Ecological Questions 37(2026)2 http://dx.doi.org/10.12775/EQ.2026.023

Biodiversity conservation challenges in Wadi El-Gemal, Egypt: A Hotspot under pressure

Abdelraouf A. Moustafa [1]*, Yasmin S. Khalil [1], Menna Khalaf [1], Roba A. Elganainy [1], Mohamed S. Zaghloul [1], Samira R. Mansour [1], Wael N. Hozzein[2], Areej A. Alkhalal[3] and Monier M. Abd El-Ghani [4]

[1]Botany and Microbiology Department, Faculty of Science, Suez Canal University, Ismailia 41522, Egypt
[2]Botany and Microbiology Department, Faculty of Science, Beni-Suef University, Beni-Suef, Egypt
[3]Biology Department, College of Science, Princess Nourah Bint Abdulrahman University, Riyadh 11671, Saudi Arabia
[4]Botany and Microbiology Department, Faculty of Science, Cairo University, Giza 12613, Egypt

*Corresponding author e-mail: raoufmoustafa2@hotmail.com

Received: 12 March 2025 / Accepted: 30 March 2026

Abstract. Wadi El-Gemal–Hamata Protected Area (WGHPA), located in the southeastern desert of Egypt along the southern Red Sea coast, represents a unique ecological system characterized by high biological diversity despite its arid environment. This study aimed to assess recent changes in the floristic composition of WGHPA in relation to anthropogenic pressures and climatic variability, while also providing an overview of the associated faunal diversity. Seasonal field surveys were conducted over two consecutive years (2022–2023) to document plant species, their life spans, growth forms, and conservation status, with complementary observations of vertebrate fauna and their conservation status. The floristic survey recorded a total of 77 plant species belonging to 31 families, with *Amaranthaceae*, *Apocynaceae*, *Asteraceae*, *Fabaceae*, and *Zygophyllaceae* representing the dominant families. Faunal surveys documented 73 animal species from 41 families, including birds, mammals, and reptiles, highlighting the importance of WGHPA as a habitat for rare, endemic, and migratory species. Field observations identified ecologically significant habitats, particularly wadis and mangrove stand, that function as biodiversity hotspots and play a crucial role in maintaining regional ecological balance. Despite its protected status, WGHPA is increasingly threatened by human activities, climate change, and unsustainable resource use. The findings underscore the need for integrated, ecosystem-based management strategies that balance conservation priorities with sustainable development. By documenting biological diversity and identifying key conservation areas, this study contributes to the sustainable management of WGHPA and supports broader conservation efforts for desert ecosystems in Egypt.

Keywords: endangered flora and fauna; marine species; conservation; Wadi El-Gemal (WGHPA).

1. Introduction

Biodiversity, encompassing ecosystems, species, and genetic diversity, underpins ecosystem functioning and supports essential services such as food production, soil fertility, and climate regulation, which are vital for human well-being (EEAA, 2009). Yet, development activities, including overexploitation, pollution, habitat destruction, and climate-induced changes, have led to substantial and often irreversible biodiversity loss globally (Hegazy, 1999). In the Mediterranean region, human impacts over millennia, including forest clearance, grazing, cultivation, urbanization, and tourism, have significantly altered vegetation patterns and ecosystem structure (Heywood, 2000).

In Egypt, biodiversity conservation has been prioritized over the past two decades through legislation, establishment of the Egyptian Environmental Affairs Agency (EEAA, 1982), ratification of the Convention on Biological Diversity (1994), and creation of 30 protected areas covering approximately 149,000 km² (14.9% of national territory) (NBSAP, 2016). These areas safeguard key terrestrial and marine ecosystems, including endemic species of the Red Sea, the northernmost coral reefs, and mangrove habitats, which are increasingly vulnerable to climate change and human pressures (EEAA, 2012).

The Wadi El-Gemal–Hamata Protected Area (WGHPA), established in 2003 and classified as IUCN Category II, represents one of the last relatively undisturbed coastal landscapes along the southern Red Sea (Baha El Din, 2003).

Despite these efforts, several studies have reported ongoing threats to biodiversity in the southern Red Sea region, including habitat degradation, overgrazing, unregulated tourism, and mining (Frazier and Salas, 1984; Baha El Din, 2003; Mahmoud, 2010). Previous floristic and faunal surveys in WGHPA have documented important plant and animal species, yet a comprehensive synthesis integrating vegetation patterns, species conservation status, and environmental gradients remains lacking (Moustafa et al., 2023).

"This study provides baseline documentation of plant and animal communities, their conservation status, and descriptive environmental gradients in WGHPA, to inform sustainable management and conservation strategies.

2. Materials and Methods

2.1 Study area and location

Wadi El-Gemal is located on the Red Sea coast, approximately 150 km south of Mersa Alam, at a latitude from 2 southwest to northeast, with roughly 100 km of shoreline, about 15 km offshore, and approximately 55 km into mountainous highlands. The Wadi El-Gemal Protected Area encompasses diverse terrestrial and marine ecosystems, including a network of wadis—dry valleys or seasonal riverbeds that carry water episodically during rainfall events—and prominent mountain peaks. These landscape features support a variety of habitats for local flora and fauna (Wikipedia contributors 2026**)**. Wadi, ephemeral desert drainage systems characterized by seasonal runoff and distinct geomorphological features.

The Wadi El-Gemal–Hamata Protected Area (WGHPA) comprises several major drainage systems that flow eastward into the Red Sea, including Wadi El-Gemal, Wadi Abu Ghusoon, Wadi El-Ranga, and Wadi El-Rada. Slopes are generally steep, reflecting the high resistance of wall-forming rocks, but slope steepness varies locally depending on geomorphology and rock type (Khaleal et al., 2008). Wadi El-Gemal is the largest and most prominent, with relatively dense vegetation and a watershed area of approximately 1,476.7 km² (Mansour, 2003). Several prominent mountain peaks are present, including Gebel Hamata, Gebel Nugrus, Gebel Hafafeet, Gebel Hamamid, Gebel Sartut, and Gebel Sikait.

The study area is characterized by diverse geomorphological features and comprises six main habitat types, including mangrove swamps, reed swamps, coastal dunes, littoral salt marshes, coastal sand plains, and wadi beds, which together represent a range of terrestrial and marine ecosystems under largely natural conditions.

2.2 Climate

The study area is among the most arid deserts worldwide, exhibiting a rainfall coefficient of variation of approximately 200%. Beyond its highly sporadic rainfall and occasional orographic precipitation, non-rainfall water inputs—such as dew, mist, and fog—also play a significant role in sustaining local moisture availability. (Hassib, 1951).

- **Temperature and Humidity:** Mean monthly air temperatures range from 24–35.6 °C in summer and 13.2–26 °C in winter. Relative humidity averages 28% in summer and 57% in winter. Evapotranspiration averages 8.7 mm/day in winter and 28 mm/day in summer (Figure 1).

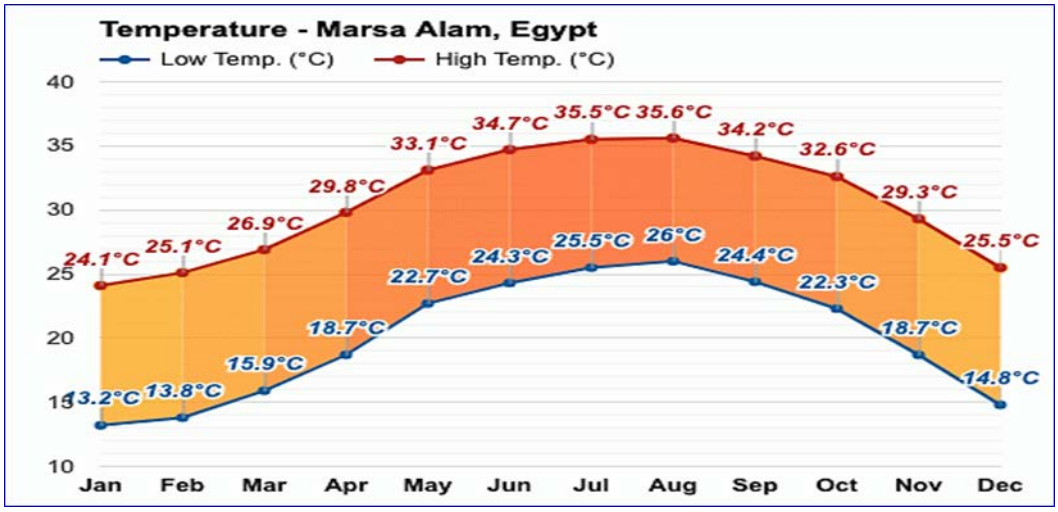

Figure 1. Average of low and high temperatures (1995-2024) in Mersa Alam in 2023, Egypt (Source by https://www.weather-atlas.com/en/egypt/marsa-alam-climate; accessed on 10 September 2024).

Precipitation: Annual rainfall at Mersa Alam station (1995–2024) averages 17.4 mm, with short but intense events occasionally causing flash floods (Figure 2). The maximum recorded daily rainfall was 64 mm (24 November 1966).

Figure 2. Average of rainfall (1995-2924) in Mersa Alam in 2023, Egypt (Source by https://www.weather-atlas.com/en/egypt/marsa-alam-climate; accessed on 10 September 2024).

Wind Regime: Northwesterly winds dominate most of the year, with occasional southerly winds. Average wind speeds are 22.04 km/h in summer and 19.26 km/h in winter. Northwestern winds contribute to sediment transport toward coastal zones (Mansour, 2003).

2.3 Sampling design and survey strategy

A stratified random sampling approach was employed across the six habitat types. Vegetation surveys used 50 plots , while faunal surveys were adapted to taxa: reptiles were surveyed using visual encounter and pitfall trapping, birds were surveyed with point counts, and mammals were monitored with camera traps and live traps. Each site was visited multiple times over a 12-month period to capture seasonal variation. Tools included GPS units, binoculars, quadrats, and camera traps.

2.4 Fieldwork and Data Collection

Biodiversity hotspots within WGHPA were identified based on species richness, the presence of IUCN-listed species, and habitat uniqueness. Sites scoring highest across these criteria were considered hotspots. Species distributions and hotspot locations were georeferenced and visualized on maps to support spatial analyses (Figure 3). The location of each site was georeferenced using GPS, and a map was produced showing all sampling points and the boundaries of sub-areas (Figure 3).

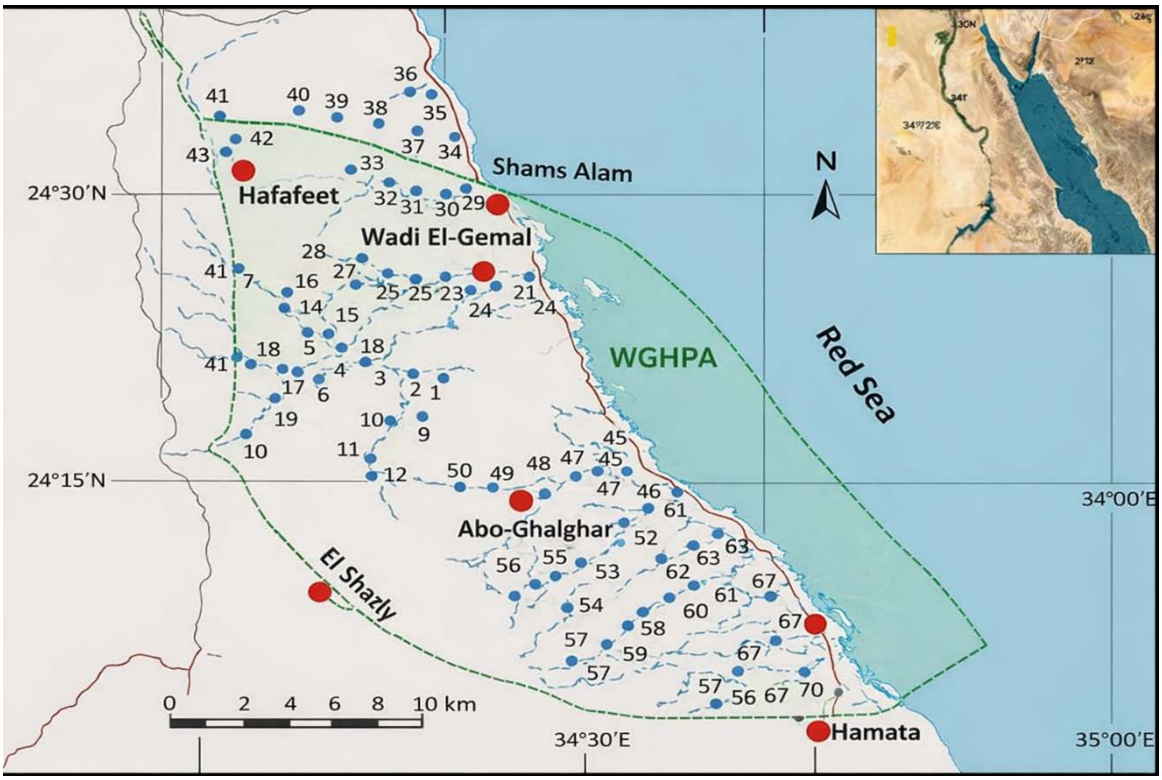

Figure 3**.** Map showing the boundary of the Wadi El-Gemal–Hamata protected area (dotted lines) with numbers representing the selected sites investigated.

Figure 1 shows the boundaries of WGHPA (dotted lines) and the 50 sampling sites investigated, with symbols indicating habitat type and potential hotspots. Sub-area boundaries are highlighted, and the legend clarifies habitat codes and sampling point markers.

Field surveys were conducted during two seasons (2022 and 2023) across the Red Sea coast to document plant and faunal communities in Wadi El-Gemal–Hamata Protected Area (WGHPA). To ensure comprehensive coverage of habitat variability, a stratified systematic sampling design was applied (Greig-Smith, 1983; Ludwig and Reynold, 1988). The study area was divided into sub-areas based on geomorphological features, habitat types, and key ecological factors.

Seventy sampling sites were selected across these features to capture the ecological diversity of the area.

Table 1. Habitat types surveyed in the study area, their main ecological characteristics, and the number of relevés.

Habitat type	**Main characteristics**	**Number of relevés**
Wadi beds	Deep sandy–loamy soils; subject to episodic flash floods; higher moisture availability.	18
Wadi slopes	Shallow, rocky soil; high runoff; low water retention.	12
Alluvial fans	Coarse sediments ; moderate drainage ; transitional habitats.	10
Rocky plateaus	Hard substrate; sparse soil cover; exposed conditions.	8
Coastal plains	Sandy substrate; influenced by marine aerosols.	9
Sand dunes	Mobile sandy soils; low stability; wind-shaped morphology.	7
Saline depressions	Fine-textured saline soils; occasional water accumulation.	6
Mangrove stands	Muddy saline substrate; tidal influence; dominated by *Avicennia marina.*	5

At each site, plant communities were sampled using sampling plots, recording presence/absence as well as quantitative metrics such as percentage cover, relative density, and frequency. The size of each sampling plot ranged from 10 × 10 m in areas of dense vegetation cover to 20 × 20 m in open, sparsely vegetated habitats **(**Moustafa, 1990**).** This approach follows established ecological sampling methodology, which recommends adapting plot size to vegetation structure to ensure representative sampling units (i.e., plots large enough to encompass the

community's species composition yet practical for field work), and is consistent with phytosociological research that uses 10 × 10 m plots for dense vegetation and larger plots for more open vegetation types. Plant species were first classified according to life span into two groups: ephemerals (annuals) and perennials, reflecting contrasting survival strategies under extreme arid conditions. For floristic and structural analyses, species were further categorized using the Raunkiaer (1934) growth-form classification.

Species identification and nomenclature followed Täckholm (1974), Zohary (1966, 1972), Feinbrun-Dothan (1978, 1986), and Boulos (1999–2005), and were verified against online databases, including GBIF and Plants of the World Online (POWO).

The conservation status of plant species was evaluated using IUCN criteria (IUCN, 2024), integrating field observations, population data, habitat specificity, and local threats. "Information on species threat categories was obtained from the IUCN Red List website (IUCN, 2024) and integrated with field observations, population data, habitat specificity, and local threat .This allowed identification of species potentially at risk at the local scale (Kassem et al., 2025).

Faunal surveys included reptiles, birds, and mammals, employing direct observation, trapping, and examination of signs (tracks, droppings), complemented by comparison with historical records. Species identification followed Osborn and Helmy (1980) and Osborn and Osbornová (1998).

3. Results

Floristic composition

The current survey documented a total of 77 species from 35 families of the vascular plants (Table 2), with the majority belonging to Fabaceae (10 species; 13.1% of the total flora), followed by *Zygophyllaceae* (8 species; 10.5%), *Amaranthaceae*, *Apocynaceae*, and *Asteraceae* (5 species for each; 6.6%). The perennials consisted of the main bulk of species composition (61 perennials; 80.3%) while annuals accounted for 15 annuals (19.7%).

"The stratification of vegetation (layering) is characterized by the occurrence of multiple growth forms (Table 1)): the tree layer was represented by 14 species (18.4%) such as *Hyphaene thebaica, Moringa peregrina, Balanites aegyptiaca*. and *Acacia tortilis* subsp. *raddiana*, *Avicennia marina* and *Tamarix aphylla*. The shrubby layer (16 species) and the sub-shrubs (24 species) dominated the vegetation structure with 40 species (52.6%), and were represented, amongst others, by shrubs of *Suaeda monoica, Calotropis procera, Ochradenus baccatus, Solenostemma arghel*,

and sub-shrubs of *Aerva javanica*. ~~ex Schult~~., *Cleome droserifolia, Lavandula pubescens, Cucumis prophetarum,* and *Fagonia indica*. The herb layer was indicated by perennials (7 species) such as *Panicum turgidum, Heliotropium strigosum, Lindenbergia indica,* and *Aeluropus littoralis*, while the annual herbs were represented by 15 species such as *Zygophyllum simplex, Trichodesma africanum, Chenopodium murale, Tephrosia purpurea, Aizoon canariense,* and *Erodium laciniatum.*

More than 65% of the floristic composition in Wadi El-Gemal (53 species) is classified as Least Concern (Table 2) and is distributed across nearly all recorded plant families in Wadi El-Gemal–Hamata Protected Area (WGHPA), including species such as *Echinops spinosissimus* ~~*Turra*~~, *Citrullus colocynthis , Arthrocaulon macrostachyum , Cocculus pendulus , Lycium shawii*, and *Cyperus conglomeratus*. The non-evaluated category comprised 22 species (32.8%), including *Heliotropium strigosum, Farsetia longisiliqua, Limonium axillare, Aizoon canariense,* and *Astragalus vogelii*. Only one species was classified as not threatened: *Calotropis procera*.

Based on relative abundance and ecological prominence, documented plant species were classified into five distribution categories:

1. **Dominant species:** highest cover and ecological influence (23 species)
2. **Co-dominant species:** substantial cover and influence secondary to dominants (10 species)
3. **Associated species:** occur regularly with dominants/co-dominants, contributing to structure (19 species)
4. **Common species:** frequently observed but not necessarily abundant (4 species)
5. **Rare species:** infrequent, low abundance, often restricted to microhabitats (21 species)

those occurring infrequently and with low abundance, often restricted to specific microhabitats. The rare species are: *Atriplex farinosa, Cocculus pendulus, Farsetia longisiliqua, Heliotropium strigosum, Lindenbergia abyssinica, Lotononis platycarpa, Pergularia tomentosa, Searsia tripartita,* and (Majead et al., 2025).

To document changes in the floristic composition of the study area, it is essential to examine previous floristic surveys. Accordingly, all major botanical and ecological studies conducted over the past two decades in the Red Sea Governorate, along the Red Sea coastline, within Wadi El-Gemal–Hamata Protected Area, and across Egypt were thoroughly reviewed. Owing to the comprehensive data on taxon distribution provided by Barakat (2003), this study was used as the

primary reference for comparing the current distribution and status of each taxon. Table 3 presents a concise comparison between earlier floristic studies and the present investigation. Notable variation was observed in the number of recorded species among these studies, ranging from a maximum of 95 species in 2003 to as few as 23 species in 2017. Such differences are likely attributable to variations in sampling period, spatial scale of the surveyed areas, and rainfall conditions during the respective study periods. Figure 4 presents representative plant species recorded in the Wadi El-Gemal Protected Area. The images include *Acacia tortilis* (Forssk.) Hayne, *Balanites aegyptiaca* (L.) Del., *Cleome amblyocarpa* Barratte & Murb., *Nitraria retusa* (Forssk.) Asch., *Tamarix aphylla* L., and *Avicennia marina* (Forssk.). These species reflect the diverse flora of the region, ranging from desert-adapted trees and shrubs to halophytic plants near coastal and saline habitats.

Table 2. Diversity of plant species recorded in the WGHPA: life span, growth form, habitat categories, distribution, and IUCN (2024) conservation status.

https://www.iucnredlist.org/ (accessed on 10 September 2024). Distribution: ass= associated, c=common, d=dominant, cd=co-dominant, r=rare.

Plant species	**Family**	**Life span**	**Growth form**	**Habitat type**	**Distribution**	**Conservation status**
Acacia ehrenbergiana Hayne	*Fabaceae*	Per.	Shrub or Tree	arid sandy plains	ass.	Least Concern
Acacia etbaica Schweinf	*Fabaceae*	Per.	Shrub or Tree	arid sandy plains	ass.	Least Concern
Acacia tortilis (Forssk.) Hayne subsp. raddiana (Savi) Brenan	*Fabaceae*	Per.	Tree	arid sandy plains	d.	Least Concern
Acacia tortilis (Forssk.) Hayne subsp. *tortilis*	*Fabaceae*	Per.	Shrub or Tree	arid sandy plains	d.	Least Concern
Aeluropus littoralis (Gouan) Parl.	*Poaceae*	Ann. or Per.	Herb	arid sandy plains	cd.	Not Evaluated
Aeluropus lagopoides (Fres.) Mattei	*Poaceae*	Per.	Perennial Herb	Salt marshes	d.	Not Evaluated
Aerva javanica (Burm. f.) Juss. ex-Schult.	*Amaranthaceae*	Per.	Sub-Shrub	arid sandy plains	ass.	Not Evaluated
Aizoon canariense L.	*Aizoaceae*	Ann.	Herb	arid sandy plains	d.	Not Evaluated

Anastatica hierochuntica L.	*Brassicaceae*	Ann.	Herb	arid sandy plains	ass.	Not Evaluated
Artemisia judaica L.	*Asteraceae*	Per.	Sub-Shrub	arid sandy plains	r.	NE
Arthrocaulon macrostachyum (Moric.) K. Koch.	*Amaranthaceae*	Per.	Sub-Shrub	Salt marshes	d.	Not Evaluated
Asphodelus tenuifolius Cav.	*Asphodelaceae*	Ann.	Herb	arid sandy plains	ass.	Not Evaluated
Astragalus vogelii (Webb) Bornm.	*Fabaceae*	Ann.	Herb	arid sandy plains	c.	Not Evaluated
Atriplex farinosa Forssk.	*Amaranthaceae*	Per.	Shrub	arid sandy plains	r.	Not Evaluated
Avicennia marina (Forssk.) Vierh.	*Acanthaceae*	Per.	Shrub or Tree	Coastal swamps	d.	Least Concern
Balanites aegyptiaca (L.) Del.	*Zygophyllaceae*	Per.	Tree	arid sandy plains	d.	Not Evaluated
Calligonum polygonoides L. subsp. *comosum* (L'Hér.) Soskov	*Polygonaceae*	Per.	Shrub	arid sandy plains, dunes	ass.	Not Evaluated
Calotropis procera (Aiton) W. T. Aiton	*Apocynaceae*	Per.	Shrub	arid sandy plains	r.	Not Evaluated
Capparis decidua (Forssk.) Edgew.	*Capparaceae*	Per.	Shrub	arid sandy plains	cd.	Not Evaluated
Capparis spinosa L.	*Capparaceae*	Per.	Shrub	arid sandy plains	d.	Not Evaluated
Chenopodium murale L.	*Chenopodiaceae*	Ann.	Herb	Grasslands, Roadsides	cd.	Not Evaluated
Chrozophora tinctoria (L.) Raf.	*Euphorbiaceae*	Per.	Sub-Shrub	Grasslands, Roadsides	r.	Not Evaluated
Citrullus colocynthis (L.) Schrad.	*Cucurbitaceae*	Per.	Sub-Shrub	arid sandy plains	ass.	NE
Cleome amblyocarpa Barratte & Murb.	*Cleomaceae*	Ann.	Herb	arid sandy plains, dunes	ass.	Not Evaluated
Cleome chrysantha Decne	*Cleomaceae*	Per.	Sub-Shrub	arid sandy plains	ass.	Not Evaluated
Cleome droserifolia (Forssk.) Delile	*Cleomaceae*	Per.	Sub-Shrub	arid sandy plains	d.	Not Evaluated

Cocculus pendulus (J.R.&G. Forst.) Diels	*Menispermaceae*	Per.	Shrub	arid sandy plains	r.	Not Evaluated
Cucumis prophetarum L.	*Cucurbitaceae*	Per.	Sub-Shrub	arid sandy plains	ass.	Not Evaluated
Cyperus conglomeratus Rottb.	*Cyperaceae*	Per.	Perennial Herb	arid sandy plains, dunes	cd.	Not Evaluated
Echinops spinosissimus Turra	*Asteraceae*	Per.	Sub-Shrub	arid sandy plains, Rocky outcrops	r.	Not Evaluated
Erodium laciniatum (Cav.) Willd.	*Geraniaceae*	Ann.	Herb	arid sandy plains	c.	Not Evaluated
Euphorbia granulata Forssk.	*Euphorbiaceae*	Ann.	Herb	arid sandy plains	r.	Not Evaluated
Fagonia arabica L.	*Zygophyllaceae*	Per.	Sub-Shrub	arid sandy plains	d.	Not Evaluated
Fagonia indica Burm.f.	*Zygophyllaceae*	Per.	Sub-Shrub	arid sandy plains	d.	Not Evaluated
Fagonia mollis Delile	*Zygophyllaceae*	Per.	Sub-Shrub	arid sandy plains	ass.	Not Evaluated
Farsetia aegyptia Turra	*Brassicaceae*	Per.	Sub-Shrub	arid sandy plains	ass.	Not Evaluated
Farsetia longisiliqua Decne.	*Brassicaceae*	Per.	Sub-Shrub	arid sandy plains	r.	Not Evaluated
Forsskaolea tenacissima L.	*Urticaceae*	Per.	Sub-Shrub	arid sandy plains	r.	Not Evaluated
Heliotropium strigosum Willd.	*Boraginaceae*	Per.	Perennial Herb	Grasslands, Roadsides, arid sandy plains	r.	Not Evaluated
Hyphaene thebaica (L.) Mart.	*Arecaceae*	Per.	Tree	Grasslands, Deserts	c.	Not Evaluated
Iphiona scabra DC.	*Asteraceae*	Per.	Sub-Shrub	arid sandy plains	ass.	Not Evaluated
Juncus rigidus C.A.Mey.	*Juncaceae*	Per.	Sub-Shrub	Salt marshes	d.	Not Evaluated

Lavandula pubescens Decne.	*Lamiaceae*	Per.	Sub-Shrub	arid sandy plains	r.	Not Evaluated
Leptadenia pyrotechnica (Forssk.) Decne.	*Apocynaceae*	Per.	Shrub or Tree	arid sandy plains	r.	Not Evaluated
Limonium axillare (Forssk.) Ktze	*Plumbaginaceae*	Per.	Sub-Shrub	Salt marshes	d.	Not Evaluated
Lindenbergia indica Hochst. Ex Benth.	*Orobanchaceae*	Per.	Perennial Herb	arid sandy plains	r.	Not Evaluated
Leobordea platycarpa. (Viv.) Pic.Serm.	*Fabaceae*	Ann.	Herb	arid sandy plains	r.	Not Evaluated
Lotus hebranicus Hochst. ex Brand	*Fabaceae*	Per.	Sub-Shrub	arid sandy plains	ass.	Not Evaluated
Lycium shawii Roem. & Schult.	*Solanaceae*	Per.	Shrub	arid sandy plains	cd.	Not Evaluated
Moringa peregrina (Forsk.) Fiori	*Moringaceae*	Per.	Tree	Rocky slopes	cd.	Not Evaluated
Neurada procumbens L.	*Neuradaceae*	Ann.	Herb	arid sandy plains, dunes	ass.	Not Evaluated
Nitraria retusa (Forssk.) Asch.	*Nitrariaceae*	Per.	Shrub	Salt marshes	cd.	Not Evaluated
Ochradenus baccatus Delile	*Resedaceae*	Per.	Shrub	arid sandy plains	ass.	Not Evaluated
Panicum turgidum Forssk.	*Poaceae*	Per.	Perennial Herb	arid sandy plains	d.	Not Evaluated
Pergularia tomentosa L.	*Apocynaceae*	Per.	Sub-Shrub	arid sandy plains	r.	Not Evaluated
Periploca aphylla Decne.	*Apocynaceae*	Per.	Shrub	Rocky outcrops	r.	Not Evaluated
Phoenix dactylifera L.	*Arecaceae*	Per.	Tree	arid sandy plains	d.	Not Evaluated
Phragmites australis (Cav.) Trin. Ex Steud.	*Poaceae*	Per.	Perennial Herb	Salt marshes	d.	Not Evaluated
Pulicaria crispa (Forssk.) Oliv.	*Asteraceae*	Ann.	Herb	arid sandy plains	ass.	Not Evaluated
Pulicaria incisa (Lam.) DC.	*Asteraceae*	Ann.	Herb	arid sandy plains	r.	Not Evaluated

Pulicaria undulata (L.) C.A.Mey.	*Asteraceae*	Ann. or Per.	Sub-Shrub	arid sandy plains	cd.	Not Evaluated
Rhizophora mucronata Poir.	*Rhizophoraceae*	Per.	Tree	Mangrove swamps	ass.	Not Evaluated
Searsia tripartita (Ucria) Grande	*Anacardiaceae*	Per.	Shrub or Tree	arid sandy plains	r.	Not Evaluated
Salvadora persica L.	*Salvadoraceae*	Per.	Shrub	arid sandy plains	d.	Not Evaluated
Senna alexandrina Garsault	*Fabaceae*	Per.	Shrub	arid sandy plains	c.	Not Evaluated
Solenostemma arghel (Del.) Hyne	*Apocynaceae*	Per.	Shrub	arid sandy plains	r.	Not Evaluated
Suaeda monoica Forssk. Ex J.F.Gmel.	*Amaranthaceae*	Per.	Shrub or Tree	arid sandy plains	ass.	Not Evaluated
Suaeda salsa (L.) Pall.	*Amaranthaceae*	Ann.	Herb	Salt marshes	cd.	Not Evaluated
Tamarix aphylla (L.) Karst.	*Tamaricaceae*	Per.	Tree	Rocky slopes, Sandy areas	d.	Not Evaluated
Tamarix nilotica (Ehrenb.) Bge	*Tamaricaceae*	Per.	Tree	arid sandy plains, Salty habitats	d.	Not Evaluated
Taverniera aegyptiaca Boiss.	*Fabaceae*	Per.	Shrub	arid sandy plains	cd.	Not Evaluated
Tephrosia purpurea (L.) Pers.	*Fabaceae*	Ann.	Herb	Grasslands, Roadsides	r.	Least Concern
Trichodesma africanum (L.) R.Br.	*Boraginaceae*	Ann.	Herb	arid sandy plains	r.	Not Evaluated
Zilla spinosa subsp. *spinosa* Dur. &Sch	*Zygophyllaceae*	Per.	Shrub	arid sandy plains	d.	Not Evaluated
Zygophyllum album L.	*Zygophyllaceae*	Per.	Sub-Shrub	arid sandy plains, Salt marshes	d.	Not Evaluated
Zygophyllum coccineum L.	*Zygophyllaceae*	Per.	Sub-Shrub	arid sandy plains, Salt marshes	d.	Not Evaluated

Zygophyllum simplex L.	*Zygophyllaceae*	Ann.	Herb	arid sandy plains, Salt marshes	d.	Not Evaluated

Table 3. A detailed comparison of the previous floristic studies with the present study.

References	Location of the study	No. of recorded species	No. of families
Barakat (2003)	WGHPA	95	36
Hegazy et al. (2007)	Northwestern Red Sea region	66	33
Moustafa (2007)	WGHPA	59	31
Sheded et al. (2014)	Red Sea coast	45	24
El-Khouly and Shawky (2017)	Red Sea coast	23	14
Present study (2024)	WGHPA	77	35

Figure 4. Plants recorded in Wadi El-Gemal. (**A**) *Acacia tortilis* (Forssk.) Hayne, (**B**) *Balanites aegyptiaca* (L.) Del., (**C**) *Cleome amblyocarpa* Barratte & Murb., (**D**) *Nitraria retusa* (Forssk.) Asch., (**E**, **F**) *Tamarix aphylla* L., (**G**, **H**) *Avicennia marina* (Forssk.). Photos taken by Abdelraouf Moustafa.

Faunal biodiversity

The present study recorded a total of 73 faunal species belonging to 41 families in Wadi El-Gemal–Hamata Protected Area (WGHPA). The documented fauna comprised representatives of reptiles, birds, and mammals (Table 4). Among the most frequently observed species in WGHPA were domesticated mammals such as camels, sheep, and goats, as well as wild species including the Nubian ibex (*Capra nubiana*), Cape hare (*Lepus capensis*), Rüppell's fox (*Vulpes rueppelli*), Cairo spiny mouse (*Acomys cahirinus*), and Dorcas gazelle (*Gazella dorcas*) (Moustafa, 2007).

The presence of *Gazella dorcas* is widely regarded as an indicator of biological diversity in the Egyptian environment. This species is characterized by its agility and capacity for long-distance movements in search of suitable foraging areas. *Gazella dorcas* primarily feeds on the foliage and fruits of Acacia species, as well as a variety of grasses and shrubs, and is therefore classified as a browser rather than a grazer. Through its browsing behavior, the species contributes to vegetation dynamics and can serve as a useful indicator for assessing plant community structure and ecosystem health (Khaleal et al., 2008).

Table 4. Diversity of animal species recorded in WGHPA and their conservation status according to the IUCN (2024).

(https://www.iucnredlist.org/ (accessed on 10 September 2024)).

Reptiles		
Family	**Species**	**Conservation Status**
Agamidae	*Agama spinosa* JE Gray	Least Concern
	Pseudotrapelus sinaitus Heyden	Least Concern
	Uromastyx ocellata Lichtenstein	Least Concern
Cheloniidae	*Chelonia mydas* Linnaeus	Least Concern
	Eretmochelys imbricata Linnaeus	Critically Endangered
Colubridae	*Platyceps rhodorachis* Jan	Least Concern
	Telescopus dhara Forsskål	Least Concern
Gekkonidae	*Cyrtopodion scabrum* Heyden	Least Concern
	Hemidactylus robustus Heyden	Least Concern

	Hemidactylus turcicus Linnaeus	Least Concern
	Stenodactylus sthenodactylus Lichtenstein	Least Concern
Lacertidae	*Acanthodactylus boskianus* Daudin	Least Concern
	Mesalina guttulata Lichtenstein	Least Concern
Phyllodactylidae	*Ptyodactylus hasselquistii* Donndorff	Least Concern
	Tarentola annularis St. Hilaire	Least Concern
Psammophiidae	*Malpolon moilensis* Reuss	Least Concern
Scincidae	*Chalcides ocellatus* Forsskål	Least Concern
Varanidae	*Varanus griseus* Daudin	Least Concern
Viperidae	*Cerastes cerastes* Linnaeus	Least Concern
Elapidae	*Echis coloratus* Günther	Least Concern
	Naja nigricollis	Least Concern

Birds

Family	**Species**	**Conservation Status**
Accipitridae	*Buteo rufinus* Cretzschmar	Least Concern
	Gypaetus barbatus Linnaeus	Near Threatened
	Neophron percnopterus Linnaeus	Endangered
	Torgos tracheliotos Forster	Endangered
Alaudidae	*Ammomanes deserti* Lichtenstein	Least Concern
Ardeidae	*Ardea goliath* Cretzschmar	Least Concern
	Butorides striata Linnaeus	Least Concern
	Egretta gularis Bosc	Least Concern
Burhinidae	*Burhinus oedicnemus* Linnaeus	Least Concern
Columbidae	*Columba livia* Gmelin	Least Concern
	Streptopelia decaocto Frivaldszky	Least Concern
Corvidae	*Corvus ruficollis* Lesson	Least Concern
Emberizidae	*Emberiza striolata* Lichtenstein	Least Concern
Falconidae	*Falco biarmicus* Temminck	Least Concern
	Falco concolor Temminck	Vulnerable
Glareolidae	*Cursorius cursor* Latham	Least Concern
Laridae	*Hydroprogne caspia* Pallas	Least Concern
	Ichthyaetus leucophthalmus Temminck	Least Concern
	Ichthyaetus hemprichii Bruch	Least Concern
	Sterna repressa Hartert	Least Concern
	Thalasseus bengalensis Lesson	Least Concern
Pandionidae	*Pandion haliaetus* Linnaeus	Least Concern

Phaethontidae	*Phaethon aethereus* Linnaeus	Least Concern
Phasianidae	*Ammoperdix heyi* Temminck	Least Concern
	Pterocles coronatus Lichtenstein	Least Concern
Pteroclidae	*Pterocles lichtensteinii* Temminck	Least Concern
	Pterocles senegallus Linnaeus	Least Concern
Strigidae	*Strix butleri* Hume	Least Concern
Sulidae	*Sula leucogaster* Boddaert	Least Concern
Threskiornithidae	*Platalea leucorodia* Linnaeus	Least Concern
Laridae	*Larus leucophthalmus*	Least Concern
Threskiornithidae	*Platalea flavipes*	Least concern

Mammals

Family	**Species**	**Conservation Status**
	Ammotragus lervia Pallas	Vulnerable
Bovidae	*Capra nubiana* F. Cuvier	Vulnerable
	Gazella dorcas Linnaeus	Vulnerable
Canidae	*Vulpes rueppellii* Schinz	Least Concern
Delphinidae	*Stenella longirostris* Gray	Least Concern
Dipodidae	*Jaculus jaculus* Linnaeus	Least Concern
Dugongidae	*Dugong dugon* Müller	Vulnerable
Emballonuridae	*Taphozous nudiventris* Cretzschmar	Least Concern
	Taphozous perforatus É. Geoffroy	Least Concern
Erinaceidae	*Paraechinus aethiopicus* Ehrenberg	Least Concern
Felidae	*Caracal caracal* Schreber	Least Concern
	Felis margarita Loche	Least Concern
Hyaenidae	*Hyaena hyaena* Linnaeus	Least Concern
Leporidae	*Lepus capensis* Linnaeus	Least Concern
Molossidae	*Tadarida aegyptiaca* É. Geoffroy	Least Concern
Muridae	*Acomys cahirinus* É. Geoffrey	Least Concern
	Gerbillus gerbillus Olivier	Least Concern
	Gerbillus pyramidum Geoffroy	Least Concern
	Meriones crassus Sundevall	Least Concern
	Mus musculus Linnaeus	Least Concern
	Sekeetamys calurus Thomas	Least Concern
Procaviidae	*Procavia capensis* Pallas	Least Concern
Vespertilionidae	*Otonycteris hemprichii* Peters	Least Concern

A total of 25 reptile species has been reported from the mountainous regions of the Eastern Desert (Kassas & Zahran, 1967, 1971). Within Wadi El-Gemal–Hamata Protected Area (WGHPA), commonly recorded reptile species include *Cerastes cerastes*, a *venomous viper*; *Naja nigricollis*, a spitting cobra typically reaching 1.0–1.2 m in length, and *Telescopus dhara*, with adults generally measuring 40–70 cm (Khaleal, 2008).

Approximately 45 endemic bird species have been recorded in Wadi El-Gemal Protectorate (Goodman et al., 1989). In addition, the reserve supports 13 species of water and marine birds that primarily inhabit its marine environment. At least 12 water and marine bird species are known to occur on the islands of Wadi El-Gemal and Hamata. These islands provide important habitat for several globally recognized marine birds, including the striated heron (*Butorides striata*), the white-eyed gull (*Larus leucophthalmus*), the western reef heron (*Egretta gularis*), the spoonbill (*Platalea flavipes*), the osprey (*Pandion haliaetus*), and the Caspian tern (*Hydroprogne caspia*). Consequently, the area has gained international recognition as a critical site for bird conservation and has been designated as an Important Bird Area by BirdLife International (formerly the World Bird Society).

Wadi El-Gemal–Hamata Protected Area is also distinguished by the presence of significant populations of protected falcon species, notably the sooty falcon (*Falco concolor*). During the autumn migration period, large numbers of migratory birds traverse the mountains and wadis of the Eastern Desert. The vegetated coastal zones of WGHPA, particularly along the shoreline, provide essential stopover and resting habitats for small Arctic-breeding migratory birds. Among the most commonly observed resident bird species in the area are the common raven (*Corvus corax*) and the rock pigeon (*Columba livia*) (Khaleal, 2008). Figure 5 illustrates representative avifaunal species recorded in the Wadi El-Gemal Natural Protectorate.

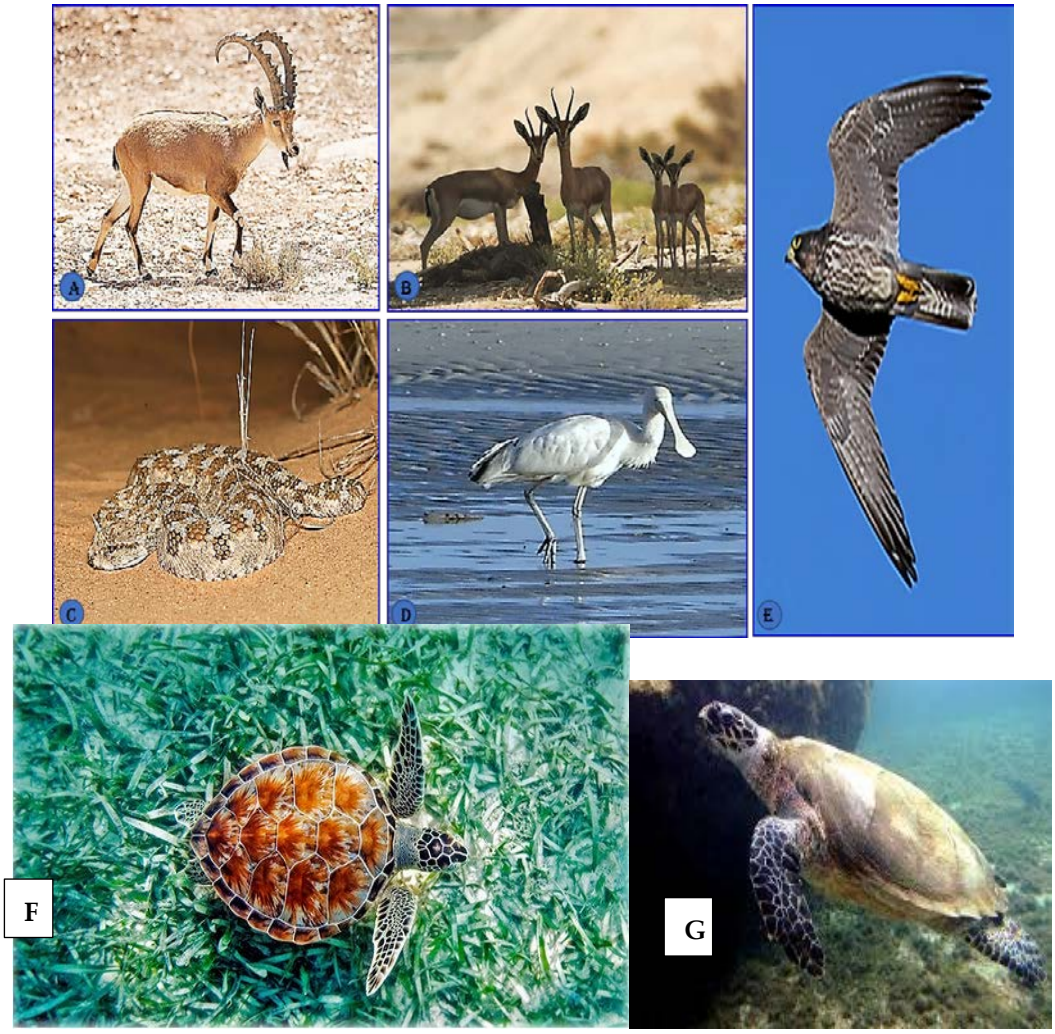

Figure 5. Diverse wildlife of Wadi El-Gemal. (**A**) *Capra nubiana* F. Cuvier (https://www.inaturalist.org/observations/210845971 (accessed on 10 September 2024)), (**B**) *Gazella dorcas* L. (https://www.inaturalist.org/observations/209239854 (accessed on 10 September 2024)), (**C**) *Cerastes cerastes* L. (https://www.inaturalist.org/observations/164496757 (accessed on 10 September 2024)), (**D**) *Platalea flavipes* Gould (https://www.inaturalist.org/observations/234473592 (accessed on 10 September 2024)), (**E**) *Falco concolor* Temminck (https://www.inaturalist.org/observations/192178518 (accessed on 10 September 2024)), (**F**) (https://share.google/XlxsNl5mWWRrM9Dp2), (**G**) *Eretmochelys imbricata* (https://share.google/XJKECFpYZ3a70dYI2)(accessed on 10 September 2024)).

Among the 73 recorded species, one species (1.36%) is classified as Critically Endangered (*Eretmochelys imbricata*), three species (4.10%) as Endangered (*Neophron percnopterus* and *Torgos tracheliotos*), five species (6.84%) as Vulnerable (*Falco concolor*, *Ammotragus lervia*, *Capra nubiana*, *Gazella dorcas*, and *Dugong dugon*),

and one species (1.36%) as Near Threatened (*Gypaetus barbatus*). The remaining 63 species are classified as Least Concern.

4. Discussion

Flora of Wadi El-Gemal–Hamata Protected Area

The flora of Wadi El-Gemal–Hamata Protected Area (WGHPA) exhibits high ecological diversity, shaped by the area's complex topography, which includes wadis, coastal plains, and mountainous landscapes. Our field surveys documented 77 plant species belonging to 31 families, updating earlier floristic records by Barakat (2003), who reported 93 species from the area. Notably, 27 of the species recorded in the present study were not previously documented, underscoring the importance of continued field surveys to capture temporal and spatial variability in floristic composition. Vegetation patterns reflect strong habitat differentiation: xerophytic species dominate wadi beds, with *Senna italica, Zilla spinosa, Pulicaria undulata*, and *Panicum turgidum* being particularly prevalent, in agreement with earlier studies (Zahran & Willis, 1992). Along valley margins, *Acacia tortilis* and *Balanites aegyptiaca* occur frequently, where their deep root systems enable access to subsurface water, representing a key adaptation to arid environments (Milto et al., 2019). In contrast, deltaic areas characterized by relatively higher soil moisture are dominated by species such as *Zygophyllum coccineum*, *Limonium axillare*, and *Tamarix aphylla* (Mahmoud, 2010).

The coastal plain of Wadi El-Gemal–Hamata Protected Area supports several rare plant species, including *Hyphaene thebaica* (dom palm), reflecting the ecological heterogeneity and conservation value of this habitat. Mangrove stands dominated by *Avicennia marina* play a disproportionately important ecological role despite their limited spatial extent. Field observations, consistent with previous studies (Frazier & Salas, 1984; Baha El Din, 2003), indicate that these mangroves serve as critical nursery habitats for juvenile fish, provide essential foraging areas for sea turtles and dugongs, and offer refugia for diverse invertebrate communities. The restricted distribution of

mangroves within the protected area—primarily concentrated on Wadi El-Gemal Island and in the Ras Qulan–Hamata sector—underscores their vulnerability to environmental change and anthropogenic pressure. Consequently, the preservation of these habitats is vital for maintaining coastal biodiversity and ecosystem functioning in the region.

Most medicinal plant species, including *Anastatica hierochuntica* and *Cleome droserifolia*, occur at low population densities across a range of growth forms, including herbs, shrubs, sub-shrubs, and trees. This sparse and fragmented distribution appears to be driven primarily by the region's harsh arid conditions and the limited availability of suitable microhabitats, rather than by harvesting pressure alone. Nevertheless, such low-density populations may be particularly vulnerable to localized disturbance, overexploitation, and ongoing environmental change. Although desert habitats dominate Wadi El-Gemal–Hamata Protected Area, salt marshes and coastal swamps—despite their limited spatial extent—support distinct and specialized plant assemblages that contribute to regional biodiversity. The conservation of these habitats is therefore critical, as their degradation could result in the loss of rare medicinal species and a reduction in overall ecosystem resilience.

Fauna of Wadi El-Gemal–Hamata Protected Area

A total of 73 animal species, comprising mammals, reptiles, and birds, were recorded in Wadi El-Gemal–Hamata Protected Area. Field observations confirmed the persistence of mountain ibex (*Capra ibex*) in remote and rugged habitats, as well as the presence of *Gazella dorcas*, wild rabbits, red foxes, and sand foxes. Other mammalian species, including the *Arabian gazelle*, were documented based on previously published records. Reptile diversity, particularly snakes, was closely associated with sandy and arid environments that provide suitable thermal and shelter conditions. The avifauna includes both resident and migratory species; however, several raptors and coastal birds were classified as rare based on literature sources rather than direct field observations, suggesting possible changes in their local abundance or detectability. Distinguishing

between species confirmed during field surveys and those reported only in earlier studies offers a more accurate assessment of the current faunal composition and underscores the importance of continued monitoring for understanding biodiversity dynamics and maintaining ecosystem resilience within the protected area (EEAA, 2009).

Local Bedouin communities in Wadi El-Gemal–Hamata Protected Area depend on a combination of traditional livelihoods, including livestock grazing, fishing, limited agriculture, and fuelwood collection. In recent years, increased participation in tourism-related activities has added further pressure on both terrestrial and marine habitats. Although mining and quarrying activities are currently largely inactive, their historical legacy has contributed to habitat modification in certain areas. Ongoing charcoal production and fuelwood collection continue to alter vegetation structure and regeneration dynamics. In the marine environment, oil contamination, solid waste accumulation, and unsustainable fishing practices pose significant threats to biodiversity, particularly to coral reef systems and critical nesting sites for sea turtles. Together, these anthropogenic pressures highlight the need for integrated management strategies that balance local livelihoods with long-term conservation objectives.

Marine and coastal ecosystems face multiple environmental threats that require urgent attention. Marine pollution from oil spills and tar balls associated with shipping not only degrades habitats but is exacerbated by intensive maritime traffic, with 25,000–30,000 ships navigating the area annually (Lintner et al., 1995; Hassan, 1998). On land, coastal and terrestrial habitats are increasingly disturbed by overgrazing, unregulated wood collection, and tourism activities, while climate change intensifies stress on coral reefs, contributing to bleaching events and posing a risk of long-term loss (Wilkinson, 2000; Hughes et al., 2003; Abdullah, 2024). Additionally, the overharvesting of medicinal plants, such as *Balanites aegyptiaca* and *Salvadora persica*, threatens the sustainability of these resources, despite their role in providing local income. Together,

these pressures underscore the need for integrated management strategies that balance ecological conservation with socio-economic development.

Endangered marine species, including sea turtles and dugongs, face multiple threats that compromise their survival, notably habitat degradation, pollution, and climate change. Climate change poses an additional challenge by intensifying water scarcity and disrupting the already fragile desert and coastal ecosystems of the region. Moreover, limited infrastructure and insufficient funding for conservation initiatives hinder effective management and protection of the rich biological diversity and cultural heritage of Wadi El-Gemal.

5. Conclusion

The Wadi El-Gemal–Hamata Protected Area represents a key ecological reserve along the southern Red Sea coast, supporting high levels of plant and animal diversity, including rare and endemic species. Field surveys updated previous floristic records, identified areas of relatively high biodiversity concentration based on field observations and species records, and highlighted the pivotal role of wadis and mangrove ecosystems in maintaining regional biodiversity. Despite its protected status, WGHPA faces increasing pressures from anthropogenic activities, climate change, and unsustainable resource use.

Effective conservation of WGHPA, therefore, requires targeted, ecosystem-based management strategies. Priority should be given to the protection and restoration of mangrove stands dominated by Avicennia marina, owing to their importance in shoreline stabilization, biodiversity support, and the provision of nursery habitats. Improved fisheries and marine resource management, particularly through monitoring coral reefs and sea turtle nesting sites, is essential to reduce overfishing and habitat degradation. Community engagement should be strengthened by promoting sustainable harvesting of medicinal plants, regulated grazing systems, and eco-tourism initiatives that support local livelihoods while minimizing environmental impacts. In addition,

stricter pollution control measures, including regulation of oil discharge and improved waste management across terrestrial and marine environments, are required. Conservation efforts should also focus on biodiversity hotspots, such as wadi deltas and mangrove-rich islands, where species richness and ecological value are highest.

An integrated approach combining habitat protection, community participation, and systematic monitoring of vulnerable species is essential to maintaining ecological integrity while supporting sustainable development. The long-term conservation of WGHPA is therefore critical for safeguarding regional biodiversity, preserving ecosystem services, and ensuring socio-economic benefits for future generations.

A spatial comparison of floristic and faunal records with observed anthropogenic activities indicates that areas of highest biodiversity value are not uniformly distributed across WGHPA. Mangrove stands in the Ras Qulan–Hamata sector and Wadi El-Gemal Island exhibit high species richness and host ecologically sensitive taxa, while simultaneously being exposed to fishing activities and tourism pressure. Similarly, wadi deltas and coastal plains that support rare medicinal plants overlap with zones affected by grazing and fuelwood collection. This spatial co-occurrence of biodiversity value and human pressure highlights priority areas where conservation interventions should be spatially targeted rather than uniformly applied across the protected area.

References

Abd El-Ghani, M. M., Salama, F., Salem, B., El-Hadidy, A., & Abdel Aleem, M. (2013). Biogeographical relations of a hyperarid desert flora in eastern Egypt. African Journal of Ecology, 52, 173–191.

Abdel-Aleem, M. (2013). Floristic analysis and phytogeographical affinities of the Eastern Desert of Egypt (Ph.D. dissertation, Cairo University, Cairo, Egypt).

Abdullah, M., Abdullah, M., Al-Ali, Z., Almousa, M., Mohan, M., & Al-Hashash, N. (2024). Seedling evaluation of native perennials for implementing large-scale

revegetation projects in arid lands. Catrina International Journal of Environmental Science, 30, 21–29. https://doi.org/10.21608/cat.2024.258211.1240.

Afefe, A. (2012). Linking territorial and coastal planning: Conservation status and management of mangrove ecosystem at the Egyptian African Red Sea coast. Aswan University Journal of Environmental Studies, 2, 91–114. https://doi.org/10.21608/aujes.2021.65951.1013.

Badr, A., & El-Shazly, H. (2024). Climate change and biodiversity loss: Interconnected challenges and priority measures. Catrina International Journal of Environmental Science, 29, 69–78. https://doi.org/10.21608/cat.2024.340596.

Baha Eddin, M. (2003). Tourism potential & management in Wadi El Gemal-Hamata. Report submitted by EEPP. Available online: https://www.abughosoun.org/wp-content/uploads/2019/04/9-Tourism-Potential-_-Management-in-WGNP.pdf (accessed on 10 September 2024).

Baha El Din, S. (2003). Management plan for Wadi el Gimal Hamata protected area. Report for Egyptian Environmental Affairs Agency, 142. Available online: https://www.abughosoun.org/wp-content/uploads/2019/04/7-Management-Plan-for-Wadi-El-Gemal%E2%80%93Hamata.pdf (accessed on 10 September 2024).

Barakat, H. N. (2003). Evaluation of the flora and plant communities in the Wadi El Gemal–Hamata Protected Area. Report for the PSU/EEPP. Available online: https://www.abughosoun.org/wp-content/uploads/2019/04/8-Plant-Communities-in-Wadi-el-Gemal%E2%80%93Hamata.pdf (accessed on 10 September 2024).

Barrania, A., & Ibrahim, A. (2003). The status of fisheries in the Egyptian Red Sea between Hurghada and Ras Banas and proposed fisheries management plan. Report for the Egyptian Environmental Policy Program (EEPP) and The Program Support Unit. Available online: https://kenanaonline.com/files/0058/58416/Fisheries%20Management%20Plan%20for%20the%20Red%20Sea2.pdf (accessed on 10 September 2024).

Boulos, L. (1999). Flora of Egypt, Volume 1: *Azollaceae–Oxalidaceae*. Al-Hadara Publishing, Cairo, Egypt.

Boulos, L. (2000). Flora of Egypt (Vol. 2): *Geraniaceae–Boraginaceae*. Al Hadara Publishing: Cairo, Egypt.

Boulos, L. (2002). Flora of Egypt (Vol. 3): *Verbenaceae–Compositae*. Al Hadara Publishing: Cairo, Egypt.

Boulos, L. (2005). Flora of Egypt (Vol. 4): *Alismataceae–Orchidaceae*. Al Hadara Publishing: Cairo, Egypt.

Egyptian Environmental Affairs Agency (EEAA). (2009). Egypt state of the environment report 2008. Available online: https://www.eeaa.gov.eg/Uploads/Reports/Files/20221115114424313.pdf (accessed on 10 September 2024).

Egyptian Environmental Affairs Agency (EEAA). (2012). Wadi el Gemal National Park: Integrated development plan. Available online: https://www.eeaa.gov.eg/Uploads/Project/Files/20221207112344792.pdf (accessed on 10 September 2024).

El-Khouly, A. A., & Shawky, R. A. (2017). Plant species diversity of some wadis at Red Sea Coast, Egypt. Environment, Resource and Ecology Journal, 1, 1–14.

Feinbrun-Dothan, N. (1978). Flora Palaestina (3rd ed.). Israel Academy of Sciences and Humanities: Jerusalem, Israel.

Feinbrun-Dothan, N. (1986). Flora Palaestina (4th ed.). Israel Academy of Sciences and Humanities: Jerusalem, Israel.

Frazier, J., & Salas, S. (1984). The status of marine turtles in the Egyptian Red Sea. Biological Conservation, 30, 41–67. https://doi.org/10.1016/0006-3207(84)90019-3.

Global Atlas of Environmental Justice (Ej Atlas). (2012). Tourism development versus nature conservation in Wadi El Gemal Protected Area along the Red Sea, Egypt. Available online: https://ejatlas.org/conflict/tourism-development-versus-nature-conservation-conflict-in-wadi-el-gemal-protected-area-along-the-egyptian-red-sea (accessed on 10 September 2024).

Goodman, S. M., Meininger, P. L., Baha El Din, S. M., Hobbs, J. J., & Mullie, W. C. (1989). The Birds of Egypt. Oxford University Press.

Hany, S., Shendi, E., Monsef, H., Mohamed, E., & Smith, S. (2022). Geotechnical evaluation of soil for the suitability of urban planning purposes, Western Bitter Lakes, Suez Canal Region, Egypt. Catrina International Journal of Environmental Science, 26, 57–65. https://doi.org/10.21608/cat.2022.114258.1115.

Hassan, A. (1998). Marine pollution control. I—Field observation report. Report funded by GEF.

Hassib, M. (1951). Distribution of plant communities in Egypt. Cairo University Bulletin of the Faculty of Science, 29, 59–261.

Hegazy, A. K. (Ed.). (1999). The United Nations conservation on biological diversity: From adoption to implementation. In Environment 2000 and beyond (pp. 442). UNESCO, ICED: Cairo, Egypt.

Hegazy, A., Lovett-Doust, J., & Hammouda, O. (2007). Vegetation distribution along the altitudinal gradient in the northwestern Red Sea region. Community Ecology, 8, 151–162. https://doi.org/10.1556/ComEc.8.2007.2.2.

Heywood, V. (2000). Biodiversity conservation strategies. In Proceedings of the International Short Course of Conservation and Sustainable Use of Biodiversity (pp. 18–30 September 2000). El-Arish, Egypt.

Hughes, T. P., Baird, A. H., Bellwood, D. R., Card, M., Connolly, S. R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J. B. C., Kleypas, J., et al. (2003). Climate change, human impacts, and the resilience of coral reefs. Science, 301, 929–933.

Issa, M., El-Bakhshawngi, M., & Abed, M. (2024). Wild bird species structure and feeding guilds in agricultural area at Zagazig District, Sharkia Governorate, Egypt. Catrina: The International Journal of Environmental Sciences, 32(1), 73–81. https://doi.org/10.21608/cat.2024.280589.1267

Kassas, M. (Ed.). (1993). Habitat diversity (No. 1). NBU: Egypt.

Kassas, M., & Zahran, M. (1967). On the ecology of the Red Sea littoral salt marsh, Egypt. Ecological Monographs, 37, 297–316.

Kassas, M., & Zahran, M. (1971). Plant life on the coastal mountains of the Red Sea, Egypt. Journal of the Indian Botanical Society, 50, 571–589.

Kassem H. M., Ali H. E., Arnous M. O., Zaghloul M. S. (2025). Variation of bioenergy efficiency of Arundo donax L. growing in northern and middle Egypt. Catrina International Journal of Environmental Science,10.21608/cat.2025.242233.1214.

Khaleal, F., Oraby, F., Abdalla, F., & Hassan, M. (2008). Natural resources assessment of Wadi El-Gemal Basin, Red Sea, Egypt. Catrina International Journal of Environmental Science, 3, 131–139.

Lintner, S. F., Arif, S., & Hatziolos, M. (1995). The experience of the World Bank in the legal, institutional and financial aspects of regional environmental programmes: Potential application of lessons learned for the ROPME and PERSGA programmes. Background Papers from the Sea to Sea Conference, Jeddah. Available online: https://txst.locate.ebsco.com/instances/0034ee52-70b1-5704-be46 e24b07e6cc67?option=subject&query=Coastal%20zone%20management-Environmental%20aspects (accessed on 10 September 2024).

Mahmoud, T. (2010). Desert Plants of Egypt's Wadi el Gemal National Park. The American University in Cairo Press.

Mahmoud, T., & Gairola, S. (2013). Traditional knowledge and use of medicinal plants in the Eastern Desert of Egypt: A case study from Wadi El-Gemal National Park. Journal of Medicinal Plants Studies, 1, 10–17.

Majead Abed, R., Abbas, R. A., Al-Chalabi, F. A., & Ahmed, Z. A. (2025). Assessment of mycorrhizal colonization and heavy metal accumulation in Phragmites australis from the Euphrates River banks, Iraq. CATRINA: The International Journal of Environmental Sciences, 34(1), 11–17.

Mansour, A. M. (2003). Wadi El-Gemal–Hamata protected area: Mining and quarrying activities, geology and mineral resources. Report Submitted to PSU/NCS. Available online:

https://www.abughosoun.org/wp-content/uploads/2019/04/6-Mining-Quarrying-Geology-_-Minerals-at-WGNP.pdf (accessed on 10 September 2024).

Milto, K. D., Saber, S. A., Nagy, A. M., Nazarov, R. A., Melnikov, D. A., & Ananjeva, N. B. (2019). First report on the reptile diversity of Wadi El Gemal National Park, Eastern Desert, Egypt. Russian Journal of Herpetology, 26, 175. https://doi.org/10.30906/1026-2296-2019-26-3-175-184.

Moustafa, A. A. (1990). Environmental Gradient and Species Distribution on Sinai Mountains. Ph.D. Thesis, Botany Department, Faculty of Science, Suez Canal University, Egypt, 115 pp.

Moustafa, A. (2007). Status of medical plants as a source of income and job creation for local community residents in WGHPA and related areas (263-M-00-04-00032-00).

Moustafa, A., & Ghowail, L. (2022). Exploring climate change mitigation: Innovative technologies and strategies for carbon dioxide removal. Catrina International Journal of Environmental Science, 26, 75–81. https://doi.org/10.21608/cat.2023.220393.1180.

Moustafa, A., Elganainy, R., & Mansour, S. (2023). Insights into the UNSG announcement: The end of climate change and the arrival of the global boiling era, July 2023 confirmed as the hottest month recorded in the past 120,000 years. Catrina International Journal of Environmental Science, 28, 43–51. https://doi.org/10.21608/cat.2023.234635.1197.

NBSAP. (2016). Egyptian biodiversity strategy and action plan (2015–2030). Available online: https://www.cbd.int/doc/world/eg/eg-nbsap-v2-en.pdf (accessed on 10 September 2024).

Osborn, D. J., & Helmy, I. (1980). The contemporary land mammals of Egypt (including Sinai). Field Museum of Natural History, Chicago. Available online: https://www.biodiversitylibrary.org/bibliography/2801 (accessed on 10 September 2024).

Osborn, D. J., & Osbornova, J. C. (1988). The mammals of ancient Egypt. Aris and Phillips Ltd.: Warminster, UK.

Riegel, B., & Luke, K. (1997). Red Sea National Marine Protectorate—Suggested mooring sites in the southern Egyptian Red Sea. Produced for the EEAA and DNP; USAID and Winrock International.

Romañach, S. S., DeAngelis, D. L., Koh, H. L., Li, Y., Teh, S. Y., Raja Barizan, R. S., & Zhai, L. (2018). Conservation and restoration of mangroves: Global status, perspectives, and prognosis. Ocean & Coastal Management, 154, 72–82. https://doi.org/10.1016/j.ocecoaman.2018.01.009.

Salama, F., El-Ghani, M. A., Gadallah, M., El-Naggar, S., & Amro, A. (2014). Variations in vegetation structure, species dominance, and plant communities in the south of the Eastern Desert, Egypt. Notulae Scientia Biologicae, 6, 41–58. https://doi.org/10.15835/nsb619191.

Sheded, M. G., Ahmed, M. K., & Hammad, S. A. (2014). Vegetation analysis in the Red Sea-Eastern Desert ecotone at the area between Safaga and South Qusseir, Egypt. Ecologia Balkanica, 6(2).

Soliman, M. A., Kafrawy, S. B., Said, R. E. M., Saber, S. A., & Muller-Karge, F. E. (2021). Geomatics approach to assess nesting habitat of green turtles Wadi El Gemal, Red Sea, Egypt. Egyptian Journal of Remote Sensing and Space Science, 24(2), 815–824. https://doi.org/10.1016/j.ejrs.2021.09.001.

Täckholm, V. (1974). Students' flora of Egypt (2nd ed.). Cairo University Publishing: Beirut, Lebanon.

Wang, L., Jia, M., Yin, D., & Tian, J. (2019). A review of remote sensing for mangrove forests: 1956–2018. Remote Sensing of Environment, 231, 111223. https://doi.org/10.1016/j.rse.2019.111223.

Wikipedia contributors. (2026, March). *Wadi El Gemal National Park*. In *Wikipedia, The Free Encyclopedia*. Retrieved March 24, 2026, from https://en.wikipedia.org/wiki/Wadi_El_Gemal_National_Park

Wilkinson, C. (2000). Status of coral reefs of the world. Australian Institute of Marine Science.

Zahran, M. A., & Willis, A. J. (1992). The Vegetation of Egypt. Chapman and Hall.

Zohary, M. (1966). Flora Palaestina (1st ed.). Israel Academy of Sciences and Humanities: Jerusalem, Israel.

Zohary, M. (1972). Flora Palaestina (2nd ed.). Israel Academy of Sciences and Humanities: Jerusalem, Israel