GEODIVERSITY OF KARST LANDFORMS WITH HIGH PRIORITY CONSERVATION AREAS FOR SOOTY FALCON (*FALCO CONCOLOR*) IN THE WHITE DESERT NATIONAL PARK, WESTERN DESERT, EGYPT

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ABSTRACT

This paper examines the relationship between karst landforms and biological diversity. We investigated the distribution of a migratory threatened species, the Sooty Falcon (*Falco concolor*), within different karst landform zones identified in the White Desert National Park in the Farafra Oasis, Western Desert, Egypt. Field surveys of the distribution and breeding of Sooty Falcons were conducted within different karst landforms in the White Desert National Park during September to November from 2009 to 2013. Numbers of Sooty Falcon pairs recorded in the park have ranged from 33 to 101 per annum and the species has been recorded in all years from 2009 to 2013. The number of single adults and juveniles ranges from 11 to 71, while the nestlings recorded range between 29 and 88 through the study period. Our results confirm that the distribution pattern, density and breeding success of the falcons are strongly related to solution cavities formed within tower karsts which are the home base for the species. The increased numbers in the last two years are likely related to lesser impacts of human disturbance as a result of a decrease in tourist activity in the study area due to security concerns.

Key words: White Desert, karst landforms, solution cavities, tower karst, Sooty Falcon, *Falco concolor*

INTRODUCTION

Ecosystems depend on their non-living parts such as bedrock, landforms, soils and related processes. In the early nineties, the term 'geodiversity' was first introduced by geologists as an analogue to biodiversity (Sharples, 1993; Wiedenbein, 1994). Geodiversity is known as the variety of rocks, fossils, minerals, natural processes, landforms and soils that underlie and determine the character of our landscape and environment (Dudley, 2008; Gray, 2013; Crofts & Gordon, 2014). The term biodiversity (biological diversity) means the variety of all life on Earth. It includes all living things: plants, animals, fungi, algae and bacteria. Often geodiversity provides fundamental elements for biodiversity in forming major ecosystem attributes. The variation in Earth's abiotic processes has strong effects on biodiversity patterns (Zarnetske et al., 2018). The interesting pioneer study by Anderson and Ferree (2010) drew attention to the importance of areas that represent a diversity of current abiotic conditions and that will likely provide the diversity of environments needed to support future biodiversity, even if the climatic conditions and species in those areas change.

Although the Middle East supports a high level of avian biodiversity, few detailed studies have been conducted on the ecology of species that use the region. Despite its restricted breeding distribution in the Middle East, and apparent unfavourable conservation status, little is known about the population ecology of the Sooty Falcon (*Falco concolor*) (McGrady et al., 2015).

The Sooty Falcon is a small to medium sized migratory species, which breeds in mountainous desert areas with canyons and cliffs, across eastern North Africa, from eastern Libya through Egypt and Jordan, to the coasts of the Red Sea and Arabian Gulf, through the Middle East to southwest Pakistan in summer (Walter, 1979a, b; Cramp & Simmons, 1980; Del Hoyo et al., 1994; Gaucher et al., 1995; Jennings, 1995; Semere et al., 2008; McGrady et al., 2019). Recently they have been recorded nesting in Iran (Fahimi & Jowkar, 2010; Kashfi et al., 2019). In the non-breeding season (winter),

they are predominantly found in Madagascar (Javed et al., 2011). No surveys have been conducted to establish their distribution in the Western Desert before. The objective of this study was to assess whether the geodiversity in White Desert National Park influenced Sooty Falcon distribution patterns.

Sooty Falcon (*Falco concolor*) in flight ©Mohamed Gebrel

STUDY AREA

The White Desert National Park occupies the northern part of the El Farafra Depression, Western Desert, New Valley Governorate, Egypt. It covers an area of about 3,010 km2 (Figure 1) and was declared to protect the desert ecosystems, karst landforms and spectacular scenery and erosional features in the chalky limestones. It is listed as IUCN category II - National Park based on the management objectives.

The exposed rocks in the Bahariya-Farafra territories are sedimentary in nature and can be classified into two types, karst and non-karst rocks (El Aref et al., 2017a). The first type includes the carbonate rocks of the El

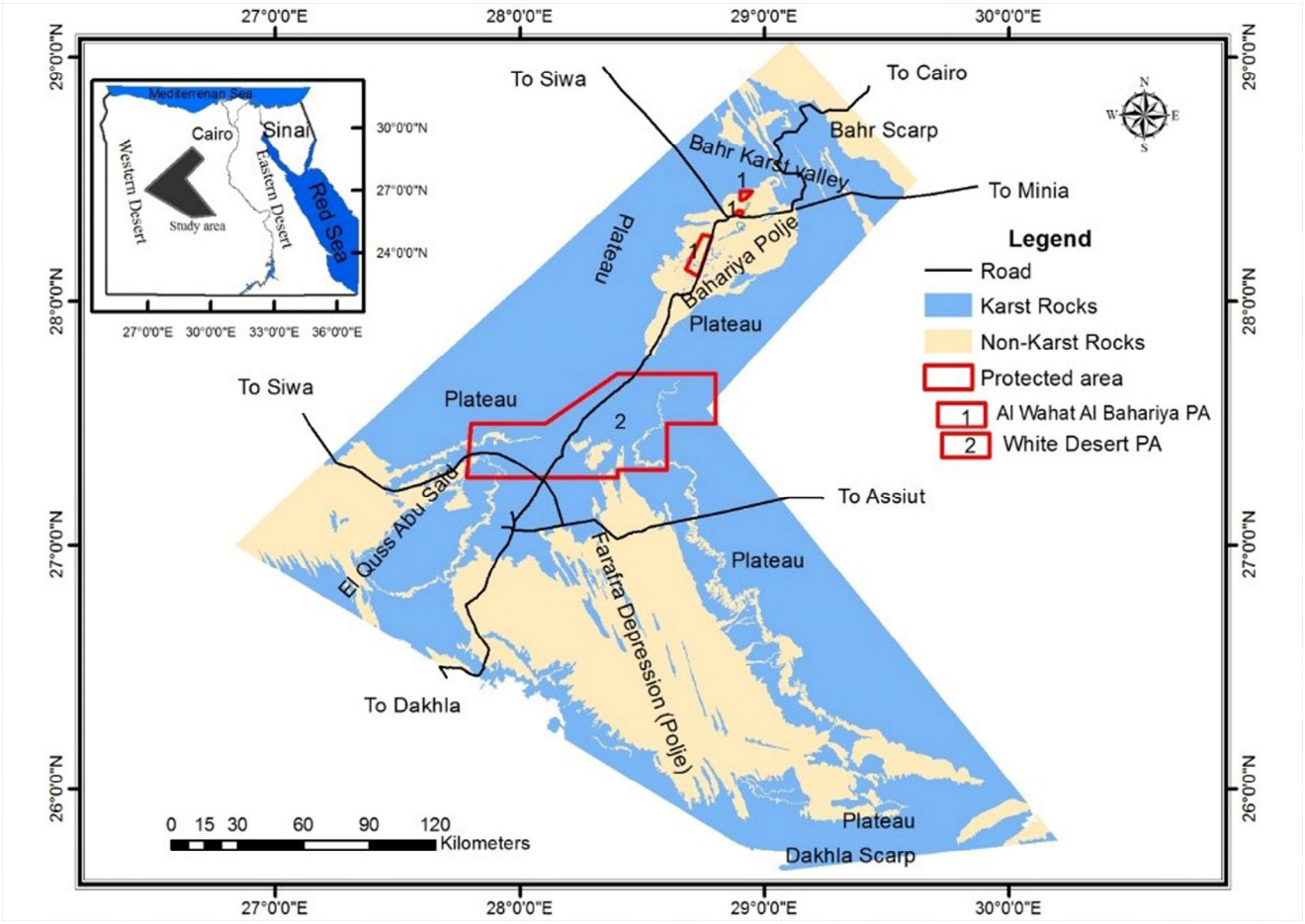

Figure 1. Map of the study area including protected areas Note the distribution of karst and non-karst rocks (after El Aref et al., 2017a)

Hefhuf, Khoman Chalk, Tarawan and Naqb formations of the Campanian, Cretaceous, Palaeocene and Eocene ages respectively. Non-carbonate rocks include the Bahariya, Wadi Hennis, Dakhla and Esna formations of the Cenomanian, Cretaceous and Palaeocene ages in addition to sand dunes of the Quaternary period covering a huge area.

METHODS

The annual survey began in 2009 as part of an inventory of the geological heritage in a unique area of the White Desert National Park to record geosites (El Aref et al., 2017b). The survey was conducted annually from September to November from 2009 to 2013. During these surveys, direct observations of the Sooty Falcon identified pairs of birds, individuals and nesting location with GPS locations noted. We systematically followed the same GPS routes used in the first year to monitor the whole national park in the following years.

RESULTS

The results of the mapping identified twelve karst zones (Figure 2).

Protection of karst landforms, White Desert National Park, Egypt
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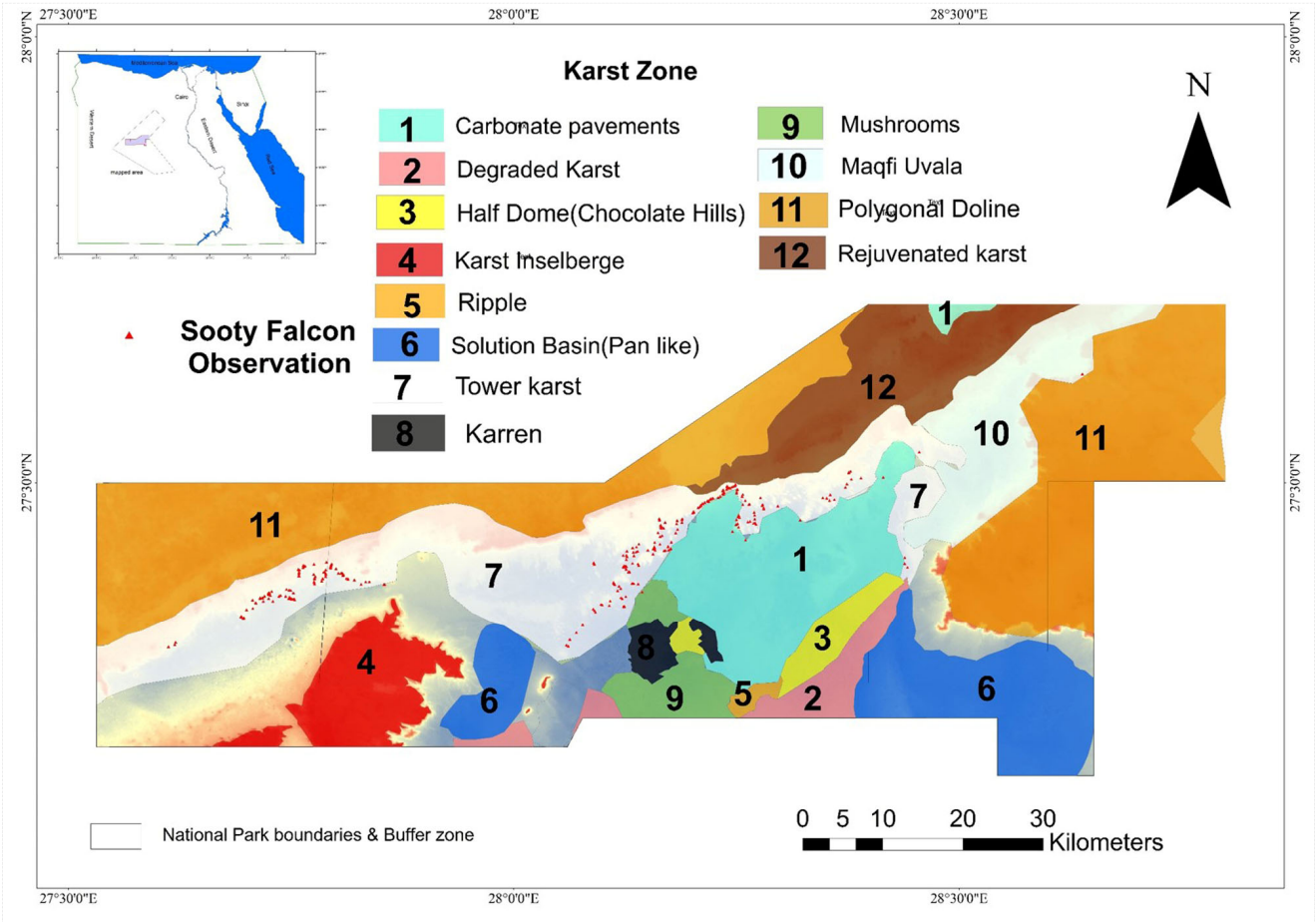

Figure 2. Zonation map of karst landforms in the White Desert National Park (modified after El Aref et al., 2017a)

Carbonate pavements zone

This field covers an area of about 402 km2 in the northern part of El Farafra Depression (Figure 2). Small -scale structurally controlled grikes of rectangular shape develop along crosscutting fractures and faults (Figure 3a).

Degraded karst zone

Typical degraded karst chalk and limestone scenery of the White Desert, showing eroded remains of all shapes and sizes, creating a spectacular and amazing landscape of outstanding natural beauty (stone art), which has made the region a globally renowned tourist site (Figure 3b). This 1,129 km2 field represents the main destination for visitors to the national park

Polygonal half-dome zone

This field (about 76 km²) encompasses a compound of symmetrical half-dome hills (up to 5 m in diameter and 5 m high) like chocolate balls (Figure 3c), formed of Cretaceous chalks in the lower levels and white silty chalky Quaternary playa sediments in the upper levels.

Karst isolated inselbergs

Many carbonate inselbergs are distributed over the floors of El Farafra Depression (such as El Quss Abu Said Plateau and Gebal Gunna) (Figure 3d), both inselbergs are located in the buffer zone of White Desert National Park.

Polygonal ripple or cuesta-like zone

This zone (about 15 km2) consists of asymmetrical small ridges forming a ripple or cuesta-like range between 0.5 and 2 m in length, 1 to 3 m width and 1 to 3 m in height, with a steep slope on one side and a gentle slope on the other (Figure 3e).

Polygonal solution basins (pan-like) zone

This zone is located at the pediments of the eastern and western Farafra scarps. It is formed of small-scale and closely spaced chalky rounded hills topped by a hard dolomitic cap of pan-like shape having well developed outlets running downwards through solution channels disappearing into solution sinks commonly distributed in the surrounding lowlands (Figure 3f).

Polygonal tower karst zone

This zone covers an area of about 884 km2 delineating the northern scarp of El Farafra Depression (Figure 2). The Cretaceous chalks form spectacular steep sided and high-standing tower forms together with variable varieties of smaller-sized pedestal rocks, and smooth cylindrical pinnacles. The walls of karst towers are characterised by the association of trittkarren (armchair -like or heelprint shape) and small-scale solution cavities. This zone represents one of the most attractive habitats for Sooty Falcons (Figure 4a).

Karren zone

These zones demarcate nearly flat areas, some of which are characterised by a wide distribution of round and dish-shaped hollows (kamenitza), developed on gently sloping sides or along fractures (Figure 4b).

Mushroom zone

This zone covers an area of about 244 km2 in El Farafra Depression, dominated by irregularly distributed short mushroom-like solution columns having a stem or neck and cap. The cap is larger than the stem that supports it. They stand in isolation above the depression floor (Figure 4c). This zone is easily accessed by visitors by an asphalt road.

Polygonal solution dolines

The Early Eocene carbonate of the eastern and western plateau of El Farafra Depression are commonly pitted by dense populations of solution dolines of variable diameters, rimmed by thin walls dissected by solution channels (runnels, grooves). The dolines are surrounded by connected or disconnected ridges (Figure 4d) and commonly incised by dry blind valleys.

Maqfi uvala zone

This lies in the north-eastern part of El Farafra Depression and was excavated within the Tarawan, Esna and Farafra formations of the Palaeocene – Early Eocene period. The floor of the uvala is covered by very hard recrystallised marmorised limestones (Figure 4e).

Rejuvenated karst

This zone is located on the plateau between Bahariya and Farafra Depression, covering an area of about 401 km2 known as Qaret El Sheikh Abdallah and the associated 'Crystal Depressions'. It exhibits an amazing complex of karst landforms generated during periods of uplifting and karstification. The rejuvenated karst features include widened joints, sinkholes, collapse breccias, subsurface channels and caves (Figure 4f). These solution features are partially or completely filled by a variety of autochthonous and allochthonous palaeo-cave sediments.

Solution pavements of rectangular shape
©Ahmed Salama.

Karst isolated inselbergs - Panoramic view of Gebal Gunna north ©Ahmed Salama.

Rabbit-like shape in chalk limestone
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Cuesta-like ripple
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Half-dome symmetrical forms (like chocolate balls)
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Solution basin with pan-like shape
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Figure 3a. to 3f. Karst zones mapped in White Desert National Park.

3a. Carbonate pavements zone; 3b. Degraded Karst zone; 3c. Polygonal half-dome zone; 3d. Karst isolated inselbergs; 3e. Polygonal ripple or cuesta-like zone; 3f.Polygonal solution basins (pan-like) zone

A pair of juvenile Sooty Falcons in a cavity in a carbonate tower karst ©Mohamed Gebrel.

Google Earth photo showing solution dolines

Large circular dish shape kamenitza ©Ahmed Salama.

Hard crystallised dolomite at the base of Maqfi uvala ©Ahmed Salama.

Mushroom shape ©Ahmed Salama.

Grain-supported in-situ breccia invaded by red soils ©Ahmed Salama.

Figure 4a. to 4f. Karst zones mapped in White Desert National Park.

4a. Polygonal tower karst zone; 4b. Karren zone; 4c. Mushroom zone; 4d. Polygonal solution dolines; 4e. PMaqfi uvala zone; 4f.Rejuvenated karst

Juvenile Sooty Falcon roosting in solution cavities in the tower karst zone ©Ahmed Salama

Sooty Falcon observations in the karst zones

The number of Sooty Falcon pairs recorded in the White Desert National Park ranges from 33 to 101 per annum (Table 1) over the years from 2009 to 2013. The number of single birds (adults and juveniles) ranges from 11 to 71, while occupied nests range from 29 to 88 per annum. The trend has been one of gradual increase in the number of breeding pairs in the park over the period of the survey (Table 1).

The increased numbers in the last two years may be related to low levels of human disturbance as a result of a fall in tourist activities in the study area due to security concerns. The majority of Sooty Falcons were observed in the tower karst zone, except for a few that were seen in the carbonate pavements zone.

Our field survey shows that Sooty Falcon communities live and build their nests in solution cavities of very high

Table 1. Direct observations of Sooty Falcons (pairs, singles and nestlings) in the karst zone

				Karst Landform assemblages											
Year	Pairs	Single	Nestling	CP	DK	HD	KI	R	SB	TK	K	M	MQU	PD	RE
2009	34	20	30	✓	x	x	x	x	x	✓	x	x	x	x	x
2010	33	11	29	x	x	x	x	x	x	✓	x	x	x	x	x
2011	81	36	58	x	x	x	x	x	x	✓	x	x	x	x	x
2012	101	71	88	x	x	x	x	x	x	✓	x	x	x	x	x
2013	101	71	88	x	x	x	x	x	x	✓	x	x	x	x	x
Mean	70	41.8	58.6	X = not recorded						✓ = recorded					

CP=Carbonate Pavements, DK=Degraded, HD=Half Dome, KI=Karst Inselbergs, R=Ripple, SB=Solution Basin, TK=Tower Karst, M=Mushrooms, MQU= Maqfi Uvala, PD=Polygonal Doline, RE=Rejuvenated

steep tower karsts up to 55 m in height on the northern scarp of El Farafra Depression. These solution cavities are the main nesting habitat for Sooty Falcons in the White Desert National Park.

CONCLUSIONS AND RECOMMENDATIONS

In spite of the White Desert National Park not being rich in elements of biological diversity due to the hyper aridity of the area, the diversity of karst landforms provides the basis for a diversity of species. A similar observation was reported by Anderson and Ferree (2010) who concluded that unique cave and karst features that are formed in limestone regions are host to a unique set of species found only on these landforms. The classification of karst landforms provides markedly different environments for the development of specific habitat types from limestone pavements to tower karst. One significant species to make use of karst landforms is the Sooty Falcon, a migratory, near-threatened species. We suggest that Sooty Falcons favour the tower karst zone for different reasons: firstly, the high topographic features of this zone may be the most important factor influencing the distribution of Sooty Falcons in the area by providing elevated nesting areas. Secondly, cavities and caves protect their nests from predation. Thirdly, the tower karst zone is located in areas that are not accessible to visitors due to security concerns. The other eleven types of karst zone may not be suitable because of lower elevation and the absence of protected cavities or caves. In addition, these lower elevation areas are very easily accessible, therefore disturbance by visitation would be higher. Similar trends have also been noted in the study of McGrady et al., (2019) on the Daymaniyat Islands of Oman which concluded that the number of Sooty Falcon breeding pairs on islands accessible to humans are less than half those on inaccessible islands. We recommend restricting tourist visits during the breeding season of Sooty Falcon in important zones for this species. It is essential to consider the protection of the karst landform zones when updating the management plan for White Desert National Park.

ABOUT THE AUTHORS

Ahmed Salama graduated from Cairo University with a BSc, MSc and PhD in geology. He has worked for 26 years in the management and planning of protected areas in Egypt. He is former Head of the Nature Conservation Sector and General Manager of Western Desert Protected Area in the Egyptian Environmental Affairs Agency, Ministry of Environment. He was responsible for the management of 30 protected areas and biodiversity. Ahmed is now working as adviser to the Chief Executive Officer of the Egyptian Environmental Affairs Agency for Nature Conservation.

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Wael Thabet has an MSc in Geology from Menoufia University and he worked as environmental researcher at the White Desert National Park from 2008 to 2016. Now Wael is the Director of El Wahat El Bahariya Protected Area.

Mohamed Gebrel completed a PhD degree at the Faculty of Agriculture, Minia University, and he now works as an environmental researcher in White Desert National Park since 2008 and is responsible for monitoring the fauna in the park.

Connected solution cavities of different shapes host pairs of Sooty Falcons ©Wael Thabet

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RESUMEN

Este artículo examina la relación entre los accidentes geográficos kársticos y la diversidad biológica. Investigamos la distribución de una especie migratoria amenazada, el halcón pizarroso, *Falco concolor*, dentro de diferentes zonas de relieve kárstico identificadas en el Parque Nacional del Desierto Blanco en el Oasis de Farafra, Desierto Occidental, Egipto. Los estudios de campo de la distribución y cría del halcón pizarroso se llevaron a cabo dentro de diferentes formas de relieve kárstico en el Parque Nacional del Desierto Blanco durante septiembre a noviembre de 2009 a 2013. El número de parejas de halcones pizarrosos registrados en el parque ha oscilado entre 33 y 101 por año y la especie ha sido registrada en todos los años desde 2009 a 2013. El número de adultos solteros y juveniles varía de 11 a 71, mientras que los pichones registrados varían entre 29 y 88 durante el período de referencia. Nuestros resultados confirman que el patrón de distribución, la densidad y el éxito reproductivo de los halcones están estrechamente relacionados con las cavidades de disolución formadas dentro de las torres kársticas, que constituyen el emplazamiento de la especie. El incremento del número en los últimos dos años probablemente esté relacionado con un menor grado de perturbación humana como resultado de la disminución de la actividad turística en el área de estudio debido a consideraciones de seguridad.

RÉSUMÉ

Cet article examine la relation entre les reliefs karstiques et la diversité biologique. Nous avons étudié la distribution d'une espèce migratoire menacée, le faucon fuligineux, Falco concolor, dans différentes zones de relief karstique identifiées dans le parc national du désert blanc dans l'oasis de Farafra, désert occidental, en Égypte. Des relevés sur le terrain de la distribution et de la reproduction des faucons fuligineux ont été menés dans différents reliefs karstiques dans le parc national du désert blanc de septembre à novembre de 2009 à 2013. Le nombre de couples de faucons fuligineux enregistrés dans le parc a fluctué entre 33 et 101 par an et les enregistrements ont été effectués chaque année de 2009 à 2013. Au cours de la période d'étude, le nombre d'adultes et de jeunes isolés varie de 11 à 71, tandis que les oisillons enregistrés varient entre 29 et 88. Nos résultats confirment que le modèle de distribution, la densité et le succès de reproduction des faucons sont fortement liés aux cavités de solution formées dans les karsts à tour qui sont l'habitat d'origine de l'espèce. L'augmentation du nombre de faucons au cours des deux dernières années est vraisemblablement imputable à l'impact réduit des perturbations humaines dans la zone d'étude suite à une diminution d'activité touristique en raison de préoccupations d'ordre sécuritaires.