shifting in distribution range to suitable habitats, responding and adjusting to the changes by phenotypic plasticity without altering their genetic constitution, and adaptation to these changes through genetic alteration, the process called "evolution" (Davis et al. 2005; Reusch and Wood 2007). In addition, shifts in the distributions of various species toward the poles and to higher altitudes were reported by many authors such as Parmesan and Yohe (2003), Root et al. (2003), Walther et al. (2005), Wilson et al. (2005), Franco et al. (2006), and Hickling et al. (2006); distribution alterations of most types of vegetation by Cramer et al. (2001) and Scholze et al. (2006); and changes in species and communities by Parmesan (1996), Brown et al. (1999), Parmesan (2007), Pounds et al. (1999), and Thomas and Lennon (1999).

Previous studies described the evolutionary responses and genetic variations in response to climate change (Davis and Shaw 2001; Davis et al. 2005; Reusch and Wood 2007; Anderson et al. 2012; Pauls et al. 2013). Others reported the genetic variation in response to gradients of temperature and water availability in many plant species (Kelly et al. 2003; Owuor et al. 1997; Jump et al. 2006, 2009; Parisod and Christin 2008; Manel et al. 2010; Franks 2011; Hegazy et al. 2014).

The climate change scenarios suggest that there is considerable uncertainty about possible future ecological impact, and some scenarios produce opposite signs for ecological responses (Bachelet et al. 2001; Hegazy et al. 2008a). In addition, Parmesan (2007) claimed that only long-term field observations can reveal complex interdependencies between species, an essential component in estimating future responses to global warming.

Hitherto, previous studies in the past few decades did not cover the impact of climatic change (mainly temperature and rainfall) on floristic composition and genetic traits of species under long-term climatic changes in Egypt.

This study was carried out to analyze the floristic composition, species richness, evenness, and species diversity during the last ten decades (1925–2018), in Sallum site, to provide a past, present, and the expected future vegetation trend, and to elaborate the following: (**1**) vegetation change through the last ten decades in terms of species types and chorology, (**2**) the impact of climatic changes as represented by temperature and rainfall, (**3**) the northward desert expansion monitored as a spatial distribution of xerophytic species, and (**4**) the genetic alteration in two wild species over the past few decades on perennial shrub *Retama raetam* and the annual herb *Vicia monantha*.

Material and Methods

Study Area

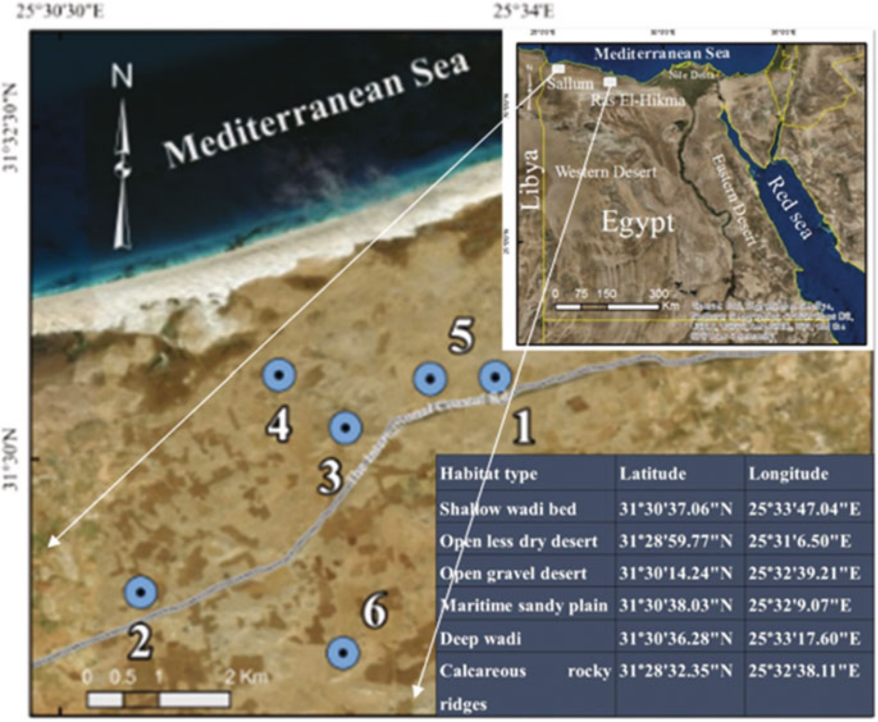
Sallum site is a limestone plateau dissected with shallow wadies running south to north which ends with limestone ridge close to the sea shore of about 200 m asl (El-Hadidi 2000). Sallum site is bordered from the east by Ras El Hekma in the east at 27°51′E and 31°15′N that extends to 10 km westwards to Sallum city at 25°

9′25.32″E and 31°34′38.81″N. The site extends from the seashore and runs 15 km southward to the fringes of the Diffa plateau (Map 1). This site was selected based on literature data and approved by field excavation to be free (as far as possible) from human impact.

Vegetation Analysis

The field observation and literature data indicate that the vegetation and soil showed considerable variability in this site. Six quadrats (each 20 × 20 m^2) were selected to cover the different vegetation and habitat types, namely: shallow wadi, open desert with moist sand sheet, open gravel desert, calcareous-maritime sandy plain, deep wadi, and the limestone rocky ridge (Map 1).

The species in each quadrate were counted and identified and representative samples deposited in Cairo University Herbarium (CAI). The sites were positioned using GPS model BHC NAVA 300 (positioned in Map 1 as the quadrate center point). The identification of species was based on voucher herbarium specimens and the taxonomic reference books. The previous species composition was compiled from earlier studies such as El-Hadidi and Ayyad (1975), Shaltout (1985), El-Hadidi



Habitat type	Latitude	Longitude
Shallow wadi bed	31°30'37.06"N	25°33'47.04"E
Open less dry desert	31°28'59.77"N	25°31'6.50"E
Open gravel desert	31°30'14.24"N	25°32'39.21"E
Maritime sandy plain	31°30'38.03"N	25°32'9.07"E
Deep wadi	31°30'36.28"N	25°33'17.60"E
Calcareous rocky ridges	31°28'32.35"N	25°32'38.11"E

Map 1 Sallum site with characteristic habitats, represented by quadrates (1–6)

et al. (1986), El-kady and Sadek (1992), Kamal and El-kady (1993), Ayyad and Fakhry (1996), El Garf (2003), Salama et al. (2003, 2005), Osman et al. (2009), Osman and El Garf (2015), and Abdelaal et al. (2019).

The studied ecological parameters (species density, relative density, frequency, relative frequency, cover, relative cover, and importance value (IV)) were calculated, based on Phillips (1959).

Study Species

Mature seeds of the study species were collected in April 2018 from the standing plant populations in Burg El Arab area, 60 km east of Sallum site. The old seeds collected in 1975 were preserved in the storage chamber in Cairo University Herbarium (CAI). The old seeds and the seeds collected in 2018 were collected from the same localities.

Retama raetam (Forssk.) Webb & Berthel. (Leguminosae) is an evergreen perennial desert shrub that inhabits the arid ecosystems around the Mediterranean basin and belongs to Mediterrranean-IranoTuranian-SaharoSindian chorotype.

Vicia monantha Retz. (Leguminosae) is an annual herb that is widely spread in the western Mediterranean coast and belongs to the Mediterrranean-IranoTuranian chorotype.

DNA Extraction

Genomic DNA was extracted from seeds of the study plant species following Pallotta et al. (2003). Exact 0.5 g of seed powder was ground in liquid nitrogen and homogenized in 500 μl lysis buffer (0.1 M Tris-HCl, 0.05 EDTA, 1.25% SDS, pH = 8) and incubated at 65 °C for 30 min. The samples were cooled down and mixed with 250 μl of 6 M ammonium acetate for 15 min on ice and then centrifuged at 4000 rpm for 15 min. DNA in the supernatant was precipitated with 360 μl cold isopropyl alcohol and kept frozen for 20 min. The DNA pellet was centrifuged at 4000 rpm for 15 min and washed twice in 70% ethanol. Briefly dried pellet was dissolved in 100–200 μl sterile double distilled H_2O. DNA concentration was measured by spectro-photometer on 1% agarose gel.

Estimation of the DNA

The concentration of DNA was carried out in sample of 2 μl from the parent's DNA samples on 1% agarose gel in comparison to 10 μl of a DNA size marker (lambda DNA Hind III digest Phi X 174/Hae III digest). The degree of fluorescence of the DNA sample with the different bands in DNA size marker was compared.

ISSR-PCR Reactions

A set of 10 of ISSR primers (sequence outlined in Table 3) was used in the detection of polymorphism. The amplification reaction was carried out in 25 μl reaction volume containing 1X PCR buffer, 1.5 mM $MgCl_2$, 0.2 mM dNTPs, 1 μM primer, 1 U Taq DNA polymerase, and 30 ng template DNA.

Thermocyling Profile and PCR Products

PCR amplification was performed in a Perkin Elmer/GeneAmp® PCR System 9700 (PE Applied Biosystems) programmed to fulfill 35 cycles after an initial denaturation cycle for 5 min at 94 °C. Each cycle consisted of a denaturation step at 94 °C for 1 min, an annealing step at 45 °C for 1 min, and an elongation step at 72 °C for 1.5 min. The primer extension segment was extended to 7 min at 72 °C in the final cycle. The amplification products were resolved by electrophoresis in a 1.5% agarose gel containing ethidium bromide (0.5ug/ml) in 1X TBE buffer at 95 volts. A 100 bp DNA ladder was used as a molecular size standard. PCR products were visualized on UV light and photographed using a Gel Documentation System.

Data Analysis

The banding patterns generated by ISSR-PCR marker analyses were compared to determine the genetic relatedness of the samples. Clear and distinct amplification products were scored as “1” for presence and “0” for absence of bands. Bands of the same mobility were scored as identical. Genetic similarity coefficient (GS) between two genotypes was estimated according to Dice coefficient.

$$\mathrm{GS_{ij}} = 2a/(2a + b + c)$$

where GSij is the measure of genetic similarity between individuals “I” and “j,” “a” is the number of bands shared by “I” and “j,” “b” is the number of bands present in “i” and absent in “j,” and “c” is the number of bands present in “j” and absent in “I.” The similarity matrix was used in the cluster analysis, and the distances between the old “i” and recent “j” populations are defined by the chosen distance measure (Dice coefficient). The UPGMA (Unweighted Pair Group Method using Arithmetic Average) was according to Sneath and Sokal.

The Mediterranean climate is characterized by mild wet winters and warm to hot, dry summers and may occur on the west side of continents between about 30° and 40° latitudes.

Climatic Data

Based on the climatic data retrieved from the "National Meteorological Authority in Egypt" of Sallum Plateau station (No. 305), latitude 31° 57′ longitude 25° 13′ and elevation 6 m), covers the last nine decades (92 years) from 1925 to 2017. The mean values of temperature and rainfall are shown in Fig. 1, for the transitional periods: 1925–1950, 1946–1975, 1976–2000, and 2001–2017. The fundamental climate is the arid Mediterranean with mild winters, where January is the coldest month with mean minimum temperature ranges from 14.8 °C during the period from 1925 to 1950 to 18.5 °C (1976–2000). It reached 17.3 °C during the last 17 years (2001–2017). August is the hottest month with a mean maximum temperature 30.1 °C (1925–1950) that increased to 31.1 °C (1976–2000), and beyond this, the temperature was 31.6 °C during the last 17 years (2001–2017).

The distribution of the mean annual rainfall (Fig. 1) shows a sharp decrease from about 241.2 mm/year during the period 1925–1950 to 105.0 mm/year in 1946–1975 and 98.9 mm/year in 1976–2000. During the last period 2001–2017, rainfall was significantly lower; it reached 53.8 mm/year. Winter is the main rainy season, with a maximum amount of rainfall during the 4 months November to February. The average maximum monthly rainfall moved from November in 1925–1950, where rainfall value reached 51.09 mm and decreased to 23.9 mm in 1946–1976, to January in 1976–2000, where 29.4 mm was the maximum amount recorded in December (2001–2017), with lower values reaching 15.7 mm.

Results

Vegetation

Vegetation pattern of Sallum site (Table 1), during 2018, was distinguished to the six habitats (full data was elaborated by Amer et al. 2020), and the characteristic species in each quadrate will be elaborated here:

Shallow wadi bed "Q1": This habitat type was characterized by a fine sand sheet of total vegetation cover c. 23%. It shows that this habitat is dominated by annual legume species, namely, *Astragalus peregrinus* (IV 25.6) and A. *annularis* (IV 23.9), and co-dominated by Mediterranean perennial species like *Asparagus stipularis* (IV 14.0), *Asphodelus aestivus* (IV 12.6), *Lotus polyphyllos* (IV 13.0), and *L. creticus* (IV 10.12). In addition to the notable presence of the SaharoSindian species (*Deverra tortuosa;* IV 19.2).

Open less dry non-saline desert "Q2": This habitat is dominated by perennial xeric vegetation which reached a cover of 17%, including *Haloxylon salicornicum* (IV 38.7) and *Helianthemum lippii* (IV 33.7), and co-dominated by *Deverra tortuosa* (IV 23.8) and *Gymnocarpos decandrus* (IV 19.7).

Open gravel desert "Q3": This habitat showed a total plant cover of 22%, dominated by perennial Mediterranean-SaharoSindian chorotype: *Thymelaea hirsuta* (IV 34.5), *Gymnocarpos decandrus* (IV 17.0), and *Marrubium alysson* (IV

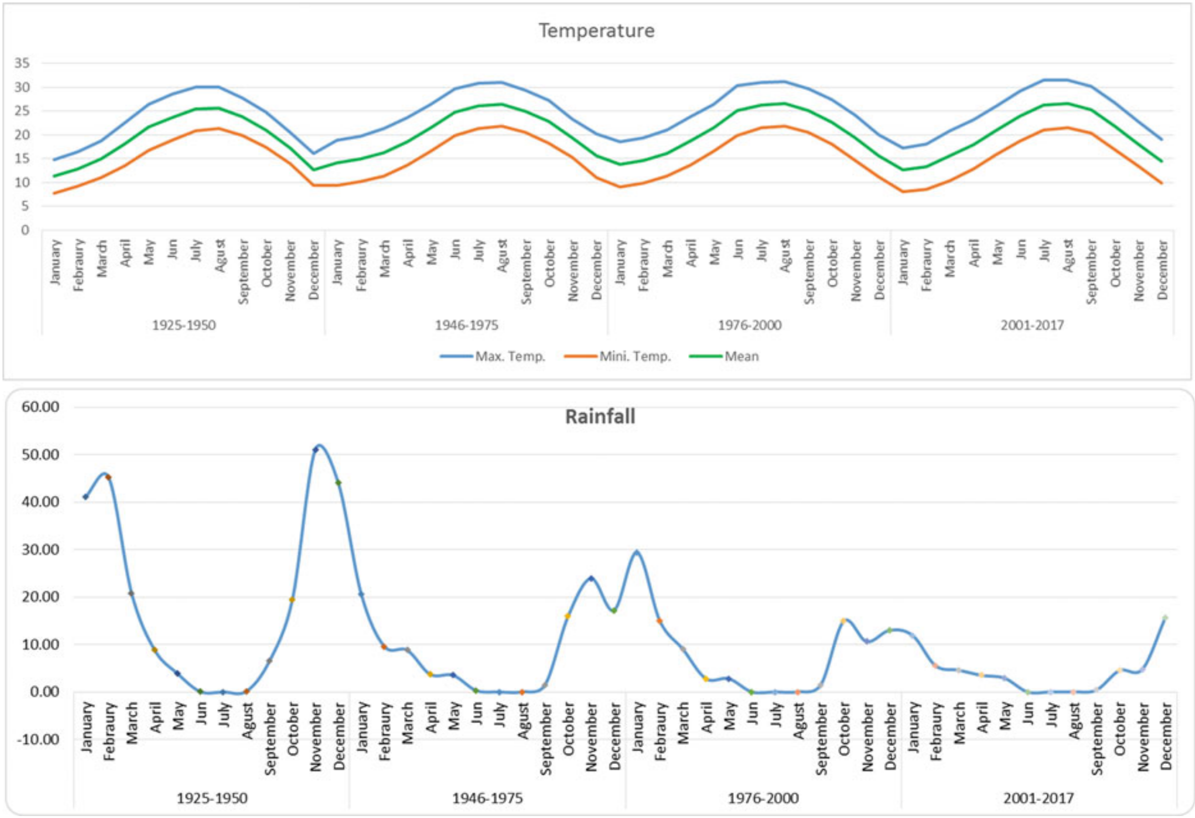


Fig. 1 Indicator climatic data of Sallum site as mean values of the studied decades. (Based on the data retrieved from the National Meteorological Authority in Egypt; Amer et al. 2020)

Table 1 Ecological parameters in Sallum site vegetation (in 2018), represented by Quadrates "Q1–Q6" (species arranged based on IV/quadrate & C% = cover percentage)

Species	Life form	Floristic categories	C %	IV
Q1: Shallow wadi bed with total vegetation cover 23%				
Astragalus peregrinus Vahl	Annual	SA-SI	5	25.6
Astragalus annularis Forssk.	Annual	MED + SA-SI	5	23.9
Deverra tortuosa (Desf.) DC.	Perennial	SA-SI	3	19.2
Asparagus stipularis Forssk.	Perennial	MED	2	14.0
Hyoscyamus muticus L.	Perennial	MED + IR-TR	2	13.0
Lotus polyphyllos E. D. Clarke	Perennial	MED	1	13.0
Asphodelus aestivus Brot.	Perennial	MED	2	12.6
Lotus creticus L.	Perennial	MED	1	10.1
Marrubium alysson L.	Perennial	MED + SA-SI	1	9.2
Brassica nigra (L.) Koch	Annual	MED + ER-SR	1	8.6
Q 2: Open less dry non-saline desert plain with total vegetation cover 17%				
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	Perennial	SA-SI + IR-TR + S-Z	6	38.7
Helianthemum lippii (L.) Dum. Cours.	Perennial	SA-SI + S-Z	5	33.1
Deverra tortuosa (Desf.) DC.	Perennial	SA-SI	3	23.8
Gymnocarpos decandrus Forssk.	Perennial	MED + SA-SI	2	19.7
Salsola kali L.	Annual	PAL	1	10.5
Q3: Gravel desert with total vegetation cover 22%				
Thymelaea hirsuta (L.) Endl.	Perennial	MED + SA-SI	6	34.5
Zygophyllum album L.f.	Perennial	MED + SA-SI	4	21.5
Lycium europaeum L.	Perennial	MED	3	19.6
Gymnocarpos decandrus Forssk.	Perennial	MED + SA-SI	2	17.0
Marrubium alysson L.	Perennial	MED + SA-SI	1.5	11.7
Echinops spinosus L.	Perennial	MED	0.8	11.6
Helianthemum lippii (L.) Dum. Cours.	Perennial	SA-SI + S-Z	1.6	11.0
Peganum harmala L.	Perennial	MED + IR-TR + SA-SI	0.6	7.5
Herniaria hemistemon J. Gay	Perennial	MED	0.3	7.4
Astragalus peregrinus Vahl	Annual	SA-SI	0.5	6.1
Asparagus stipularis Forssk.	Perennial	MED	0.1	5.8
Farsetia aegyptia Turra	Perennial	SA-SI + S-Z	0.1	5.4
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	Perennial	SA-SI + IR-TR + S-Z	0.4	5.3
Zilla spinosa (L.) Prantl	Perennial	SA-SI	0.3	4.8
Anabasis articulata (Forssk.) Moq.	Perennial	SA-SI	0.2	3.5
Urginea maritima L.	Perennial	MED + ER-SR	0.5	3.4
Neurada procumbens L.	Annual	SA-SI	0.1	3.0
Q 4: Maritime non-saline sand dunes with total vegetation cover 13%				
Carduncellus mareoticus (Delile) Hanelt	Perennial	MED	5	43.9
Lotus creticus L.	Perennial	MED	2	21.1

(continued)

Table 1 (continued)

Species	Life form	Floristic categories	C %	IV
Asparagus stipularis Forssk v. *tenuispinus* Holmboe	Perennial	MED	2	20.7
Pancratium maritimum L.	Perennial	MED	2	17.1
Lotus polyphyllos E. D. Clarke	Perennial	MED	1	16.3
Ononis vaginalis Vahl	Perennial	SA-SI + IR-TR	1	9.8
Q 5: Deep wadi with total vegetation cover 19%				
Atractylis carduus (Forssk.) C. Chr.	Perennial	MED + SA-SI	5	32.2
Astragalus mareoticus Delile	Annual	MED	5	29.6
Hippocrepis cyclocarpa Murb.	Annual	MED	4	24.3
Thymelaea hirsuta (L.) Endl.	Perennial	MED + SA-SI	3	23.0
Marrubium alysson L.	Perennial	MED + SA-SI	1	10.1
Citrullus colocynthis (L.) Schrad.	Perennial	SA-SI	1	7.7
Q6: Calcareous rocky ridge with total vegetation cover 18%				
Deverra tortuosa (Desf.) DC.	Perennial	SA-SI	6	39.5
Herniaria hemistemon J. Gay	Perennial	MED	5	33.8
Thymelaea hirsuta (L.) Endl.	Perennial	MED + SA-SI	3	23.8
Gymnocarpos decandrus Forssk.	Perennial	MED + SA-SI	2	19.0
Farsetia aegyptia Turra	Perennial	SA-SI + S-Z	1	10.5
Salsola kali L.	Annual	PAL	1	10.2

11.7). The mono-regional Mediterranean species is represented by the four species: *Lycium europaeum* (IV 19.5), *Echinops spinosus* (IV 11.6), *Herniaria hemistemon* (IV 7.4), and *Asparagus stipularis* (IV 5.8). However, Zygophyllum *album* (IV 21.5), *Astragalus peregrinus* (IV 6.1), *Neurada procumbens* (IV 3.0), *Zilla spinosa* (IV 4.8), and *Anabasis articulata* (IV 3.5) are the mono-regional xeric (SaharoSindian chorotype).

Maritime sand dunes "Q4": This habitat is of non-saline type, with the lowest vegetation cover (13%; Table 1) among the studied habitats. Psamophyte perennials of Mediterranean chorotype are the dominant species, namely: *Carduncellus mareoticus* (IV 43.9), *Lotus creticus* (IV 21.1), *Asparagus stipularis* (IV 20.9), *Pancratium maritimum* (IV 17.1), and *Lotus polyphyllos* (IV 16.3). The IranoTuranian-SaharoSindian chorotype is presented by the calcareous sand dune indicator *"Ononis vaginalis*; IV 9.8."

Deep wadi "Q5": The annuals were co-dominant with perennials in 19% total cover. Mediterranean SaharoSindian perennial species are the dominant species, namely, *Atractylis carduus* (IV 32.2), *Thymelaea hirsuta* (IV 23.0), and *Marrubium alysson* (IV 10.1), and two annuals (*Astragalus mareoticus* IV 29.6 and *Hippocrepis cyclocarpa* IV 24.3), of Mediterranean chorotype.

Calcareous rocky ridge "Q6": The calcareous limestone rocky ridges habitat type (not exceeding 20 m asl) with total vegetation cover reaching 18% is dominated by the xeric SaharoSindian perennial element (*Deverra tortuosa*; IV 39.5) and co-dominated by Mediterranean *Herniaria hemistemon* (IV 33.8). In contrast, the Mediterranean-SaharoSindian chorotype was represented by the common xeric species, namely: *Thymelaea hirsuta* (IV 23.8), *Gymnocarpos decandrus* (IV 19.0), and *Farsetia aegyptia* (IV 10.4).

Taxonomic Grouping

A total of 198 species (45 families of phanerogams and Ephedraceae from the vascular cryptogams) were identified from this site during a field study in 2018. Five families represented 60.6% out of the total recorded species, namely: Asteraceae (40 species), Leguminosae (27 species), Gramineae (25 species), Chenopodiaceae (18 species), and Brassicaceae (10 species). Forty families were represented by few species, like Labiatae (5 species) and Boraginaceae (6 species), and one species for the rest 18 families.

Sallum vegetation traced in 2018 is of simple form comprising 41.9% annuals and 58.1% perennials. Annual species were represented in Asteraceae (23 species), Leguminosae (19 species), Gramineae (10 species), and Brassicaceae (8 species). The highest number of perennials was recorded in Chenopodiaceae (15 species).

Chorological Analysis

The chorology of the identified species in Sallum site during 2018 is shown in Table 2. The total mono-regional species represented 41.9% (83 species), followed by bi-regionals with 40.9% (81 species), and the pleuri-regionals comprise 17.1% (34 species) of the total chorotypes. The typical Mediterranean species represent 21.2% (42 species) of the total recorded species such as the Mediterranean species: *Arisarum vulgare*, *Caralluma europaea*, *Hyoseris radiata*, *Lobularia libyca*, *Elymus fractus*, *Lotus polyphyllos*, *Lycium europaeum*, and *Thymelaea hirsuta*.

Generally, the Mediterranean chorotype is the dominant type (42 species), followed by SaharoSindian (40 species), and the Mediterranean elements extended to the SaharoSindian region which is represented by 41 species. The Mediterranean elements extended to the IranoTuranian region that was represented by 10 species. *Allium aschersonianum* is the only species recorded from the mono-regional IranoTuranion chorotype.

Vegetation Feature in the Last Ten Decades

The long-term floristic survey covers the period from 1925 to 2018. The climatic data showed the negative shift in rainfall and positive temperature shift (Fig. 1). The reflection of these shifts on the species presence and diversity in Sallum site will be elucidated as a comparison between the historical and the field surveys during 2018 as follows:

Table 2 Chorotypes of the plant species collected from Sallum site (in 2018)

Pytochoria	Number of species	Percentage (%)
Mono-regionals	42	21.2
MED	40	20.2
SA-SI	1	0.5
IR-TR **Sub-total**	**83**	**41.9%**
Bi-regionals	41	20.7
MED + SA-SI	10	5.0
MED + IR-TR	13	6.5
MED + ER-SR	8	4.0
SA-SI + IR-TR	8	4.0
SA-SI + S-Z	1	0.5
IR-TR + S-Z		
Sub-total	**81**	**40.9%**
Pleuri-regionals	10	5.0
MED + SA-SI + IR-TR	5	2.5
MED + IR-TR + ER-SR	5	2.5
MED + SA-SI + S-Z	3	1.5
IR-TR + SA-SI + S-Z	2	1.0
MED + SA-SI + ER-SR	1	0.5
MED + IR-TR + SA-SI + ER-SR	4	2.0
COSM	2	1.0
PAL	1	0.5
PAN	1	0.5
NEO **Sub-total**	**34**	**17.1%**
Total	**198**	**99.9%**

Abbreviations: MED, Mediterranean; SA-SI, SaharoSindian; ER-SR, EuroSiberian; IR-TR, IranoTuranian; S-Z, SudanoZambezian; COSM, Cosmopolitan; PAI, Palaeotropic; PAN, Pantropic; NEO, Neotropic

Characteristic species of this study site, from 1925 to 2018, include *Globularia arabica*, *Diplotaxis erucoides*, *Lathyrus marmoratus*, *Scorzonera undulata*, *Noaea mucronata*, *Lycium europaeum*, *Sporobolus pungens*, *Teucrium polium*, *Melilotus messanensis*, *Polygonum maritimum*, *Gagea fibrosa*, *Marrubium alysson*, *Caralluma europaea*, and *Asphodelus aestivus*.

During the past decades, the five families, namely, Asteraceae, Leguminosae, Gramineae, Brassicaceae, and Chenopodiaceae, were the common families as represented with a relatively high number of species. The number of species in four of these families decreased in the recent years. However, the family Chenopodiaceae possesses salt-tolerant species showed higher evenness after 2000 such as *Atriplex halimus*, *Suaeda aegyptiaca,* and *Sarcocornia fruticosa*. The field observation and the literature survey about the vegetation in Sallum site showed an increase in species evenness and diversity of the halophytic and halotolerant species. Among the species recorded in this site for the first time after 1950 were *Mesembryanthemum crystallinum* and *Mesembryanthemum forsskalii. Mesembryanthemum nodiflorum* was traced after 2000. Other species showed northward expansion after 2000 as *Arthrocnemum macrostachyum*, *Atriplex halimus*, *Suaeda pruinosa*, *S. vera* (Chenopodiaceae), and *Spergularia marina* (Caryophyllaceae).

The mean total number of species recorded in the study site decreased from 226 species (1925–1950) to 198 species (2001–2018). A similar trend was noticed in perennial species which decreased from 128 species (56.6%; in 1925–1950) to 115 species (58.0%; in 2001–2018). Annuals decreased from 43.3% (98 species) to 41.9% (83 species), in the same intervals. Some of the annual species of Mediterranean-SaharoSindian chorotype were not recorded after 1975, such as *Hippocrepis areolata*, *Astragalus annularis*, and *Medicago littoralis*.

Chorotype Shifting

The Mediterranean elements: The chorology of the vegetation elements (species) showed a shift from Mediterranean, IranoTuranian, and EuroSiberian to more xeric elements of SaharoSindian chorotype during the studied ten decades. The number of species grouped under Mediterranean chorotype decreased from 70 species (30.6%) in 1925–1950 to 42 species (21.2%) in 2001–2018 (Fig. 2). Among the Mediterranean elements, not recorded after 1950, is the *Prasium majus*. Other species were not recorded after 1975 including *Daucus syrticus*, *Malabaila suaveolens*, *Arisarum vulgare*, *Erucaria hispanica*, *Alkanna lehmannii*, *Ajuga iva*, and *Hymenocarpos circinnatus*. Some of the Mediterranean species sustained to 2018, but showed decreased evenness after year 2000, including *Lathyrus marmoratus*, *Astragalus hamosus*, *Papaver rhoeas*, and *Limonium narbonense*.

Mediterranean-IranoTuranian elements: The elements of this chorotype decreased from 36 species (15.9%; in 1925–1950) to 10 species (5.0%; in 2001–2018). Some of these species are not recorded after 1950 such as *Plantago lagopus*, while some other species not recorded after 1975 include *Narcissus tazetta*, *Eryngium campestre*, *Garhadiolus angulosus*, *Phagnalon rupestre*, *Ranunculus*

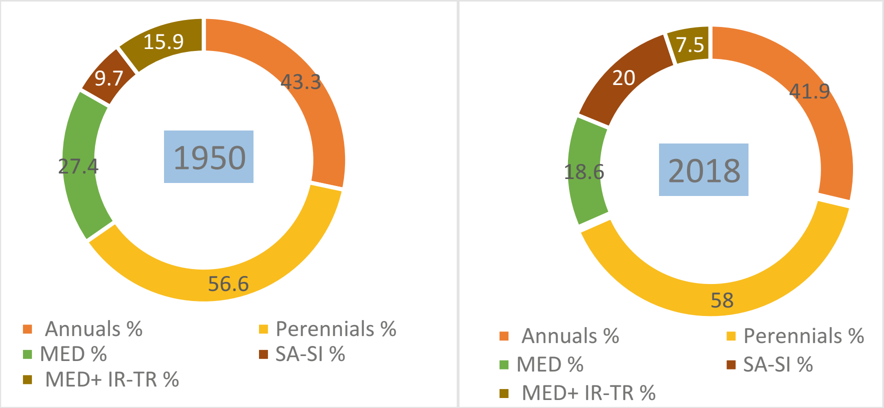


Fig. 2 Change in indicator features of Sallum site vegetation from 1950 to 2018

asiaticus, and *Lathyrus gorgonei*. Alternatively, populations of some species decreased in the number of individuals with time such as *Teucrium polium*, *Melilotus messanensis*, *Ranunculus rionii,* and *Chenopodium giganteum*.

A contradictory observation was noticed for the halophytic species of the Mediterranean-IranoTuranian chorotype, which showed increased occurrence in its northward distribution such as *Cressa cretica* and *Spergularia marina*. Elements of the Mediterranean-EuroSiberian chorotype showed decline as *Echium rubrum* was not recorded after year 1950 and *Brassica nigra* was not recorded after year 2000, while *Polygonum maritimum* was occasionally recorded after year 2000, in lower species evenness. The halophytic *Sarcocornia fruticosa* showed wider northward distribution and an increase in the number of individuals/population after year 2000.

SaharoSindian elements: The species belonging to this chorotype reflect the xeric nature, where the number of species increased from 22 species (9.7%) in 1925–1950 to 40 species (20.2%) in 2001–2018 (Fig. 2). The common xeric species such as *Deverra tortuosa*, *Anthemis melampodina*, *Heliotropium arbainense*, and *Heliotropium digynum* were traced after 1950. In contrast, *Zilla spinosa*, *Zygophyllum simplex*, and *Fagonia cretica* showed a wider northward distribution after year 2000.

Pluri-regional elements: The elements of Mediterranean-IranoTuranian-EuroSiberian chorotype decreased in the number of individual/population such as *Senecio vulgaris* and *Papaver argemone*, which showed decreased in species evenness after year 1975. Some other species disappeared after 1975 including *Frankenia hirsuta*, *Frankenia pulverulenta*, *Fumaria bracteosa*, and *Beta vulgaris*.

Plant Molecular Variations

Molecular variations over the two transitional periods 1976–2000 and 2001–2017 as tested by ISSR markers are shown in Table 3. A total of 95 scoreable bands were recovered, which varied from 6 to 14 bands/primer. Primers, number 5, revealed monomorphic bands in both species.

- ***Retama raetam:*** A total of 76 bands were retrieved, with 59 monomorphic (77%) and 17 polymorphic (Table 3). Of the polymorphic bands, 14 bands appeared in the time period 1976–2000 and 3 bands in the time period 2001–2017. The five ISSR primers 2, 4, 5, 9, and 10 showed only monomorphic bands in the two populations of the periods 1976–2000 and 2001–2017. The remaining primers showed polymorphic bands.
- ***Vicia monantha:*** A total of 67 bands are detected with the used primers with 61 (91%) monomorphic and 6 polymorphic bands (Table 3). The characteristic polymorphic bands are five bands in the population of the time period 1976–2000, and the remaining band appeared in the population of the time period 2001–2017. Seven primers, numbers 1, 3, 4, 5, 6, 9, and 10, showed monomorphic

Table 3 **Indicator primers for genetic variability in the studied species.** (Bands scored as a = monomorphic bands (bands shared by i (old) and j (recent) populations) and polymorphic bands: b is the number of bands present in i only, and c is the number of bands present in j only)

Species Primer code and sequences	*Retama raetam* Monomorphic	Polymorphic	Total no. of bands	*Vicia monantha* Monomorphic	Polymorphic	Total no. of bands
	a	b (c)	a + b + c	a	b (c)	a + b + c
Primer 1 5′-AGAGAGAGAGAGAGAGCC-3′	2	2 (0)	4	5	0 (0)	5
Primer 2 5′-AGAGAGAGAGAGAGAGCG-3′	11	0 (0)	11	8	1 (0)	9
Primer 3 5′-ACACACACACACACACCT-3′	5	2 (0)	7	4	0 (0)	4
Primer 4 5′-ACACACACACACACACCG-3′	4	0 (0)	4	8	0 (0)	8
Primer 5 5′-GTGTGTGTGTGTGTGTCG-3′	9	0 (0)	9	9	0 (0)	9
Primer 6 5′-CGCGATAGATAGATAGATA-3′	2	3 (1)	6	2	0 (0)	2
Primer 7 5′-GACGATAGATAGATAGATA-3′	3	6 (1)	10	7	1 (1)	9
Primer 8 5′-AGACAGACAGACAGACGC-3′	8	1 (1)	10	5	3 (0)	8
Primer 9 5′-CTCCTCCTCCTCCTCTT-3′	7	0 (0)	7	7	0 (0)	7
Primer 10 5′-CTCTCTCTCTCTCTCTAG-3′	8	0 (0)	8	6	0 (0)	6
Total	**59**	**17**	**76**	**61**	**6**	**67**
%	**77**	**23**	**100**	**91**	**9**	**100**

bands in the two populations in the two time periods. The differential polymorphic bands appeared in the three primers, numbers 2, 7, and 8.

Some of the used primers sowed high differential features between the populations in the two time periods, as appears with primer ISSR-7 which developed 7 (out of 10). Also, primer ISSR-8 showed 3 (out of 8) polymorphic bands developed in *V. monantha* population.

The genetic similarity between the populations in the time period 1976–2000 “i” and that in 2001–2018 period “j” was measured by Dice coefficient. The retrieved data showed the genetic similarity between the studied populations reached up to 88% in the perennial shrub *R. raetam* and 95% in the annual herb *V. monantha* (Table 3).

Discussion

Sallum site situated in the western province of the Mediterranean strip within Egyptian borders is characterized by the salient features of its land dissection into extensive shallow wadi system (El-Hadidi 2000; Salama et al. 2005). Sallum site encompasses rich floristic composition estimated by Zahran and Willis (2009) as c. 50% of the total Egyptian species.

Six quadrates (Map 1 and Table 1) represent the different habitat types and vegetation patterns of this site during 2018. The data retrieved from this study charted the presence of simple vegetation type, with highly adapted drought-resistant annual (41.9%) and perennial (58.1%) species. Analogous features adopted earlier by Salama et al. (2005). Five families, namely, Astraceae, Leguminosae, Gramineae, Chenopodiaceae, and Brassicaceae, represented in 60.6% (out of 198 species in 2018), of the identified species, in ascending order. This feature was adopted earlier for the western Mediterranean flora as part of the Mediterranean North African flora (Quézel 1978; Shaltout and El-Kady 1999). The retrieved data reflects the semiarid features of this environment, as claimed earlier by Bornkamm and Kehl (1985), while Salama et al. (2005) claimed that the dominance of therophytes indicating the site aridity. Zahran and Willis (2009) reported that the perennial xerophytes c. 90% species (out of them 67% are therophytes), in with the western Mediterranean coast.

The studied quadrates in this site showed vegetation cover ranging from 23% to 13% (Table 1). The species diversity in the shallow wadi bed, supporting the highest vegetation cover (23%). This habitat supports the annual leguminous species *Astragalus peregrinus* and *A. annularis* with IV = 25.6 and 23.9, respectively. The high vegetation cover seems to be attributed to the edaphic factors including water availability due to runoff water in this shallow wadi and accumulation of moisture, organic matter, and fine soil granules forming microhabitats encouraging the species persistence; Abdelaal et al. (2019) supported this postulation. Nevertheless, Salama et al. (2005) reported that Sallum site is part of the Egyptian desert supporting open vegetation pattern with 5% total cover. Zahran and Willis (2009), increased the desert vegetation cover to 60%, decreased to 20%, in the western Mediterranean strip, owing to the habitat and climatic diversity.

The dry desert habitat types represented by quadrates 2 and 3 accomplished vegetation cover (17% and 22%, respectively), compared to the wadi bed in quadrate 1. *Haloxylon salicornicum*, *Helianthemum lippii*, *Deverra tortuosa*, and *Gymnocarpos decanderus* (IV = 38.7, 33.1, 23.8, and 19.7, respectively, in quadrate 2) are the dominant perennial drought-tolerant species. Similar species, namely, *Thymelaea hirsuta*, *Zygophyllum album*, *Lycium europaeum*, and *Gymnocarpos decanderus* ((IV = 34.5, 21.5, 19.5, and 17.0, respectively), were dominant in quadrate 3. Other perennial species were recorded in significant evenness, in all the study quadrates, representing diffident habitats including *Thymelaea hirsuta*, *Lycium europaeum*, *Echinops spinosus*, and *Asparagus stipularis*. Such species repetition is a feature of the Mediterranean coastal land of Egypt (Quèzel 1978) and observed by Salama et al. (2005), in aridisol with subsoil layers enclosing adequate moisture.

The maritime non-saline sand dunes, prevailing the lowest vegetation cover (13%; Table 1); this vegetation decline is an expression of rainfall scarcity. The soil of this habitat is formed of loose, pseudo-ooltic sand with low species diversity, dominated by Mediterranean element *Carduncellus mareoticus* (IV = 43.6; Table 1), co-dominated by *Lotus creticus* and *Asparagus stipularis* (IV = 21.16 and 20.7, respectively).

The chorotype analysis of the vegetation during 2018 (Table 2) revealed the presence of 41.9% of mono-regional chorotype, grouped in the two chorotypes, Mediterranean (21.2%) and SaharoSindian (20.2%). The high presence of Mediterranean chorotype was reported earlier by Osman and El Garf (2015). However, the co-dominance of the SaharoSindian chorotype may be related to its position in a Mediterranean Sahara regional transitional zone (Salama et al. 2005). The bioregional chorotype comprises 40.9% (Table 2) in the study area; Osman and El Garf (2015) reported a relevant percentage (41.02%).

The Mediterranean chorotype showed northern shift during the study decades (1925–2018), and it decreased from 30.6% to 21.2% in the periods 1925–1950 and 2001–2018. *Prasium majus* is among these Mediterranean elements not recorded after 1950. Other species not recorded after 1975 include *Daucus syrticus*, *Malabaila suaveolens*, *Arisarum vulgare*, *Erucaria hispanica*, *Alkanna lehmannii*, *Ajuga iva*, and *Hymenocarpos circinnatus*. *Lathyrus marmoratus*, *Astragalus hamosus*, *Papaver rhoeas,* and *Limonium narbonense* showed lower evenness after 2000. These results confirm the intimate relationship between species diversity and climatic aspects. This postulation was based on the notable negative shift in the Mediterranean chorotype, and its replacement by SaharoSindian chorotype (xeric species) indicates the increased aridity. Galal and Fawzy (2007) reported a notable decline in the coastal communities where only 35% of them were traced. The sharp decrease in the mean annual rainfall from about 241.2 mm/year during the 25 years (1925–1950) to 105.0 mm/year (1946–1975), to 98.9 mm/year (1976–2000) and it reached to 53.8 mm/year in the last 17 years (2001–2017). The dectected rainfall

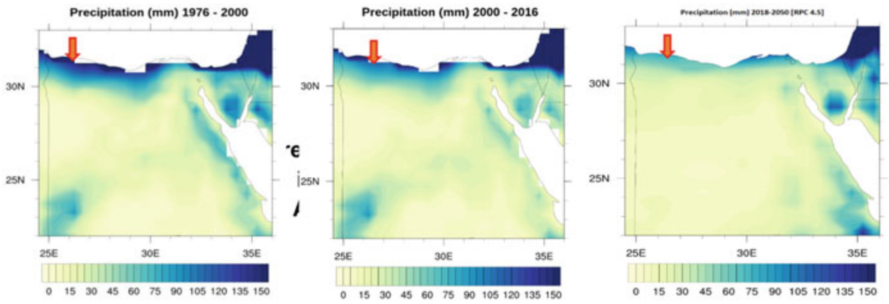


Fig. 3 The aridity trend at Sallum site represented by rainfall data from 1976 to 2016 and its projection in 2050. (Based on data retrieved from the National Meteorological Authority in Egypt, using ArcGIS)

decline reflected in this study as sharp vegetation decline in the studied last ten decades (1925–2018).

The notable northward expansion of the xeric habitats is proved by the positive shift in the SaharoSindian chorotype, from 9.7% to 20.2% (of the total recorded species) in the period 1925–1950 and 2001–2018, respectively. After 1950, in addition to the sharp decline in rainfall, the mean maximum temperature increased by 1.5 °C (Fig. 1). Both temperature increase and rainfall decrease were reflected the vegetation composition of the study region where common xeric species were recorded after 1950, and recently *Deverra tortuosa*, *Anthemis melampodina*, *Heliotropium arbainense*, and *Heliotropium digynum* showed higher evenness. Other species including *Zilla spinosa*, *Zygophyllum simplex*, and *Fagonia cretica* showed northward expansion after year 2000, as well as more evenness. Generally, this study proved the northward shift of the SaharoSindian chorotype and replaced Mediterranean one.

This northward expansion of xerophytes, as a reflection of rainfall shortage, will be worth its time. Where the rainfall decline (Figs. 1 and 3), supported by Zahran and Willis (2009) who reported that the rainfall was 217 mm/year (1901–1906), decreased to 207 mm/year (1966–1970). As well, the positive shift in mean maximum temperature with 1.5 °C (Fig. 1), this result supported by Grytnes (2003) and the IPCC (2007), who mentioned that the global mean land surface has warmed 0.27 °C/decade since 1979. The threats of the climatic change on arid land vegetation will be increased. Parmesan and Yohe (2003) cleared that the meta-analysis of long-term (48–132 years) datasets showed that the geographic location of the northern range boundaries for 100% of the studeied 44 species were mirrored decadal temperature trends over the twentieth century.

The reported vegetation decline (decreased from 226 to 198) through the study decades (Fig. 1) is a direct reflection of temperature increase and precipitation decline in recent years as well its projection threats (Fig. 3). This postulation is inconsistent with other studies such as Ciccarelli et al. (2012), Ciccarelli (2014), and Abdelaal et al. (2019). Drought induced 46% vegetation decline, from 1977 to 2007, in South California (Kelly and Goulden (2008).

Notable variation was observed in the species tends to prevail in the cold climatic spectrum as Mediterranean-Euro Siberian chorotype, as *Echium rubrum* not recorded after 1950, while, *Polygonum maritimum* occasionally recorded after year 2000, in lower species evenness. This species variation was claimed by Parmesan (2007), who claimed that variation among species at a given site is the variation across geographic regions.

Thymelaea hirsuta is among the interesting Mediterranean perennial species recorded in all the studied quadrates, with increased species evenness northward and westward. The distribution of this species was restricted northward and not recorded beyond 15–20 km from the seashore to southward. Shaltout et al. (2015) recorded similar observations. Four decades ago Zahran and Boulos reported that the southern geographic limit of this species was 70–75 km (from the seashore to southward). Globally, Parmesan and Yohe (2003) reported the poleward species shift, and the average shift was 6.1 km/decade for many of the studied species. However, Bachelet et al. (2001) claimed that climate change scenarios suggest that there is considerable uncertainty about possible future ecological impact, and some scenarios produce opposite signs for ecological responses. Six equilibrium scenarios conclude that moderate warming could produce an increase in vegetation growth over broad areas in the USA, but the greater warmer could produce large areas of drought stress.

Over the past ten study decades, due to climate change, the average monthly air temperature and rainfall decreased from January 1925 to December 2017. The genetic variations over the period 1975–2018 in the studied species *Retama raetam* and *Vicia monantha* proved notable genome variability, where the genetic uniformity ranges were 77% and 91%, respectively.

Perennial species *R. raetam* showed high genetic variations when compared to the annual *Vicia monantha*. This diversity is reflected by the presence of 17 polymorphic bands representing 18.43% of the total bands, indicating the possible threats facing the species in the future under the expected climate change during the twenty-first century (Hegazy et al. 2008b). This assumption was reported earlier by Reusch et al. (2005), who claimed that the ongoing losses of genetic diversity endanger the evolutionary potential of populations. The decrease in genetic variation reduces the species fitness (Hill et al. 2011, Faisal et al. 2012) and reduces the species adaptability to climatic changes (Allentoft and O'Brien 2010), where the genetic erosion occurs due to the loss of combinations of alleles over time (Brown 2008).

Genetic changes (unidirectional) in *R. raetam* indicate threats to the occurrence of this shrubby species. The study of Jump and Peñuelas (2005) described the ability to respond genetically to environmental fluctuations in the future, leading to unpredictable effects on a species' presence and abundance at the level of the plant community. In contrast, the genetic variation supports the species dominance, conservation, and evolution ability (Kabiel et al. 2013; Pauls et al. 2013).

In *Vicia monantha*, the retrieved data showed the highest genetic similarity (95%). This indicating that this species was facing the highest threats to the upcoming climatic changes as the species lost 0.07% of its genome loci during the last four decades and replaced by only 0.001%, reflected lower genetic flexibility and suitability to genetic erosion. Genome flexibility was reported by Jump et al. (2009) in *Brassica rapa* subjected to multiyear drought episode which led to its evolution toward drought-avoiding phenotypes. Genetic diversity allows species to resist climate change by permitting evolutionary responses forming more adaptive characters (Kabiel et al. 2013; Hegazy et al. 2014; Ravenscroft et al. 2015; Abood et al. 2017).

Many previous studies indicated that the perennial species respond less rapidly than the annual species to environmental stresses (Eyre-Walker and Gaut 1997; Gaut 1998; Andreasen and Baldwin 2001; Reusch et al. 2005). This study revealed that under the same environmental conditions, the shrub species *R. raetam* showed high genetic erosion as compared to the annual *V. monantha* indicating that the genetic response to climatic change is species-dependent.

The integration of neutral and functional genetic diversity leads to a better understanding of the species autecology and provides the bases to forecast the species responses to ongoing global climatic changes (Pauls et al. 2013).

Conclusion

The long-term vegetation monitoring is an efficient tool to study the expression of climate change. The rainfall shortage and poleward shift of the xeric features, as well as the reduction in Mediterranean chorotype elements, are a direct expression of climate change in northern Egypt. Tree species are more vulnerable to climate change as their genetic material declines with time. Finally, we recommend adopting the link between vegetation monitoring and climate change programs and announce the importance of seed banking of the wild species for future studies (climatic, genetic, diversity, geography, etc.). An urgent conservation program is requested to cover the western Mediterranean vegetation in Egypt.

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