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RESEARCH ARTICLE

THE CHARACTERIZATION OF THE SKULL AND DENTAL MEASUREMENTS OF THE FENNEC FOX "*VULPES ZERDA*" COLLECTED FROM THE WESTERN DESERT AND SINAI PENINSULA, EGYPT

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ABSTRACT

As a result of the previous studies over the past few years, a number of intriguing characteristics regarding the relationships between various mammalian populations across the Isthmus of Suez have been emerging. The mammalian populations in Sinai and Africa differ by this isthmus. All animals inhabiting the Egyptian Western Desert and Sinai Peninsula cannot cross the Nile Delta and Valley, as well as the Isthmus of Suez, which together represent significant ecological barriers. Fourteen skulls of the fennec fox "*Vulpes zerda*" that have been stored in Al-Azhar University Zoological Collection (AUZC) at Al-Azhar University (Cairo, Egypt) were used in the current study. These skulls were collected between 1983 and 2007 from the Egyptian Western Desert and Sinai Peninsula. The absolute cranial and dental measurements used here showed significant differences ($P<0.05$) between the two studied populations. The cranial and dental measurement ratios also showed significant differences ($P<0.05$) between the two studied populations. Thirteen differences between the fennec fox skulls from the two studied populations were detected. These differences may be enough to make the two populations separate from each other taxonomically, perhaps at the subspecies level. Principal component analysis of the cranial and dental measurements used in the current study confirmed the differences between the two studied *V. zerda* populations. More future studies should take place to confirm or deny the separation of these populations at the subspecies level.

INTRODUCTION

The typical fox of the Sahara is the fennec fox "*V. zerda*"; from Mauritania and the Western Sahara to Egypt west of the Nile River, it occupies sandy terrain in the hyperarid interior of North Africa[1-3]. The northeastern Sinai Peninsula is home to a population of this fox[1-3]. The Nile Delta, the northern part of the Egyptian Eastern Desert, and the low-lying wetlands of the Isthmus Desert separate this community from the Saharan population. The distribution of animals on the two sides of this ostensibly strong ecological bottleneck between Africa and Asia appears to have been affected by the landscape characteristics of this area[4].

When faunal forms can travel between two continents, where they can distribute, they are influenced strongly by the nature of the environment and its changes during the region's geological history. In addition, the formation of certain of these landscape elements frequently disrupts faunal distribution, separating populations from one another, and from the "mainstream" population or reconnecting disjunct populations[4]. The fennec fox appears to have had its prior distribution area split between populations in North Africa and Sinai Peninsula during the Pleistocene development of the Nile Delta and the inundation of the Gulf of Suez[4].

Most taxonomic and evolutionary research include morphometric data as an important component of their analysis. Mammalian skulls are incredibly insightful structures that serve as an effective tool for phylogenetics, classification, and biogeography[5]. Mammalian populations within one species have been distinguished using skull measurements[6]. Every morphological characteristic of every group of organisms is the consequence of interactions between the group and the environment that it has existed in, either throughout its prior evolutionary history or during the lives of the specimens. These morphological traits are separated into two categories for taxonomic purposes: those due to the effect of the environment on the ancestors of the individuals and those due to the effects of the environment during the individual life spans[6].

A number of researchers have examined the morphological and physiological adaptations of the fennec fox to living in the desert[7-9]. According to Noll-Banholzer[7], the fennec fox can tolerate high urea levels in urine and can survive without drinking water depending on their nocturnal activity and the moisture content of their prey. In addition to occasionally taking birds and their eggs, the fennec fox primarily feeds on insects, arachnids, small rodents, and reptiles[1,7,10]. According to Noll-Banholzer[7], the fennec fox is well suited to life in a sandy desert because of its thick fur that keeps it warm on chilly desert nights and its well-furred feet that make it easier to move on sand. In addition to aiding in thermoregulation, the very large ears may also help in the detection of insects and other small vertebrates[11]. The fennec is nocturnal and crepuscular, spending the day in its burrow. The water needs of the fennec are met by the water content of its prey[12].

Egypt, which is a part of the Sahara, has a hot and dry climate. Rainfall in the Egyptian northern coastal region, which stretches from Sallum to Rafah, higher mountains in southern Sinai, and Gabal Elba is comparatively heavy. Their floral and faunal composition reflects this climate[1]. According to Larsen[13] and El Hawagry and Gilbert[14], Egypt is divided into eight biological regions: Sinai Peninsula, Western Desert, Eastern Desert, Gabal Elba, Upper Nile Valley, Lower Nile Valley and Delta, El Faiyum Depression, and North Coastal Strip. Between 600 and 850 km wide, the Western Desert of Egypt stretches westward from the Nile Valley to the Libyan border and northward from the Mediterranean coast to the Egyptian-Sudanese border (1073 kilometers)[15]. The Western Desert, excluding Faiyum, occupies an area of around 681000 km^2. Its surface is made up of high-lying stony and sandy plains and bare rocky plateaus, with few distant drainage lines. The plateau surface of the Western Desert's northern and central regions is sporadically interrupted by enormous depressions and oases. The mountains are seen only in the extreme southwestern part of the country where the highest peak of Gabal Uweinat (1907 m above sea level) is watched[15]. The nature and distribution of its water sources are another distinguishing feature of the Western Desert[16]. Along the narrow belt of the Mediterranean Sea, there are wells and tanks fed by local rainfall. The annual rains that fall on the mountain mass at the base of Gabal Uweinat feed springs there, although the area in between is typically dry. Although there are large depressions like Siwa, Bahariya, Farafara, Kharga, and Dakhla Oases where subsurface water can rise to the surface, the vast majority of the high plateau is devoid of water[16].

A topic of major zoogeographical interest is the interaction between the faunas of Sinai and the west. The animal fauna of Sinai exhibits a strikingly higher similarity to that of Arabia and the eastern Mediterranean than to that of Africa[1,2,17]. This has been attributed to particular characteristics of Sinai as a geographical passage between the continents of Asia and Africa. The Isthmus of Suez appears to constitute at least a partial ecological barrier between Sinai and Africa, while there is none between Sinai and the rest of Asia. Between the northern tip of the Gulf of Suez and the vast saline marshes of Lake Manzala at the northeastern edges of the Nile Delta, the Isthmus of Suez is located at the northernmost tip of Africa[18]. There must have formerly been an ecological barrier preventing the exchange of wildlife between Africa and Asia over the Isthmus of Suez. According to Saleh and Basuony[2], this may account for the Sinai mammalian fauna's closer resemblance to that of Arabia and the eastern Mediterranean than that of Africa. The Sinai Peninsula is a triangle upland, with Ras Mohmmad at its southern tip and its base along the Mediterranean Sea. It encompasses 61,000 km^2[15]. Between the Gulfs of Suez and Aqaba is where the bulk of Sinai is located. Despite the Gulf of Suez separating them, the Sinai Peninsula is a geomorphological and geological extension of the Eastern Desert[15]. The Red Sea Mountains just continue into the crystalline Sinai Mountains. The sedimentary plateaus that can be found to the north of the Red Sea mountain range continue with the Tih Plateau[15,16]. Sinai's Mediterranean coastal desert consists of broad, sand-covered plains that slope northward gradually. In the entire area, eolian sand dunes are frequent. One of the principal geomorphologic characteristics of the area is Wadi El Arish, a very wide, northward-flowing wadi with many tributaries that drains significant sections of the central Sinai highlands. Another significant geomorphologic feature of the area is Lake Bardawil, a shallow lagoon that borders the northern Sinai's Mediterranean coastline[15,16,19]. The region of domes is made up of several separate hill groups, such as Gabal Yelleq, Gabal El-Maghara, Gabal El-Halal, and others, to the south of Sinai's Mediterranean coastal belt[15]. These hills have more precipitation and are home to a wide range of extinct animals and plants. The central Sinai plateau begins to the south of this region. On the northern flanks of the massive igneous core, this area includes the rough sedimentary of the El Tih and Al-Ugma Plateaus. Two ridges are formed by these plateaus, and they resemble straight walls with no gaps[20]. Numerous wadis, which frequently support abundant and diverse vegetation and wildlife, drain the central Sinai plateaus into the lower regions to the north[19].

The distribution of fennec foxes is unique. From the Atlantic coast to the Nile Valley and Delta, it is found throughout the hyper-arid interior of the Sahara. A small community occupies sandy areas in northern Sinai, east of the Nile. The mostly stony Eastern Desert and mesic Nile Valley and Delta appear to act as a significant natural barrier between the two populations[18]. The early Pleistocene, when the ancestors of the modern Nile started flowing, appears to be when the population of the Sinai split off from the rest of the Sahara's population[18]. The current study hypothesized that the fennec fox population of the Sinai may have resulted in some morphological and ecological changes as a result of its lengthy isolation. The distribution, habitat, and ecology of the fennec fox in the Western Desert of Egypt and Sinai Peninsula were described in the current study. The skull morphology of the two fennec fox populations was also investigated in the current study for possible morphological changes associated with the well dated isolation that can be linked to changes in paleoecology and the development of landscape features of the region.

MATERIAL AND METHODS

Collected skulls

Fourteen male fennec fox "*V. zerda*" skulls from various regions of the country that were kept in the Al-Azhar University Zoological Collection (Cairo, Egypt) were examined. These samples were collected from 1983 to 2007. By natural causes, the skulls used in this study were taken from fennec foxes that were killed in car accidents. Table "1" listed the locations where the specimens were collected, their museum numbers, and their coordinates. The skull specimens with fully completed molars are regarded as adult. Therefore, the 14 fennec fox samples used in this study were all for adult animals. Five of these skulls were collected from the Western Desert of Egypt, while the other nine skulls were collected from northern Sinai (Table 1).

Table 1: Collection localities and museum numbers of the fennec fox skulls used in the current study.

Population	Collection site (Year)	Museum number	Coordinates
Western Desert	Karawein (1983)	m00012	27°10'08.28"N, 28°36'29.24"E
	Karawein (1983)	m00013	27°10'08.28"N, 28°36'29.24"E
	Maghra Oasis (2002)	m00361	30°15'43.24"N, 28°54'09.34"E
	Maghra Oasis (2002)	m00362	30°15'43.24"N, 28°54'09.34"E
	Maghra Oasis (2003)	m00461	30°13'50.58"N, 28°54'46.80"E
Northern Sinai	Al Maqdbah (1998)	m00057	30°52'16.93"N, 33°57'46.12"E
	Al Maqdbah (1998)	m00058	30°52'16.93"N, 33°57'46.12"E
	Al Hasana (2006)	m05340	30°41'36.41"N, 33°55'23.71"E
	Al Hasana (2006)	m05341	30°41'36.41"N, 33°55'23.71"E
	Al Hasana (2006)	m05342	30°41'36.41"N, 33°55'23.71"E
	Al Hasana (2007)	m05343	30°41'24.33"N, 33°55'12.60"E
	Al Hasana (2007)	m05344	30°41'24.33"N, 33°55'12.60"E
	Al Hasana (2007)	m05345	30°41'24.33"N, 33°55'12.60"E
	Al Hasana (2007)	m05346	30°41'24.33"N, 33°55'12.60"E

Skull measurements

Following the methods for measuring skulls described by von den Driesch[21] and Frackowiak *et al*.[22], a digital electronic caliper with a 0.01 mm precision was used for craniometry. A total of 55 metric variables were measured (Figures 1-4). Definitions for the abbreviations of skull measurement used in the current study are provided in Table "2".

Statistical analysis

In the current study, basic descriptive statistics including the mean and standard deviation were used. The fennec fox skull measures from the study regions were compared using the non-parametric independent-samples Mann-Whitney U-test (SPSS software package, version 25). Using PC-ORD version 5, principal component analysis (PCA) was carried out in accordance with the methodology of Grandin[24].

RESULTS

Tables "3 and 4" showed a comparison of 39 cranial and 16 mandibular characters, as well as 44 ratios of the fennec fox "*V. zerda*", of the Western Desert and northern Sinai populations. Six of the absolute cranial and dental measurements (PL, ABW, PtW, FPW, MxPW, and IOF) were significantly higher in the northern Sinai population than in the Western Desert population ($P<0.05$). Jaw thickness (JT) was the only mandibular measurement that was significantly higher in the Sinai population than in the Western Desert population ($P<0.05$). The 48 remaining characters showed no significant difference between the two populations (Table 3).

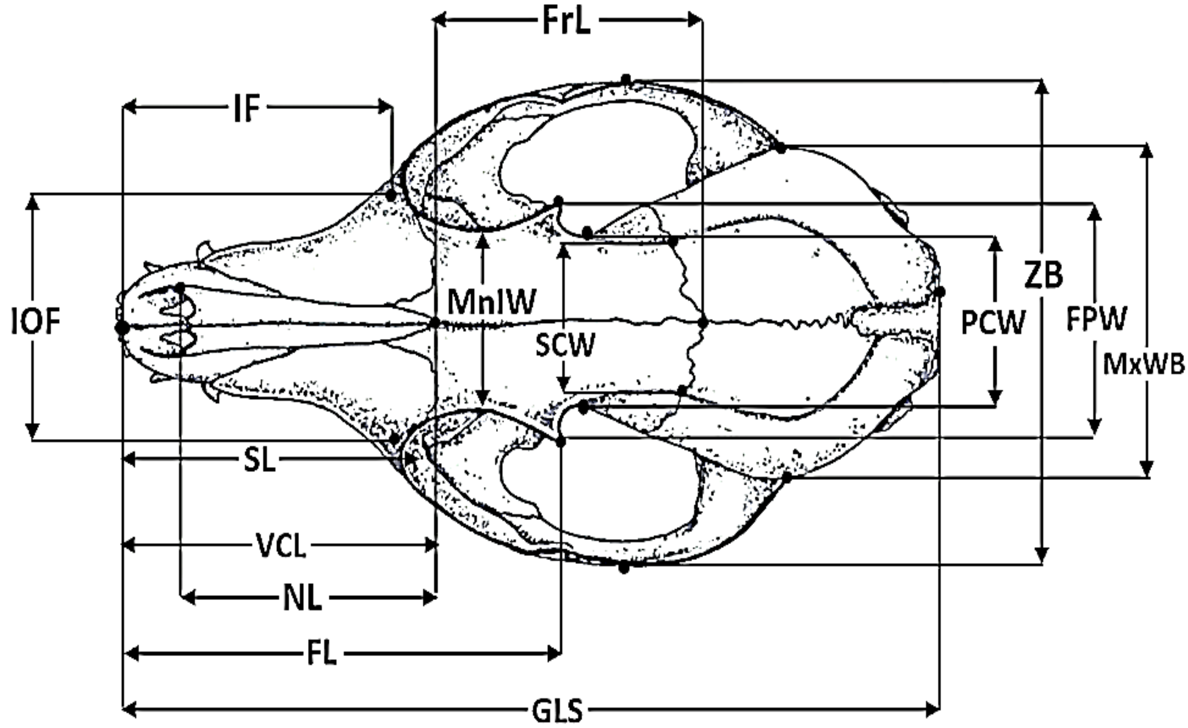

Figure 1: Dorsal view of the fennec fox skull (see Table "2" for definitions of the abbreviations).

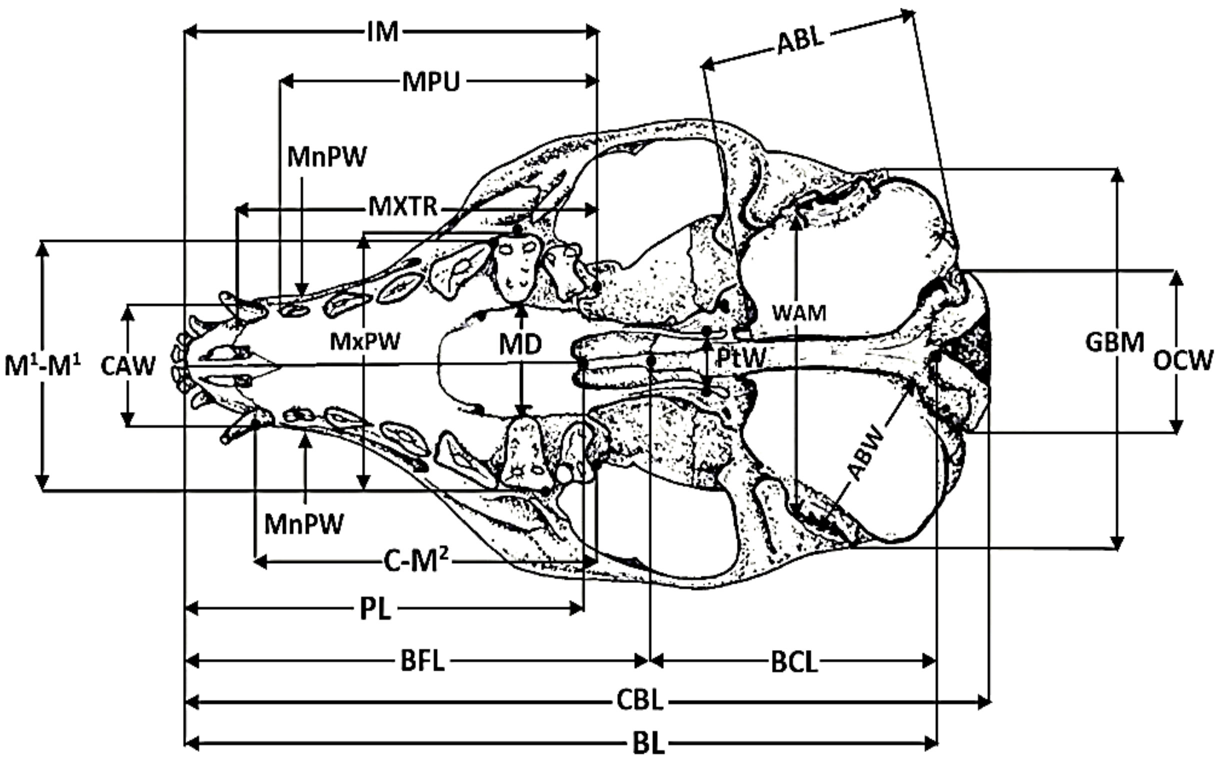

Figure 2: Ventral view of the fennec fox skull (see Table "2" for definitions of the abbreviations).

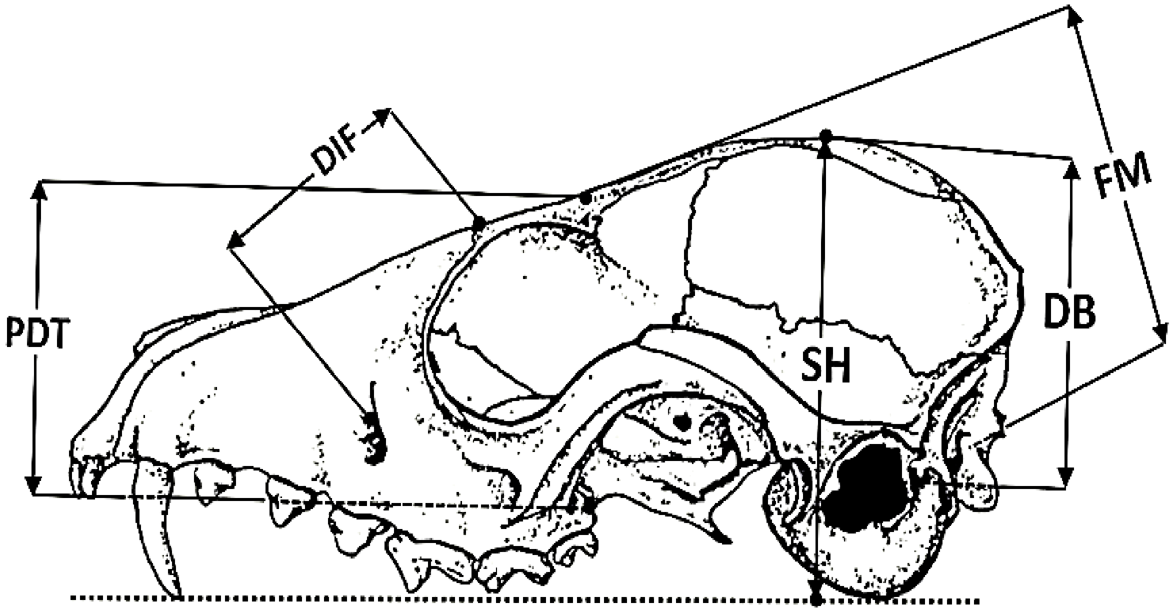

Figure 3: Lateral view of the fennec fox skull (see Table "2" for definitions of the abbreviations).

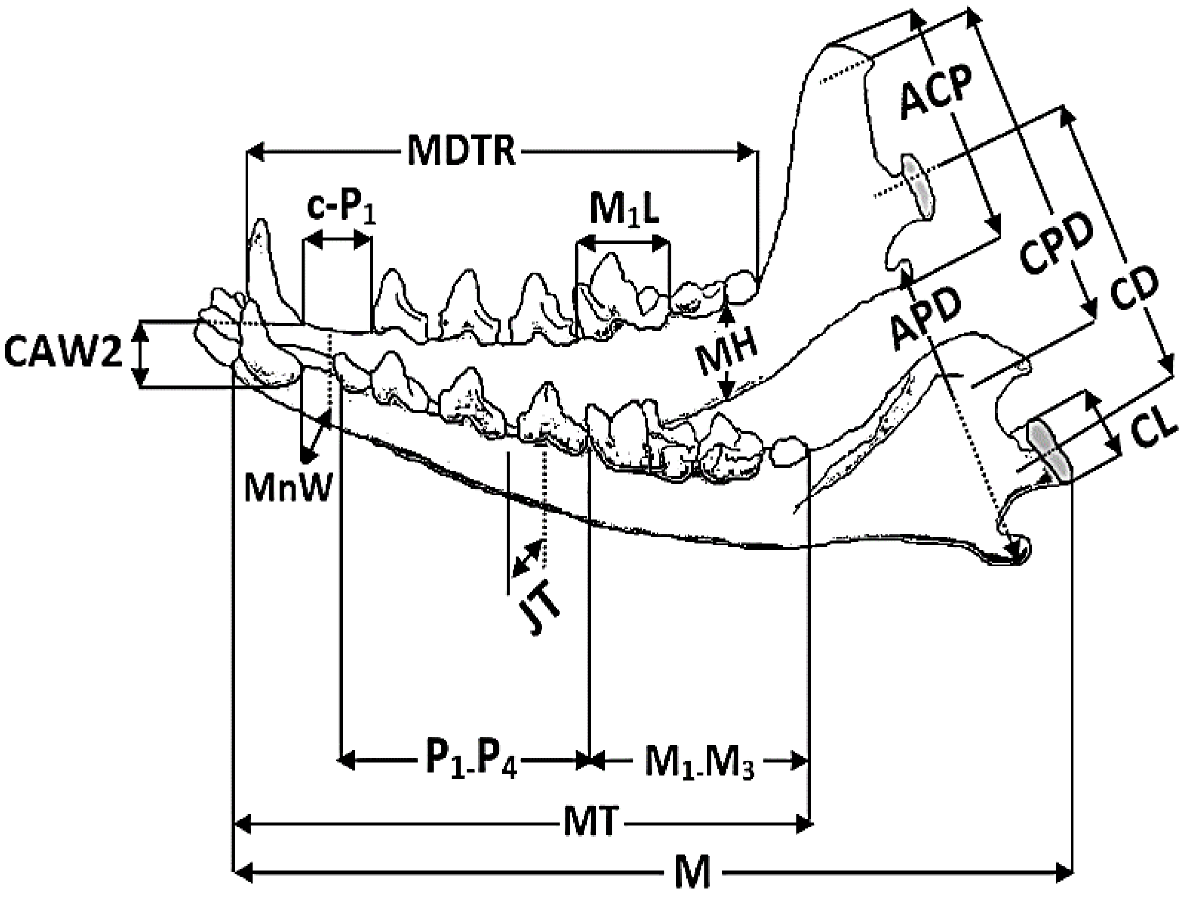

Figure 4: Lower jaw of the fennec fox (see Table "2" for definitions of the abbreviations).

Table 2: A list of cranial and mandibular measurements and their abbreviations used in the current study. These measurements and their abbreviations were taken after Younes[23].

Measurements	Abbreviations
Cranium	
The greatest length of the skull	GLS
Condylobasal length	CBL
Basal length	BL
Basicranial length	BCL
Basifacial length	BFL
Viscerocranial length	VCL
Facial length	FL
Nasal length	NL
Snout length	SL
Palatal length	PL
Greatest length of the tympanic bulla	ABL
Greatest width of the tympanic bulla	ABW
Greatest breadth across the mastoid processes	GBM
Zygomatic breadth	ZB
Pterygoid width	PtW
Frontal length	FrL
Least width of skull at the postorbital constrictions	PCW
Frontal width across the postorbital processes	FPW
Minimum interorbital constriction width	MnIW
Maximum palatal width	MxPW
Minimum palatal width	MnPW
Width at canine alveoli	CAW
Depth of braincase	DB
Prosthion: measured from the infraorbital foramen to the anterior extremity of the cranium	IF
The distance between the two infraorbital foramens	IOF
Measured from the foramen magnum to the middle point of the frontal	FM
Palatal depth behind tooth row	PDT
Depth at infraorbital foramen	DIF
Maximum width of brain case	MxWB
Width across auditory meatus	WAM
Greatest width across the occipital condyles	OCW
The sagittal crest width	SCW
Skull height: measured from the highest point of the skull to the bottom of a plate with a specified thickness, which is where the incisors, canines, and bulla are located. The measurement is then obtained by subtracting the plate's thickness (Figure 3).	SH
The distance from the end of the second molar to the anterior-most surface of the canine	$C\text{-}M^2$
The maximum width across the first upper molars	$M^1\text{-}M^1$
Molar premolar length	MPU
Incisor molar length	IM
Maxillary tooth row	MXTR
The distance between upper M^1s: the internal distance between upper M^1s	MD

Table 2 Continuous

Measurements	Abbreviations
Mandible	
Measured from the tip point of a lower jaw to the last molar	MT
Mandibular length: measured from the tip point of a lower jaw to the angular process	M
Mandibular tooth row: measured from the front of the lower canine to the back of the crown of the last lower molar	MDTR
Mandibular height: measured from the lower jaw at the base of the first molar	MH
Jaw thickness: the greatest thickness of the mandible	JT
Angular – coronoid process	ACP
The distance between canine and P_1: the length of mandible between the lower canine and the first premolar	c-P_1
The length of mandibular row from the front of the lower premolar 1 to the end of the premolar 4	P_1-P_4
The distance of mandibular row from the beginning of the lower first molar to the end of the third molar	M_1-M_3
The distance between the two condyloid processes of lower jaw	CD
The length of one condyloid process of lower jaw	CL
The distance between the two angular processes of lower jaw	APD
The distance between the two coronoid processes of lower jaw	CPD
The least width between the two canines and premolars of lower jaw	MnW
The width at canine alveoli of lower jaw	CAW2
The first molar length of the lower jaw	M_1L

Seven of the cranial and dental measurement ratios (FL/GLS, PL/GLS, ABW/GLS, PtW/GLS, PCW/GLS, FPW/GLS, and IOF/GLS) showed significant differences ($P<0.05$) between the Western Desert and northern Sinai populations. The remaining 37 ratios showed no significant difference between the two populations (Table 4).

Figure "5" showed a comparison of dorsal and ventral views, as well as lower jaws, of the fennec fox skulls from the Western Desert and northern Sinai regions. Thirteen differences between the fennec fox skulls from the Western Desert and northern Sinai regions were detected (Figure 6). The first difference is the extended bone between maxilla and nasal, which is long in the Western Desert group and short in the northern Sinai group (Figure 6A). The second difference is the nasal bone (NL), which is longer in the northern Sinai group (28.04±1.02 mm) than in the Western Desert group (27.13±1.67 mm, Figure 6A and Table 3). The third difference is the maxilla bone, which is longer in the northern Sinai group than in the Western Desert group (Figure 6A). The fourth difference is the postorbital process, which is long and pointed in the northern Sinai group and somewhat rounded in the Western Desert group (Figure 6A, B). The fifth difference is the end of frontal bone, which is elongated and pointed in the northern Sinai group than in the Western Desert group (Figure 6A). The sixth difference is the shape of sagittal crest, which is elongated in the northern Sinai group and somewhat rounded in the Western Desert group (Figure 6A). The seventh difference is the minimum palatal width (MnPW) at the first premolar, which is narrower in the Western Desert group (12.45±0.55 mm) than in the northern Sinai group (13.14±0.19 mm, Figure 6B and Table 3). The eighth difference is the shape of the orbit, which is irregular in the northern Sinai group than in the Western Desert group (Figure 6A, B). The ninth difference is the shape of the pterygoid bone (PtW), which is wider in the northern Sinai group (9.89±0.22 mm) than in the Western Desert group (8.87±0.32 mm, Figure 6B and Table 3). The tenth difference is the end of zygomatic process of squamosal, which is longer in the Western

Table 3: Mean, standard deviation, and range of cranial and dental measurements of *Vulpes zerda* specimens from the Western Desert of Egypt and Sinai Peninsula. All measurements are in mm. Characters marked with an asterisk showed significant difference between the two populations.

Measurement	Western Desert	Northern Sinai	Measurement	Western Desert	Northern Sinai
GLS	84.41±0.74	84.26±1.38	PDT	23.64±1.24	24.51±0.79
	(83.66-85.14)	(82.64-6.19)		(22.48-24.94)	(23.58-5.81)
CBL	83.51±0.68	83.61±1.64	DIF	17.69±0.66	18.52±0.50
	(82.81-84.17)	(81.39-5.98)		(17.13-18.42)	(18.03-9.52)
BL	79.82±0.58	79.55±2.40	MxWB	36.61±1.44	36.96±0.68
	(79.22-80.38)	(74.93-2.67)		(34.95-37.48)	(36.09-8.04)
BCL	31.10±1.99	30.95±1.17	WAM	25.83±2.14	28.29±0.88
	(29.07-33.04)	(28.54-2.54)		(23.55-27.80)	(27.56-9.71)
BFL	48.72±1.71	48.61±1.63	CAW	12.78±0.21	12.99±0.15
	(46.82-50.15)	(46.39-0.86)		(12.56-12.97)	(12.64-3.21)
VCL	34.22±1.00	35.70±1.26	$C\text{-}M^2$	35.15±0.23	35.23±0.72
	(33.08-34.96)	(33.91-7.98)		(34.89-35.32)	(34.32-36.76)
FL	46.87±1.04	48.21±1.04	$M^1\text{-}M^1$	24.51±0.63	24.42±0.28
	(46.19-48.07)	(47.02-9.44)		(23.79-24.99)	(23.96-24.91)
NL	27.13±1.67	28.04±1.02	MPU	29.83±0.48	30.01±0.74
	(25.36-28.67)	(26.39-9.62)		(29.39-30.34)	(28.89-1.14)
SL	30.90±0.47	30.74±0.88	IM	42.06±0.54	41.78±1.09
	(30.36-31.24)	(29.54-2.10)		(41.67-42.68)	(40.38-3.74)
PL*	40.97±0.35	42.19±0.93	MXTR	35.45±0.27	35.13±0.84
	(40.70-41.37)	(40.75-3.70)		(35.14-35.62)	(33.99-6.74)
ABL	22.15±0.31	21.55±0.52	MD	9.72±1.14	9.98±0.46
	(21.79-22.33)	(20.94-2.38)		(8.93-11.02)	(9.16-10.80)
ABW*	14.27±0.50	15.24±0.32	MT	41.96±0.05	41.03±1.04
	(13.69-14.62)	(14.84-5.70)		(41.92-42.02)	(40.01-3.25)
GBM	32.75±0.96	34.01±0.69	M	59.45±0.74	58.49±1.72
	(32.15-33.86)	(32.68-4.91)		(58.73-60.20)	(56.66-1.53)
ZB	45.60±0.45	46.32±0.82	MDTR	39.66±0.10	39.24±0.90
	(45.25-46.11)	(45.23-7.80)		(39.57-39.77)	(37.99-1.09)
PtW*	8.87±0.32	9.89±0.22	MH	8.30±0.62	7.78±0.53
	(8.51-9.13)	(9.59-10.22)		(7.65-8.89)	(7.01-8.78)
FrL	30.27±1.03	30.06±0.95	JT*	3.98±0.36	3.47±0.11
	(29.24-31.30)	(28.03-1.20)		(3.62-4.33)	(3.29-3.61)
PCW	17.72±1.18	19.89±1.33	ACP	20.47±0.39	20.34±0.46
	(16.46-18.80)	(17.52-1.90)		(20.18-20.92)	(19.34-0.79)
FPW*	20.46±0.98	22.81±0.94	$c\text{-}P_1$	3.01±0.48	3.03±0.50
	(19.79-21.59)	(20.90-3.99)		(2.52-3.47)	(2.19-3.97)
MnIW	15.84±0.62	16.08±0.48	$P_1\text{-}P_4$	18.63±0.25	18.05±0.60
	(15.28-16.51)	(15.26-6.79)		(18.35-18.85)	(17.45-9.41)
MxPW*	24.57±0.75	25.38±0.55	$M_1\text{-}M_3$	15.13±0.49	15.01±0.41
	(23.89-25.38)	(24.61-6.42)		(14.62-15.59)	(14.30-5.46)
MnPW	12.45±0.55	13.14±0.19	CD	38.21±1.26	38.10±1.76
	(11.84-12.90)	(12.77-3.50)		(36.96-39.48)	(35.36-0.95)
DB	28.11±0.58	28.78±1.50	CL	7.76±0.30	7.42±0.40
	(27.69-28.77)	(27.79-2.64)		(7.49-8.09)	(6.88-8.00)
IF	26.78±0.65	27.04±0.74	APD	31.45±0.19	32.38±1.87
	(26.36-27.53)	(26.03-8.67)		(31.27-31.65)	(28.49-5.26)
IOF*	17.02±0.89	18.83±0.54	CPD	38.91±1.59	38.73±1.47
	(16.19-17.96)	(17.82-9.51)		(37.33-40.50)	(36.71-1.14)

Table 3 Continuous

Measurement	Western Desert	Northern Sinai	Measurement	Western Desert	Northern Sinai
FM	42.36±1.00 (41.55-43.48)	41.82±2.16 (38.09-4.67)	MnW	7.06±0.07 (6.98-7.10)	6.90±0.23 (6.61-7.24)
OCW	16.84±0.69 (16.06-17.37)	16.70±0.40 (16.31-7.47)	CAW2	7.50±0.28 (7.20-7.76)	7.39±0.09 (7.23-7.53)
SCW	18.13±3.52 (14.08-20.45)	20.49±2.20 (17.28-2.64)	M1L	8.84±0.37 (8.45-9.18)	8.68±0.36 (8.03-8.99)
SH	37.37±0.75 (36.92-38.24)	38.08±0.54 (37.31-9.21)			

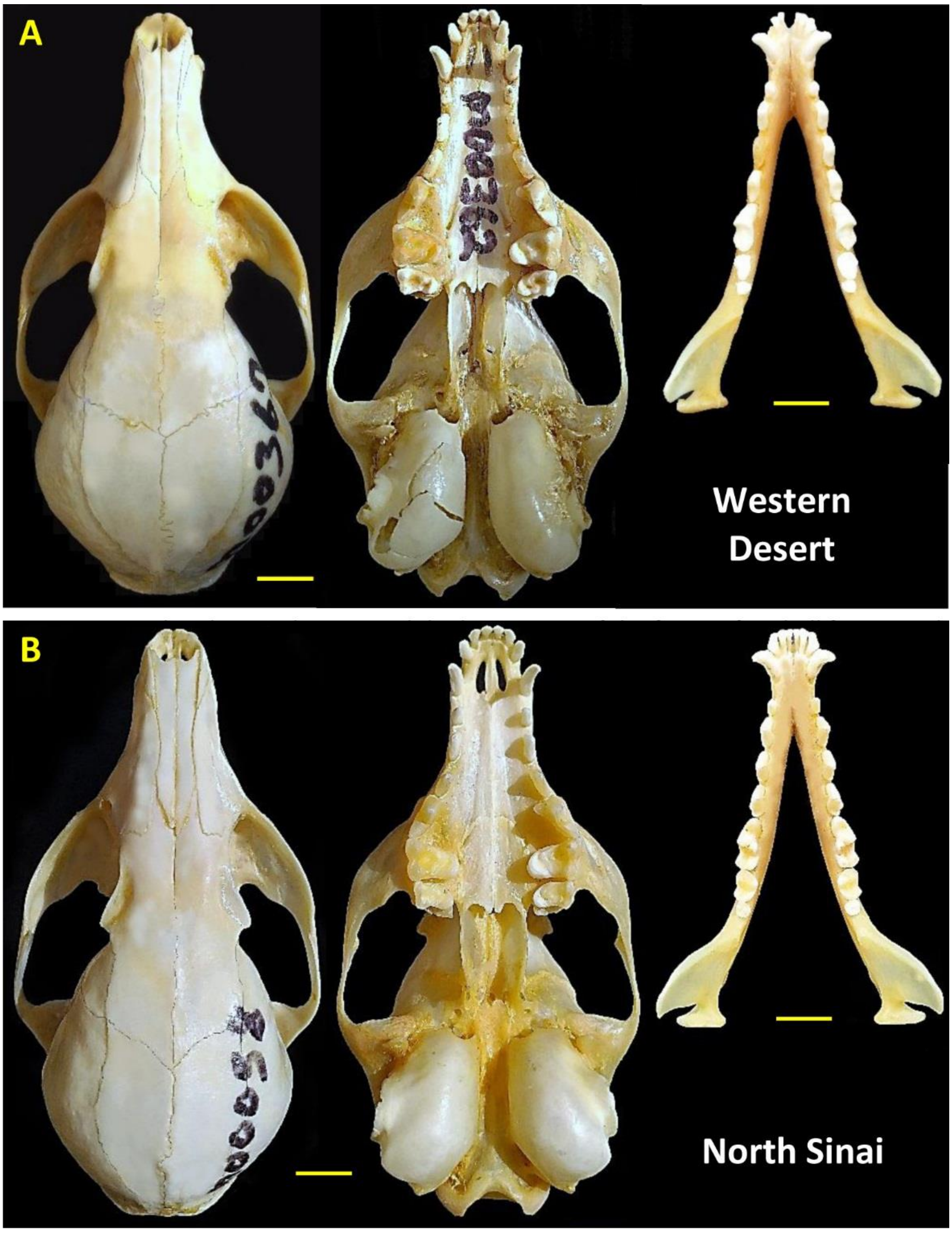

Figure 5: Dorsal and ventral views and the lower jaws of the fennec fox skull from Western Desert **(A)** and northern Sinai **(B)**, scale bar = 10 mm.

Table 4: Mean, standard deviation, and range of cranial and dental ratios of *Vulpes zerda* specimens from the Western Desert of Egypt and Sinai Peninsula. Ratios marked with an asterisk showed significant difference between the two populations.

Ratio	Western Desert	Northern Sinai	Ratio	Western Desert	Northern Sinai
VCL/GLS	0.41±0.01 (0.39-0.42)	0.42±0.01 (0.41-0.44)	OCW/GLS	0.20±0.01 (0.19-0.21)	0.20±0.00 (0.20-0.20)
FL/GLS*	0.56±0.01 (0.55-0.56)	0.57±0.01 (0.56-0.58)	OCW/MxWB	0.46±0.00 (0.46-0.46)	0.45±0.01 (0.43-0.47)
NL/GLS	0.32±0.02 (0.30-0.34)	0.33±0.01 (0.32-0.35)	OCW/DB	0.60±0.02 (0.58-0.62)	0.58±0.03 (0.50-0.62)
SL/GLS	0.37±0.01 (0.36-0.37)	0.36±0.00 (0.36-0.37)	SCW/GLS	0.21±0.04 (0.17-0.24)	0.24±0.03 (0.20-0.27)
PL/GLS*	0.49±0.01 (0.48-0.49)	0.50±0.01 (0.49-0.51)	SCW/MxWB	0.49±0.08 (0.40-0.55)	0.55±0.05 (0.48-0.61)
ABL/GLS	0.26±0.00 (0.26-0.26)	0.26±0.00 (0.25-0.26)	SCW/DB	0.64±0.12 (0.51-0.72)	0.71±0.07 (0.60-0.79)
ABW/GLS*	0.17±0.01 (0.16-0.17)	0.18±0.00 (0.18-0.19)	MPU/GLS	0.35±0.01 (0.35-0.36)	0.36±0.01 (0.35-0.36)
GBM/GLS	0.39±0.01 (0.38-0.40)	0.40±0.01 (0.39-0.42)	MPU/IM	0.71±0.02 (0.70-0.77)	0.72±0.01 (0.70-0.73)
ZB/GLS	0.54±0.01 (0.53-0.55)	0.55±0.01 (0.54-0.56)	IM/GLS	0.50±0.00 (0.49-0.50)	0.50±0.01 (0.49-0.51)
PtW/GLS*	0.11±0.00 (0.10-0.11)	0.12±0.00 (0.11-0.12)	MxTR/GLS	0.42±0.01 (0.42-0.43)	0.42±0.01 (0.41-0.43)
FrL/GLS	0.36±0.01 (0.34-0.37)	0.36±0.01 (0.34-0.38)	MxTR/IM	0.84±0.01 (0.83-0.85)	0.84±0.01 (0.83-0.85)
PCW/GLS*	0.21±0.02 (0.19-0.22)	0.24±0.02 (0.20-0.26)	M/GLS	0.70±0.01 (0.70-0.71)	0.69±0.02 (0.67-0.72)
FPW/GLS*	0.24±0.01 (0.23-0.26)	0.27±0.01 (0.24-0.29)	MT/M	0.71±0.01 (0.70-0.71)	0.70±0.02 (0.65-0.72)
MnIW/GLS	0.19±0.01 (0.18-0.20)	0.19±0.01 (0.18-0.20)	MDTR/M	0.67±0.01 (0.66-0.68)	0.67±0.01 (0.64-0.29)
MxPW/GLS	0.29±0.01 (0.28-0.30)	0.30±0.01 (0.29-0.32)	ACP/M	0.34±0.01 (0.34-0.36)	0.35±0.01 (0.33-0.37)
MnPW/GLS	0.15±0.01 (0.14-0.15)	0.16±0.00 (0.15-0.16)	CD/M	0.64±0.03 (0.61-0.67)	0.65±0.02 (0.62-0.68)
CAW/GLS	0.15±0.00 (0.15-0.16)	0.15±0.00 (0.15-0.16)	APD/M	0.53±0.00 (0.53-0.53)	0.55±0.03 (0.50-0.59)
DB/GLS	0.33±0.01 (0.33-0.34)	0.34±0.02 (0.33-0.39)	MnW/M	0.12±0.00 (0.12-0.12)	0.12±0.00 (0.11-0.13)
IF/GLS	0.32±0.01 (0.31-0.33)	0.32±0.01 (0.31-0.33)	CAW2/M	0.13±0.00 (0.12-0.12)	0.13±0.00 (0.12-0.13)
IOF/GLS*	0.20±0.01 (0.19-0.21)	0.22±0.01 (0.22-0.23)	P_1-P_4/M	0.31±0.00 (0.31-0.31)	0.31±0.01 (0.30-0.32)
MxWB/GLS	0.43±0.02 (0.41-0.45)	0.44±0.01 (0.24-0.26)	M_1-M_3/M	0.25±0.01 (0.24-0.27)	0.26±0.01 (0.24-0.27)
WAM/GLS	0.31±0.03 (0.28-0.33)	0.34±0.01 (0.32-0.36)	JT/M	0.07±0.01 (0.06-0.07)	0.06±0.00 (0.06-0.06)

Desert group than in the northern Sinai group (Figure 6B). The eleventh difference is the shape of the auditory bulla, which is elongated in the Western Desert group (the average of ABL was 22.15±0.31 mm and for ABW was 14.27±0.50 mm) and somewhat rounded in the northern Sinai group (the average of ABL was 21.55±0.52 mm and for ABW was 15.24±0.32 mm, Figure 6B and Table 3). The twelfth difference is the opening of the auditory meatus, which is wider in the northern Sinai group than in the Western Desert group (Figure 6B). The thirteenth difference is the shape of the two occipital condyles with foramen magnum, which is tortuous in the Western Desert group but somewhat smooth in the northern Sinai group (Figure 6B).

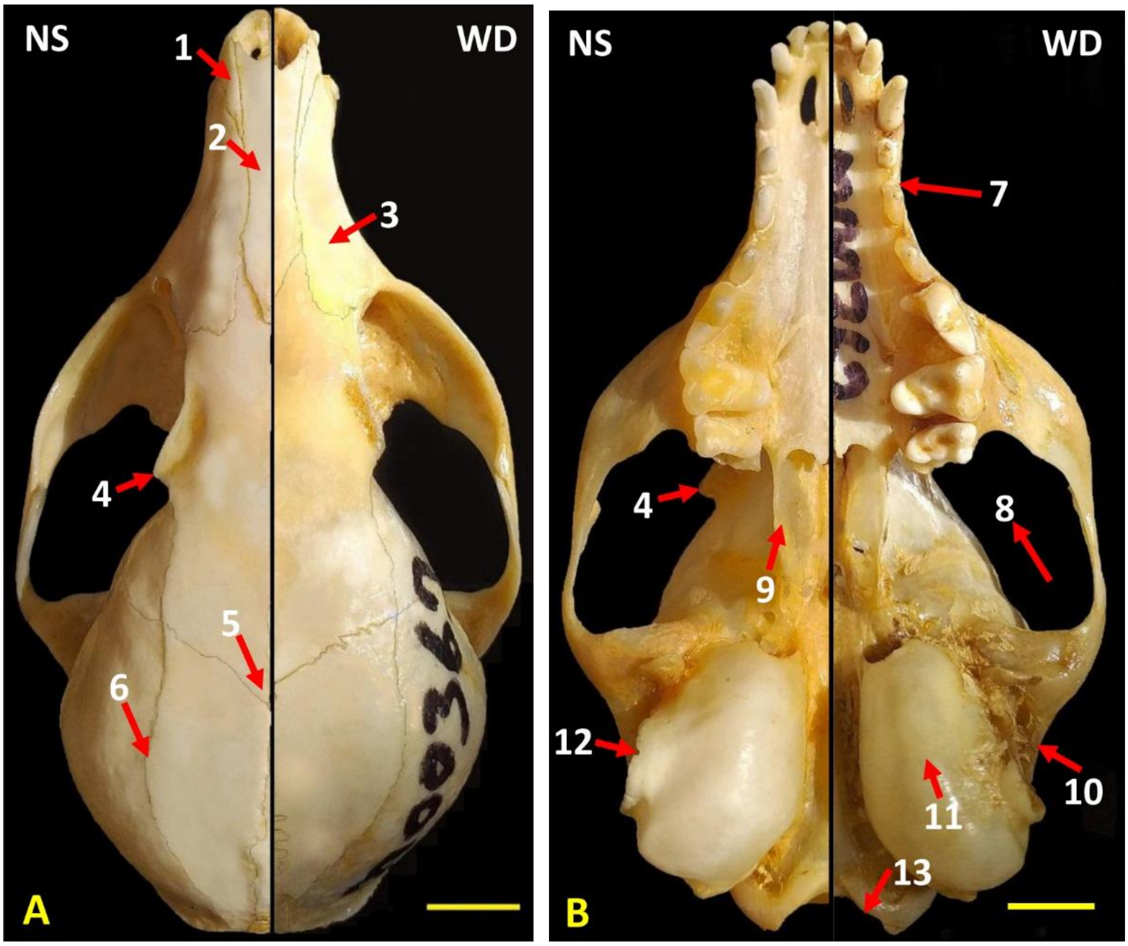

Figure 6: Two halves of dorsal **(A)** and ventral **(B)** views of the fennec fox skull from northern Sinai (left half of A and B) and Western Desert (right half of A and B) artificially adjusted to the same greatest length of the skull (GLS), scale bar = 10 mm.. NS: northern Sinai, WD: Western Desert.

PCA of the 55 cranial and dental measurements used in the current study confirmed the difference between the two studied *V. zerda* populations. The five Western Desert *V. zerda* skulls represented by m00012 W, m00013 W, m00361 M, m00362 M, and m00461 M were gathered in the fourth quarter. The nine northern Sinai *V. zerda* skulls were separated as five of which gathered in the second quarter and represented by m00058 N, m05341 N, m05342 N, m05344 N, and m05345 N. The remaining four skulls of the Sinai population were split as two *V. zerda* skulls in the first quarter represented by m00057 N, and m05346 N, and the other two skulls in the third quarter represented by m005340 N, and m005343 N (Figure 7).

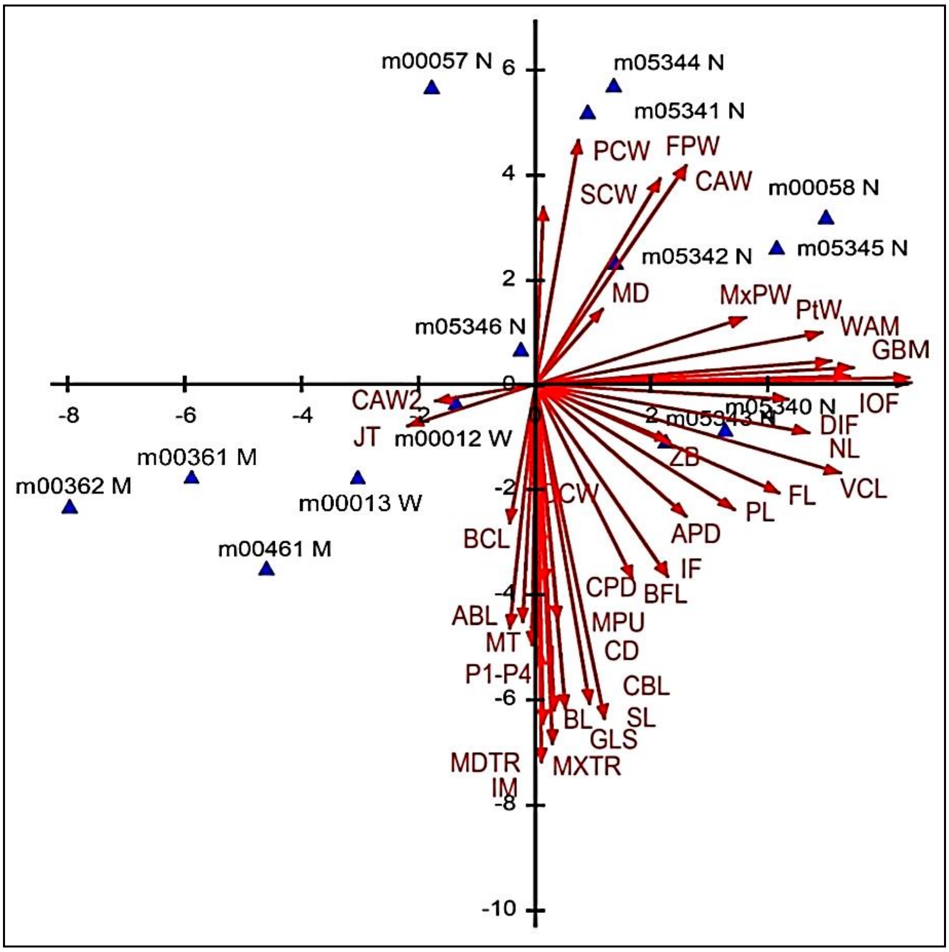

Figure 7: Principal component analysis of the cranial and dental measurements of the two studied *V. zerda* populations. M: Maghra Oasis, W: Western Desert, N: northern Sinai.

DISCUSSION

The Egyptian modern land fauna consists of elements with varying biogeographical histories. The ecological richness of the area in issue, its climatic and biogeographical history, as well as its recent geological and geomorphological evolution, have all played major roles in determining the composition and distribution of the country's fauna[2]. Evidence from vertebrate fossils indicates a substantial faunal interchange between Asia and Africa carried on *via* the Isthmus of Suez during the late Pleistocene and early Holocene, involving several mammalian species[25]. During one of the rainy episodes of that time, when North Africa was enjoying a milder temperature than it does today, it is possible that the ancestors of the modern fauna traveled between the eastern Mediterranean and Africa over the Sinai Peninsula[25]. Then, species with Asian ancestry most likely migrated to northern Africa, settling in the Nile Valley, the eastern Sahara, and the great hollow to the west, which now includes the oasis of the Egyptian Western Desert. During that time, Afro-tropical species were also able to spread into southwest Asia and perhaps even the rest of the Palearctic[26].

In the present study, the superior margin of the lambdoidal ridge of the fennec fox skulls does not rise above the foramen magnum's top lip at its posterior position. The postorbital process is dorsally concave. Nasals end at the anterior-posterior level of the frontomaxillary suture, tapering sharply at the back. There is a wide nasomaxillary contact. Bulla tympani is significantly inflated. The basisphenoid and basioccipital regions are severely compressed. The opening of the external auditory meatus is large. Lower jaw is quite narrow and shallow. Teeth are thin and tiny. Compared to other foxes, the cingulum on the anterior of the top cranium (pm^4) is more strongly developed. An accessory cusp is occasionally present on pm^3 (Figures 5 and 6). These results of fennec fox skull description were in agreement with that of Osborn and Helmy[1]. According to Vivian[26], the abandoned Maghra Oasis is located amid a barren, but stunning tract of desert at the eastern part of the Qattara Depression. Its three sides consists of sand dunes on one, an impassible scrub field on the other, and the depression's escarpment on the other two. Five water wells that were dug in the 1840s and a lake are there. The lake is 34 meters below sea level and is, of course, a salt lake. One of the outstanding aspects of the environment is the scattered heaps of petrified wood, the only moveable items in this arid area[26]. In fact, there are a number of tomb sites close to Bir Nahad that are clearly marked by petrified wood that protrudes into the air like little stone trees. Vivian[26] also documented the Karawein region, present in Western Desert of Egypt east to Farafra Oasis, which is a new agricultural project including 35000 feddans to fall under cultivation. The area is so unpolluted and untouched. It was a true wilderness and few people had journeyed to it. There is no resemblance to the White Desert. Everything here is a delicate beige, both sand sheets, and dunes. Bir Karawein is the ancient bir that made this place a stop for caravans on Darb Asyut. It is about 600 meters to the NW of the waypoint reading above[26].

According to Osborn and Helmy[1], the sides of the adult fennec foxes' skulls are roughened. Low and lyre-shaped parietal ridges are present. The postorbital process is hooked and pointed. It has merged the basioccipital-basisphenoid suture. Cranium in subadults is smooth. There is a modest development of the parietal ridges. The postorbital process is blunt. A partial fusion of the basioccipital-basisphenoid suture exists. They have extremely large inflated tympanic bullae[1,27]. Kistner *et al.*[28] emphasize that large behavioral shifts, can have a limited impact on cranial morphology. They suggest that cranial skeletal change may be an unreliable marker of the magnitude of behavioral change.

Environments in northern Sinai are different from those in the Egyptian Western Desert in terms of their nature (Figure 8). The various sizes and shapes of mammals in those two geographically remote places are a result of these differences in environmental nature. The fennec fox population from the Western Desert differs from that from northern Sinai in terms of skull size and shape (Table 3 and Figures 5 and 6). The whole Western Desert is one of the most arid regions of the globe, with the exception of the small Western Mediterranean coastal belt, which is one of the wettest regions of Egypt, and the inland oases[2]. Because of its distance from the seas and the absence of high heights that would draw orographic rain, it is hyperarid. The Western Desert Oases are separated from one another, from the Nile Valley, and from habitable areas in the Sinai Peninsula by hundreds of kilometers of arid desert. This barrier appears to be impossible for animals with limited mobility to cross. The regularity of the surface is another noteworthy aspect of the Western Desert's physiography. The interior of the plateau is flat, and as far as the eye can see, all that is present are barren or covered fields of rocks[2]. Rarely does any evident relief feature penetrate this surface[29]. The Western Desert appears to be a great rocky plateau of moderate altitude. Sand dunes are a typical landform in the Western Desert, according to Vivian[26]. Their forms and colors range from almost white to rusty red. El Gilf El Kebir has been penetrated by the Great Sand Sea from the north; while most dunes flow through the Gilf to the east or west, there are some locations where dunes have actually ascended the escarpment, a humbling sight[26].

The northern Sinai Peninsula is bordered by the folds to the south and the Mediterranean Sea to the north and stretches to the Suez Canal in the west. This region is

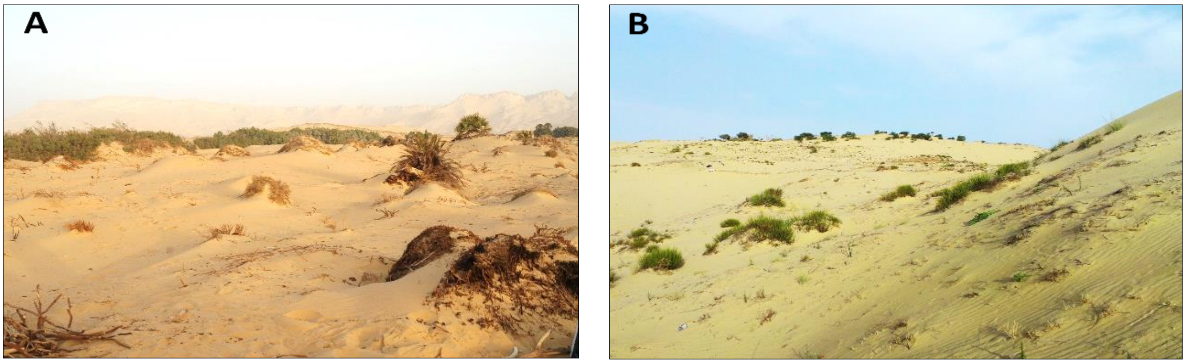

Figure 8: The typical habitat of the fennec fox in Western Desert **(A)** and northern Sinai **(B)**.

formed of wide plain sloping gradually northward. There are many of sand dunes of 80-100 m, which stretched for many kilometers in this vast plain. This wide northern part of Sinai is an extension of the Mediterranean coastal area of Egypt[30]. The northern sand dunes of this region are elongated, while at its southern edge the crescentic type of dunes are present[31]. Aeolian deposition has played an important role in this area of Sinai, consisting of dunes and is parallel to the northwesterly winds. The sand dunes near Gabal El-Maghara extend from southwest to northeast. The dunes at the northern Sinai absorb and store rain water, the low lands between these dunes being an important source of fresh water that may be tapped by digging wells[30]. The water supply of these wells differs and its quantity depends upon rainfall[15].

In Egypt, the fennec fox prefers sandy habitats and sandy dunes, and it is found in the Egyptian Western Desert south of the Mediterranean Coastal Desert, and northern Sinai Peninsula. These findings are in agreement with those of Osborn and Helmy[1] and Mohamed[32]. Also, the fennec foxes are common in the semi-arid and sandy deserts of northern Africa and northern Sinai, according to Saleh and Basuony[2]. They can be found in the north Sahelian regions and are common throughout the Sahara[17]. Fennec foxes were observed in all sandy areas of southern Morocco that were far from long-term human habitations[3]. The fennec fox typically digs its burrow near plants in sandy desert habitats[33,34]. In Egypt, the fennec fox burrows in mounds under *Zygophyllum album*, *Nitraria retusa*, and *Calligonum comosum* were dug by Osborn and Helmy[1]. No fennec fox specimens have been discovered or reported from the Egyptian Western Mediterranean Coastal Desert yet[32]. West of Giza and north of Wadi El-Natroun's sandy areas and from undulating sand dunes in northwestern Sinai Peninsula were reported specimens of the fennec fox by Flower[35]. The size and shape of the fennec fox *V. zerda's* skulls differed between the Western Desert and northern Sinai population, according to the current study. Additionally, Parsons *et al*.[36] noted some variations in skull morphology between urban and rural populations of red foxes, *V. vulpes*, from London. The length of snouts and braincases have been shown to be the main measurements affected by these changes. Also, Younes[23] noted several differences between red fox populations collected from all their distributed region in Egypt. He reported the red foxes from the Western Mediterranean Coastal Desert and Western Desert Oases are different from other parts of the country in terms of their skull measurements.

There are several differences in the composition of the habitats in both the Egyptian Western Desert and northern Sinai, which are hundreds of kilometers away from each other, but they are similar in the presence of different types of sand dune habitats. These differences led to the presence of different size and shape skull in the fennec fox "*V. zerda*" in Egypt. The detection of thirteen differences in the skull size and shape between the two fennec fox populations from the Western Desert and northern Sinai may be enough to make them separate from each other taxonomically, perhaps at the subspecies level. In conclusion, PCA of the cranial and dental measurements used in the current study confirmed the difference between the two studied *V. zerda* populations. More future studies will take place to confirm or deny the separation of these populations at the subspecies level.

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CONFLICT OF INTEREST
The author declares that there is no conflict of interest.

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توصيف الجمجمة والأسنان لثعلب الفنك "*Vulpes zerda*" الذي تم جمعه من الصحراء الغربية وشبه جزيرة سيناء، في مصر

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نتيجة للدراسات السابقة التي أجريت على مدى السنوات القليلة الماضية، ظهر عدد من الخصائص المثيرة للاهتمام فيما يتعلق بالعلاقات بين عشائر الثدييات المختلفة عبر برزخ السويس. وتختلف مجموعات الثدييات في سيناء وإفريقيا بهذا البرزخ. فلا تستطيع جميع الحيوانات التي تقطن الصحراء الغربية وشبه جزيرة سيناء في مصر عبور دلتا النيل والوادي، فضلا عن برزخ السويس، وهي تمثل معًا حواجز بيئية كبيرة. في الدراسة الحالية، تم استخدام أربعة عشر جمجمة لثعلب الفنك "*Vulpes zerda*"، الموجودة ضمن المجموعة المرجعية الحيوانية لجامعة الأزهر (AUZC)، القاهرة، مصر. تم جمع هذه الجماجم بين عامي 1983 و 2007 من الصحراء الغربية في مصر وشبه جزيرة سيناء. وأظهرت القياسات المطلقة للجمجمة والأسنان المستخدمة في هذه الدراسة اختلافات ذات دلالة إحصائية (P<0.05) بين العشيرتين محل الدراسة. كما أظهرت نسب قياس الجماجم والأسنان اختلافات ذات دلالة إحصائية (P<0.05) بين العشيرتين محل الدراسة. تم اكتشاف ثلاثة عشر اختلافًا بين جماجم ثعلب الفنك في العشيرتين محل الدراسة. قد تكون هذه الاختلافات كافية لجعل العشيرتين منفصلتين عن بعضهما البعض من الناحية التصنيفية، ربما على مستوى تحت النوع. أكد تحليل المكونات الرئيسية "PCA" لقياسات الجماجم والأسنان المستخدمة في الدراسة الحالية الاختلافات بين عشيرتي "*V. zerda*" محل الدراسة. وسيتم إجراء المزيد من الدراسات المستقبلية لتأكيد أو نفي فصل هاتين العشيرتين على مستوى تحت النوع.