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Long-term monitoring of the endemic *Evotrochis involucrata* Raf.: Conservation success and challenges

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Southern Sinai harbors a high diversity of locally endemic plant species, many of which face threats from environmental unsuitability and human activities. This study focuses on the endemic species *Evotrochis involucrata* Raf., which is confined to shaded cliff and fissure habitats sustained by melt snow, characterized by high soil moisture content near wells and sheltered mountainous areas. To monitor changes in endemic and threatened species in the St. Catherine region, 37 protective enclosures were established. Key data collected included species composition, total vegetation cover, target species abundance, individual size, vitality, exposure, and slope. In this research, we focused on some enclosures in specific sites where *Evotrochis involucrata* occurs, namely Kahf El-Ghola, Shaq Musa, and Wadi Garagnia. These enclosures were visited regularly over 25 years to track vegetation dynamics. Conservation efforts successfully preserved many species and mitigated human-induced threats. Remarkably, *Evotrochis involucrata* populations increased at Kahf El-Ghola and Wadi Garagnia. However, in Shaq Musa, severe climate change caused habitat degradation and erosion, leading to declines in plant numbers and percentage of plant total cover. Observations were conducted six times between 1999 and 2023, with ongoing monitoring to evaluate the conservation strategy's effectiveness.

Keywords: Enclosures, Endemic species, Monitoring, St. Cathrine, Threatened plants

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INTRODUCTION

Endemism plays a critical role in biodiversity and conservation biology, as endemic species often have specialized habitat requirements and limited distributions, making them particularly vulnerable to environmental changes. For species, endemism is a concept used in biology to describe a taxon's distribution that is restricted to a narrow geographic area and is consequently found naturally only in this location. As a result, endemic species are those restricted to a particular region, such as a lake, island, or mountain range. The extent of endemism varies across regions; for example, Täckholm noted variability in the number of endemic taxa within the Egyptian flora. Specifically, Boulos (2009) reported 60 endemic taxa in Egypt, while El-Khalafy et al. (2024) documented 76 endemic species, and Abd El-Ghani et al. (2024) updated the current status of endemics and near-endemics in the Egyptian flora, where 19 endemics (out of 70) and 76 near-endemics (out of 181) are newly added taxa.

The Sinai Peninsula is characterized by a high number of regional and local endemism. Southern Sinai has a clear correlation with the highest concentration of indigenous species. These endemic species are found in four main mountains namely: Mountain Catherine, Mt. Serbal, Mt. Musa, and Mt. Umm Shaumer (Ramadan et al., 2009). It has been considered a center of endemism, with many species isolated in a relatively small area, which is why it is so

important to protect them in a protected area such as St. Catherine National Park, a complex system of mountains and valleys that harbor a wealth of endemic plants and sustainable wildlife (Salah, 1995). Generally, the Saint Catherine area was described as primarily smooth-faced granite outcrops that formed mountains such as Gebel Serbal and Gebel Ras Safsafa (Said, 1962). It is the highest point in the hilly area of southern Sinai. Saint Catherine is frequently distinguished by highly rough mountains ranging in height from 1500 to 2641 meters above sea level, as well as volcanic rocks that form part of the Precambrian basement complex of the Sinai Peninsula's southern region (Moustafa & Mansour, 2020a).

Owing to its complex physiography and pronounced environmental gradients, the Sinai Peninsula supports diverse vegetation communities. Boulos (1995) estimated that Sinai harbors over one thousand species of higher plants, representing approximately 40% of Egypt's total flora. Among these, 36 species are native endemics, most of which are considered threatened due to habitat loss and environmental pressures. One of the most critically endangered endemic species in the St. Catherine region is *Primula boveana* (Sinai Primrose). The genus *Primula* is cosmopolitan, comprising approximately 500 species predominantly distributed in temperate and montane regions worldwide (Moustafa et al*.,* 2001). The restricted distribution and specialized habitat requirements of *P. boveana* underscore its vulnerability and the urgent need for targeted conservation efforts.

Evotrochis involucrata (=*Primula boveana* Decne. ex Duby, Primulaceae) is an endangered paleo-endemic to South Sinai, Egypt, where it is restricted to high-elevation year-round springs in red granitic rocks. The species is classified as belonging to rocky habitat (mountain peaks) by the IUCN Habitats Classification Scheme. It is subjected to several threats causing the populations to decline in number and size (Zaghloul et al., 2016). It considers Critically Endangered according to (IUCN, 2024). Its distribution has been correlated to high soil moisture content, carbonates, organic matter, electric conductivity, shady areas, closed caverns, and red granite fissures. It is found in most moist ground near wells and sheltered mountain areas, particularly cliffs and caves with steep granite slopes. It is also restricted to habitats found in cliffs and fissures fed by melted snow (Moustafa & Mansour, 2020b).

The general population of adults is separated into nine subpopulations totaling less than two hundred individuals. Drought and climate change pose dangers to the species, resulting in a chronic decrease in habitat quality. Subpopulation numbers have also reduced with substantial changes over time. Other factors harming the plant include disruptions and human activities such as overgrazing, urbanization, tourism, quarries, solid waste, and traditional medicine, all of which endanger its survival (Moustafa & Mansour, 2020b). In general, various pharmacological studies have demonstrated the efficacy of primrose extracts, which are high in saponins and have effective antiviral, anti-asthmatic, and anti-inflammatory properties. *Evotrochis involucrata* is known for its phenolic glycosides and saponins (Müller et al., 2006). Several scientific research facilities gather the species for pharmacological testing. *Evotrochis involucrata* flowers and roots were used as traditional medicine in Sinai to treat headaches, respiratory issues, neuralgia, limb shaking, and cardiac weakness (Moustafa & Mansour, 2020b).

Ecological observation is a set of techniques that allows for the economical collection of data on the vitality capacity of significant areas of land. Each survey reveals just static status over time. Continuous monitoring throughout time is often more effective at detecting developments in the ecosystem created by conservation measures. Ecological surveillance may give information for developing an action plan as well as feedback on the effectiveness of the action conducted. This paper asks for conservation as a tool that can protect the *Evotrochis involucrata* from being extinct, and does monitoring for long periods of time can be apposition action for keeping the *Evotrochis involucrata* and its associations in good shape. This paper aims to monitor the evaluation for *Evotrochis involucrata* plant and its numbers of individuals, total cover percent, the increasing and decreasing over a period of approximately 25 years to assess the extent to which this threatened plant and the impact of attempts to preserve it over the years.

Plant description

Evotrochis involucrata Raf. is one of the most important, extremely rare, and medicinal plant species found in Sinai. This is due to its origins as isolated plants due to environmental problems (Moustafa & Mansour, 2020b). Plants are perennial herb, with ovate, deeply serrated leaves

(Figure 1). The leaves have mealy surfaces, with rosette arrangements at the lower ones while the higher ones arrange in whorls with different internode lengths throughout the year. They have yellow, tubular flowers with spreading, regular limb whorled bracts surround the bloom. The corolla, which is about three times as long as the calyx, is lemon-colored (Figure 1). On average, a fruit contains 423 seeds, with 32,258 seeds per gram (Zaghloul, 1997). The flowering stage normally begins in February and lasts through May. It sheds seeds near July and August. Meanwhile, vegetative growth activity varies across the four seasons, peaking in September and falling to its lowest in July. Most *Evotrochis involucrata* subpopulations are tiny, with solitary plants occasionally forming small groups in damp soil. More mature plants have gone extinct than there were in 1832 (Richards, 2003), with only about 2,000 left in 1991 (Al Wadi, 1993). For updated plant nomenclature, the online global database: Plants of the World Online (POWO; https://powo.science.kew.org) was used.

Study area

Location, geography and geomorphology

Evotrochis involucrata Raf. is an endemic species found in South Sinai, Egypt, especially Mount St. Catherine and the wadies associated with it. South Sinai is located between 33° 32` to 34° 00` east and 28° 30` to 28° 46` north of Egypt, it's characterized by high and rugged mountains ranging from 1500 to 2624m above sea level (e.g., Mount St. Catherine and (2629m), Mount Mousa (2285m), and a complex system of deep wadis constructed of dark-colored sandstones. Some wadis are long (e.g., Wadi El-Sheikh), while others are shorter, narrower, and steeper, serving as tributaries to the main wadis (e.g., Wadi El-Arbaeen). *Evotrochis involucrata* has been recorded in five small localities in the Saint Catherine Protectorate (Sad Abu Hebiq, Kahf El-Ghola, Elgabal El-Ahmar, Shaq Mousa "Ain Shennarah", and Wadi Gragenia), as well as a few populations in Serbal Mountain's north-facing hills. This species has a small altitudinal range, extending from 1745 to 2210m. Elevation was shown to have a beneficial effect on population size. Many investigations have shown that *Evotrochis involucrata* is mostly found in rocky habitats (mountain peaks) along the slopes toward northeast (78%) and east (22%), with slope degrees ranging from 55° to 90° (Mansour, 2010). According to the IUCN Habitats Classification Scheme, this species; is restricted to cliffs and fissures fed by melted snow and is found in most moist ground (Figure 2) (Moustafa & Mansour, 2020b).

According to Said (1990), the geomorphology of the St. Catherine region is composed of extremely rocky terrain with acid plutonic and volcanic boulders belonging to the Precambrian basement complex of the southern part of Sinai, which is dissected by several carved wadis demonstrating traces of down cutting. Wadi El-Arbain is deep, narrow, and mostly made up of enormous stones. The bedrock in Wadi El-Arbain is granitic, whereas the major wadi and its streams are alluvial. The height of the stand studies above sea level ranges from 1580 to 1660m, and they are located on various landforms (wadi-bed, the slope, and terraces) (Figure 3). Wadi Garagnia is a subbasin made up of volcanic and alluvial boulders. It is very narrow and rudely filled with big rocks; the width of this wadi ranges from 5 to 20m and reaches about 2m at the end. The elevation above sea level of the research site ranges from 1620 to 1780m. Shaq Mousa is a sub-basin with volcanic rock units that is quite narrow and clumsily filled with huge stones. The site of the stand evaluations range in height above sea level from 1690 to 1760m, with a width of 6 to 50 m along the wadi (Moustafa et al., 2020).

Figure 1. *Evotrochis involucrata* in rocky habitats. A: The plant with severely serrated and whorled leaves, B: Showing the yellow and tubular flowers of the Evotrochis involucrata in Saint Catherine

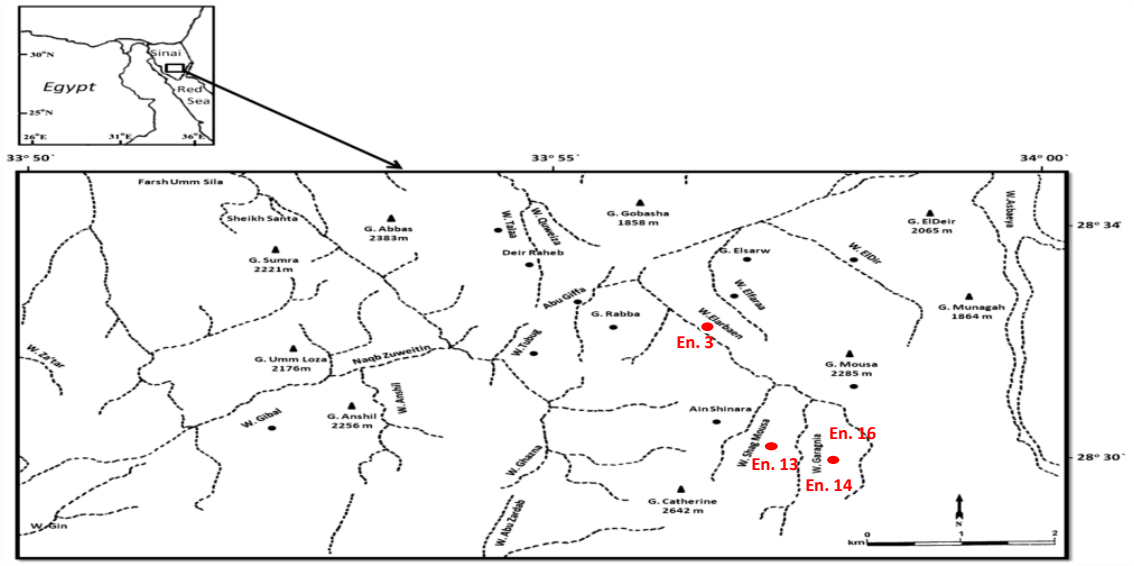


Figure 2. Locations of enclosures (En) at Kahf El-Ghola, Shaq Musa (Ain Shinnara) and Wadi Garagnia in St. Cathrine (after Zaghloul et al., 2016)

Figure 3. The granitic bed rocks on Wadi El-Arbain, with the visitor center, Saint Catherine, Egypt, 2022

Mount Catherine is a massive horst located in the middle of Egypt that rose vertically along the Wadi Sabia fault in the Catherine Plateau during the Neogene period. It is commonly found in a mid-latitude desert setting; the Catherine Plateau is made up of several volcanic rocks that formed at various points throughout the Precambrian epoch. Tuff, agglomerate, volcanic bombs, and lava flows are among the types of rocks found here. The volcanic rocks in this area have experienced extensive cracking and weathering, resulting in the formation of massive screes, increased water infiltration, and an impact on the local water cycle.

Climate

The changing patterns of temperature, precipitation, and relative humidity are the same as those of the Mediterranean regions. These changes are largely due to greenhouse gas emissions (Badr & El-Shazly, 2024). The study area has an arid climate with hot, dry summers and chilly winters (Ayyad, 2000). A year-round review of Saint Catherine's meteorological data reveals a considerable range in temperature. The city has a wide range of temperatures, from a freezing low of 1.7°C in the coldest months to a scorching high of 32°C in the hottest days of summer. Humidity levels remain relatively moderate throughout the year, with the highest at 39% and the lowest at 19%. Rainfall in Saint Catherine is sparse, usually less than 4mm (0.16") per year and with almost no rainy days. The city has the most daylight hours from May to August, averaging 13.6 to 13.9h per day. Sunlight is also abundant, with a maximum of 12h between June and August. The UV Index rises dramatically during the summer months, peaking at 12 from May to August, underlining the importance of sufficient sun protection (Weather Atlas, 2024).

As global temperatures recently continue to rise, the risks, anticipated adverse effects, and consequential losses and damages stemming from climate change are amplified (Moustafa & Ghowail, 2022). The change in temperature, wind, rainfall rate, and severe drought in those areas can cause changes in vegetation communities that are projected to be significant enough to impact biome integrity at higher levels of biodiversity, which may threaten the populations of many endemic plants in the St. Catherine area, such as the *Primula* plant (Moustafa et al., 2023). Climate change is going

to influence species interactions, community structure, plant phenology, biodiversity, and geographical ranges (Fouad et al., 2023).

MATERIALS AND METHODS

According to the project initiated in July 1998, 37 enclosures were constructed to monitor changes in endemic and threatened species in the St. Catherine area. These enclosures were protected against grazing and human interference by fencing and were designed to be permanent to facilitate long-term monitoring. The primary data collected included total vegetation cover percentage, number of individuals of the target species, species composition, individual size, vitality of the target species, exposure, slope, and other relevant environmental variables. Several monitoring methods, adapted to the vegetation structure, were implemented to ensure accurate and consistent data collection.

They included marking growing tips of trees, measuring the actual size of the plants, marking the outside edges of creeping plants, and establishing permanent quadrates for herbaceous plants consisting of three 1×1m quadrates outside and inside the fence for the target species. These enclosures were visited frequently to follow up any changes in vegetation composition; the monitoring of these enclosures was done through estimating the following criteria inside and outside the enclosure as: Measuring total plant cover, height, and the number of individuals in each species. Each species' phenology and vitality are estimated by counting the number of reproductive organs and growth status. Measuring fresh growth on indicated shrub and tree branches were done. Estimate the percentage of browsing in each species, as well as other human involvement. Determine the status of endemic, medicinal, and threatened species, as well as their hotspots, while also conducting a preliminary analysis of plant communities.

This project depends on the outcomes of a botanical survey conducted between 1996 and 1998. The survey found that 316 species already existed in Saint Catherine protectorate, with more than 200 species being difficult to locate due to several threats. As the basic factors, an excess of threatened target populations was used to choose these protected plots (Moustafa et al., 2017). *Evotrochis involucrata* was one of the most threatened endemic species that was found and monitored in these enclosures in certain sites "Kahf El-Gola, Shaq Musa (Ain Shinnara) and Wadi Garagnia", in enclosures no. (3,13,14,16) (Table 1), this plant has been followed through several years and they noticed variable ranges for number of plant populations, individuals, size, etc., which has been decreasing through time (Botanical Conservation Measures and Ecological Monitoring Program, 2001) (Moustafa, 2001).

To compare protection measures and clearly illustrate the changes in the vegetation parameters of the fenced and unfenced plots, several adjacent pairs of fenced / unfenced stands were selected per community. Cover refers to the area occupied by a plant, which might be basal or canopy. The basal cover is the land area occupied by the cross section of the stem, whereas the canopy cover is the total area under the plant's canopy. To compute the total cover percentage for a specific enclosure, we measure the cover of each plant species within the enclosure, and then add the cover of all species and divide by the entire enclosure area per centimeter square, multiplying the result by 100.

$$\text{Total cover percent within enclosure} = \frac{\text{Total cover for all species within enclosure}}{\text{Total enclosure area in Centimeter Square}} X100$$

Protection from over exploitation may provide a chance for vegetation regeneration and protection improvement.

Soil analysis

Collected soil samples were subjected to air-dried and manually passed through a 2mm sieve to remove debris and prepare them for analysis (Abd El-Ghani & Hussein, 2024; Sallam et al., 2025). Gravel content was determined by measuring the proportion of particles retained on the 2mm sieve. Soil moisture content was measured gravimetrically by drying samples at 105°C immediately after collection. Particle size distribution was assessed using dry sieving for coarse sand fractions (sieve mesh size 0.59mm), while the pipette method was employed for fine sand, silt, and clay fractions. Organic matter content was determined by the loss on ignition method (Abdullah et al., 2024), which involved heating oven-dried samples at 600°C for 3h in a muffle furnace (model MF120 Nuve; sensitivity 1°C, accuracy ± 2°C). Soil pH was measured using a pH meter (model 1671; resolution 0.01 pH units, accuracy ± 0.1% ± 1 digit). Electrical conductivity (EC) was determined in a 1:1 soil-to-water extract (w/v) using a conductivity meter (model 4310 ENWAY; accuracy ± 0.5% ± 2 units) following the method of Abd El-Ghani & Hussein (2024).

RESULTS

Table 1 presents comparative site-specific data for four distinct enclosures established in 1998 across diverse habitats within the St. Catherine Protectorate, South Sinai. These enclosures exhibit significant variation in topography, elevation, slope, and exposure, factors that likely contribute to differences in the associated vegetation communities.. Exposure differs from northeast to east, influencing microclimatic conditions such as solar radiation and soil moisture retention. The landforms include caves, gorges, and depressions, each providing unique ecological niches that support distinct plant assemblages. Species such as *Nepeta septemcrenata* and *Phlomis aurea* were common across most sites, indicating ecological generalism or resilience, whereas species like *Rosa arabica*, *Veronica kaiseri*, and *Adiantum capillus-veneris* were restricted to specific sites, reflecting specialized microhabitat requirements.

Among the 37 enclosures established within the St. Catherine Protectorate, only four (3, 13, 14 & 16). specifically support populations of the endemic species *Evotrochis involucrata.* These enclosures are located in Kahf El-Ghola, Shaq Mousa (Ain Shinnara), south of Wadi Garagnia, and east of Wadi Garagnia, as summarized in Table 1. The presence of *Evotrochis involucrata* within these diverse topographic and microclimatic settings underscores the species' habitat specificity and highlights the importance of targeted conservation efforts within these small-scale protected areas.

Ecological description of enclosures

Enclosure No. 3

The enclosure is located within a large cave on the right side of Wadi El-Arbain. The cave, formed from granite terrain, has a surface area of approximately 175m². Moisture seeping down the cave walls significantly reduces the ambient temperature, creating a cool and humid microclimate. This unique environment supports a distinct floristic composition, notably including rare and endemic species such as *Evotrochis involucrata*. Due to its high elevation and difficult terrain, the site is not easily accessible to Bedouins and tourists on a daily basis. Prior to the construction of a protective barrier, the Bedouins used the cave as a resting and cooking area during their leisure time (Moustafa et al., 2017).

Table 1. Ecological and topographical characteristics of selected enclosures (Nos. 3, 13, 14, and 16) in the St. Catherine Protectorate, South Sinai, where *Evotrochis involucrata* occurs

Enclosure	No. 3 Kahf El-Ghola	No. 13 Shaq Musa (Ain Shinnara)	No. 14 South of Wadi Garagnia	No. 16 East of Wadi Garagnia
Date of construction	June, 1998	June, 1998	October, 1998	January, 1998
Area	175m²	50.80m²	25m²	16.60m²
G.P.S. record	N: 28° 32' 949" E: 33° 56' 936"	N: 28° 30' 470" E: 33° 58' 179"	N: 28° 32' 652" E: 33° 57' 188"	N: 28° 32' 667" E: 33° 58' 824"
Elevation	1650m a.s.l.	2120m a.s.l.	1920m a.s.l.	1920m a.s.l.
Slope	23°	40 °	12°	15°
Exposure	12° (internal) & 60° (External)	North-east	South	East
Landform type	Cave, Slope	Gorge & slope bare rock	Very gently slope	A little cave with slope and depression
Associated species	*Rosa arabica* *Hypericum sinaicum* *Nepeta septamcrenata* *Origanum syriacum* *Ballota undulata*	*Nepeta septamcrenata* *Phlomis aurea* *Crataegus x sinaica*	*Phlomis aurea* *Nepeta septamcrenata*	*Veronica kaiseri* *Nepeta septamcrenata* *Phlomis aurea* *Crataegus x sinaica* *Pterocephalus sanctus* *Arenaria deflexa* *Adiantum capillis-veneris*

The enclosure is ecologically diverse and has been divided into three main sections. The first section was located at the entrance of the cave and was dominated by *Rosa arabica* shrubs along with other plant species. The second section comprised a sloping area that leads into a shallow depression with deeper soil, supporting a more diverse vegetation cover. The third section, which constitutes the largest and moistest part of the enclosure, was characterized by two distinct landforms: a vertical granite wall with water seepage that maintains continuous moisture for plant growth, and a horizontal floor. *Evotrochis involucrata* and other associated species dominated this section (Figures 4, 5). Vegetation cover of the target plant species was recorded, measured, and monitored across different seasons. Additionally, four permanent plots were established on moss mats to observe the growth and regeneration patterns of *Evotrochis involucrata* over time.

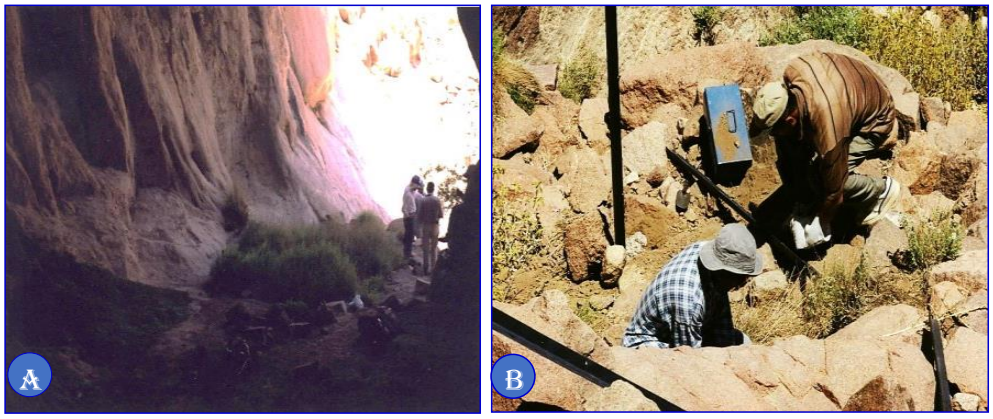


Figure 4. A: General view of Kahf El-Ghola showing the dominant vegetation at the gate area, B: Setting up the enclosure of Kahf El-Ghola without damaging plants on the ground

Figure 5. A: Monitoring process using marked sticks at the edges of the vegetation layer on the ground inside Kahf El-Ghola. B, C: Showing *Evotrochis involucrata* plant on the wall of Kahf El-Ghola

Enclosure No. 13

The main aim of this enclosure was to protect *Evotrochis involucrata*, and to monitor any changes in its habitat. This enclosure was located at Ain Shinnara; a significant tourist stopover en route to Mt. Catherine; which is currently under considerable stress caused by human disturbance and grazing. Nonetheless, it is regarded as the perfect habitat for the growth of *Evotrochis involucrata* and *Nepeta septamcrenata* (Figure 6). It can be considered medium size, which is 50 m^2. It is located in a gorge, and can be divided into two main parts: Part A represents a big fissure which is moistened most of the year and is covered completely with mosses and *Evotrochis involucrata*. Part B represents a plain area covered mostly with cobbles and small stones. Four plots were chosen and marked as permanent plots (50× 50cm each) to monitor changes in the habitat at different seasons, and to compare between the three main enclosures distinguished by a unique vegetation of *Evotrochis involucrata*, *Adiantum caillus-veneris*, and mosses. In each plot, the *Evotrochis involucrata* was divided into 8 main categories according to the diameter of each population as follows: (>2, 2-5, 5-10, 10-15, 15-20, 20-25, 25-30, and 30-35cm). The main results are summarized as follows:

Part A: In summer, the number of individuals were located mostly at the first and second categories of growth (e.g. >2, 2-5cm), and the smallest number of individuals (56 individuals) recorded at plot 3 whereas the highest one recorded at number 4 (219 individuals). In winter, the total number of individuals was 214 individuals distributed generally between the main eight categories with more presentation at the biggest categories that start from 10 to 30cm in diameter. Also, the lowest number of individuals, found at plot 1 (31 individuals), while the highest number is recorded at plot 4 (73 individuals).

Part B: In this part of the enclosure, there are another three species for different plants (*Nepeta septemcrenata, Crataegus sinaica* and *Phlomis aurea).*

Enclosure No. 14

Three key endemic species, including *Evotrochis involucrata*, were selected as target species for long-term monitoring within this enclosure. A slight decline in recorded numbers was observed between the first and second monitoring periods. This decrease is likely attributed to the loss of young seedlings owing to increased drought stress and reduced soil moisture availability. Such fluctuations in seedling survival are common in arid high-altitude environments which may reflect the sensitivity of recruitment dynamics to inter annual climatic variability. Meanwhile, continued monitoring is essential to assess long-term population trends and inform conservation strategies for these vulnerable species.

Enclosure No. 16

This enclosure is one of the most important and attractive enclosures because of its vegetation and landform types that makes it one of the most beautiful locations in the main Wadi-bed system of Garagnia. Generally, this Wadi is very narrow, closed, shaded most of the daytime, characterized by high elevations (1920 – 2100m). It lies at the end of Wadi El-Arbain where it converges with the sloped habitat of Mt. Cathrine. It is distinguished by a multitude of geomorphologic formations, cool climate, which supports unique vegetation of rare and endemic species, and a biologic crust that is hardly found anywhere. The present enclosure included several landforms (cave, a slope, a ridge, and a depression carved by running water). This perfect site is therefore fenced to conserve and monitor a group of nine species including *Primula boveana* (Figure 7).

Figure 6. *Evotrochis involucrata* grows on the north facing cliffs in Shaq Mousa (Ain Shinnara)

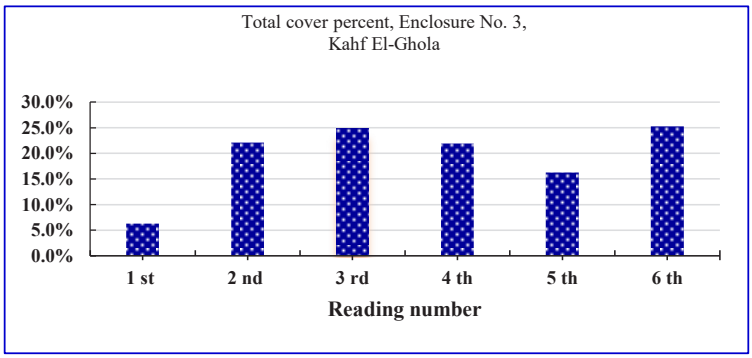
Figure 7. Enclosure No. 16 set at Wadi Garagnia to protect *Evotrochis involucrata* and *Nepeta septamcrenata* against human disturbance

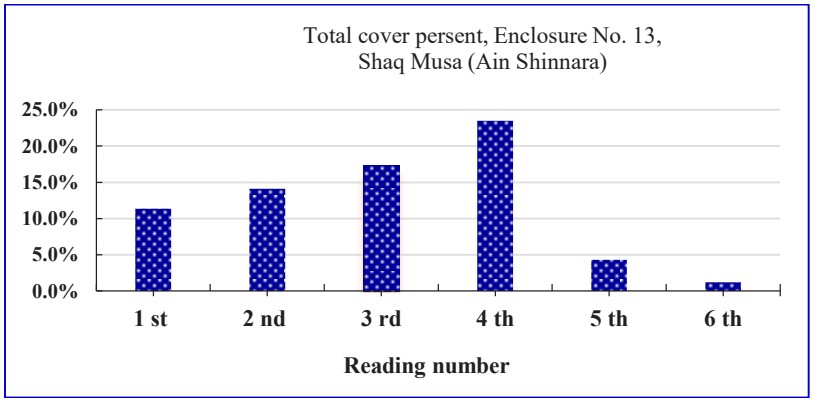
This area is divided into four parts; each part is in turn divided into several permanent plots to monitor the most important target species such as *Evotrochis involucrata*, *Nepeta septemcrenata*, and *Veronica kaiseri*. Protection efforts led to a significant increase in both species diversity and population numbers

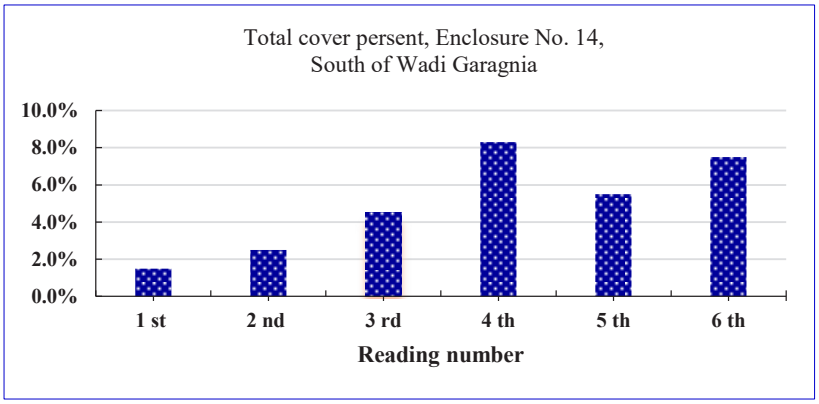
The results of long-term data analyses (Table 2, Figure 8), demonstrated a general increase in species richness and vegetative cover in most enclosures, indicating a positive effect of long-term protection. However, three enclosures, particularly Enclosure No. 13 in Shaq Mousa (Ain Shinnara), showed a notable decline in the number of *Evotrochis involucrata* individuals. This reduction may be attributed to site-specific environmental stressors, including prolonged drought, limited recruitment, or microhabitat degradation, underscoring the need for targeted conservation management at these locations.

Table 2. Long-term monitoring of *Evotrochis involucrata*. Individual counts and total cover (%) at four occurrence sites during the periods: 1999–2023

No. of records and date		Enclosure number and name							
		No. 3 (Kahf El-Ghola)		No. 13 (Shaq Musa, Ain Shinnara)		No. 14 (South of Wadi Garagnia)		No. 16 (East of Wadi Garagnia)	
Record numbers	Dates	Number of individuals	%Total cover	Number of individuals	%Total cover	Number of individuals	%Total cover	Number of individuals	%Total cover
1st	25/7/1999	40	6.30	490	11.35	5	1.50	4	0.50
2nd	27/4/2001	68	22.10	214	14.11	7	2.50	8	1.20
3rd	15/4/2007	75	24.80	190	17.30	12	4.50	17	3.50
4th	16/5/2014	71	21.90	120	23.50	15	8.30	25	7.80
5th	21/3/2017	79	16.30	50	4.30	12	5.50	30	6.50
6th	2/5/2023	85	25.30	15	1.20	17	7.50	28	7.50







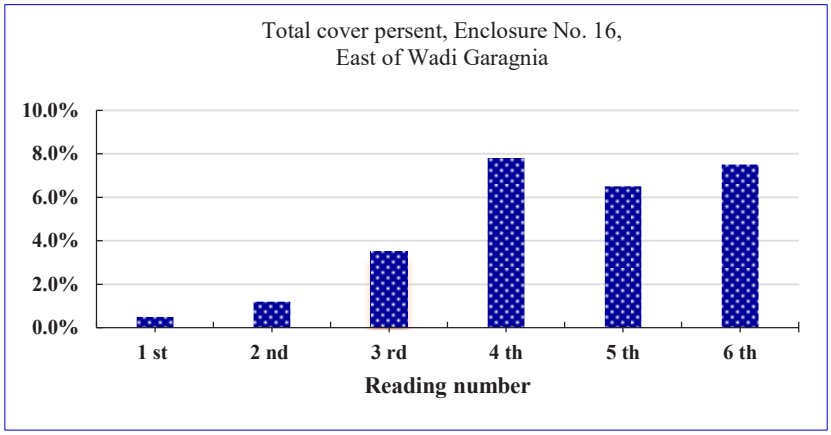


Figure 8. Percentage total cover for selected enclosure no 3, 14, 13 and 16 showing variable records in total cover percent throughout the studied years

In general, the data recorded that Kahf El-Ghola (Enclosure No. 3) consistently showed a gradual increase in both the number of individuals and total cover over the study period, reaching 85 individuals and 25.3% cover by 2023. This positive trend suggests that the microclimatic conditions and protective measures in this moist cave environment have effectively supported the persistence and growth of *Evotrochis involucrata*. In contrast, Enclosure No. 13 (Shaq Musa, Ain Shinnara) exhibited a sharp decline in both individual numbers and cover after the first two readings. From an initial count of 490 individuals in 1999, the population fell dramatically to only 15 individuals in 2023, with a corresponding drop in cover from 11.35% to 1.2%. This significant decrease indicated that environmental stressors, possibly drought, habitat degradation, or poor seedling recruitment, which may have severely squeezed the population in this site. Meanwhile, enclosures No. 14 and 16 (South and East of Wadi Garagnia, respectively) displayed a more stable yet modest increase in both parameters over time. Although initial values were very low, both enclosures showed gradual improvements in plant numbers and cover, with the highest values recorded in 2023. These patterns suggested a slow but positive response to protection measures, likely influenced by soil characteristics, slope, and exposure. In conclusion, the data highlight the importance of site-specific microhabitat conditions in determining the success of *Evotrochis involucrata* populations. While some enclosures show strong recovery and population growth under protection (Kahf El-Ghola), others like Shaq Musa, require targeted management actions to address ongoing population decline.

In parallel with vegetation monitoring, soil analysis and erosion assessments were conducted to evaluate environmental factors influencing plant distribution and health in these selected enclosures. The main results of the soil evaluations are presented in Table 3. These analyses focused on detecting changes in soil moisture, texture, pH, organic matter content, and electrical conductivity across the different enclosures. The data indicat that soil pH values across all sites ranged from slightly acidic to moderately alkaline (approximately 7.0 to 8.2), reflecting neutral to alkaline soil conditions typical of arid mountainous environments.

From the results of the soil analyses shown in Table 3, Kahf El-Ghola and East of Wadi Garagnia exhibited relatively stable pH values around 7.7 to 8.2, while Shaq Musa showed slightly more acidic readings (down to 7.0). Electrical conductivity (EC) varied considerably, with Kahf El-Ghola and East of Wadi Garagnia showing higher EC values (up to 260 mhos/cm), indicating elevated salinity levels, which may influence plant water uptake and species distribution. In contrast, South of Wadi Garagnia had consistently low EC values (<20 mhos/cm), suggesting lower salinity stress. For soil moisture content was highest at Kahf El-Ghola, ranging from approximately 27% to 34%, indicating favorable moisture availability likely due to its microhabitat conditions. Shaq Musa and South of Wadi Garagnia recorded lower moisture percentages (around 2% to 21%), while East of Wadi Garagnia showed the lowest moisture values (1.96% to 16.4%), which may reflect differences in water retention capacity or microclimatic factors.

Organic matter content varied from 6.7% to 24.6%, with Kahf El-Ghola generally exhibiting higher organic matter, which can enhance soil fertility and support endemic vegetation. Meanwhile, gravel content was notably high at Kahf El-Ghola (up to 68%), whereas Shaq Musa and South of Wadi Garagnia had moderate gravel percentages (32.5% and 51.4%, respectively), and East of Wadi Garagnia had the lowest gravel content (26%). This variation influences soil aeration and water infiltration. Particle size analysis revealed that Kahf El-Ghola and East of Wadi Garagnia soils were dominated by sand fractions (total sand >70%), with Kahf El-Ghola primarily composed of fine sand (approximately 80%) and East of Wadi Garagnia showing a more balanced distribution between coarse and fine sand. Shaq Musa exhibited a higher proportion of fine sand (54.5%) and lower clay content (5%), whereas South of Wadi Garagnia had a more heterogeneous texture with significant silt (21.5%) and clay (7.2%) fractions. In general, soil texture analysis revealed that the majority of samples were dominated by coarse to fine sand, with only small fractions of silt and clay, particularly in the East of Wadi Garagnia enclosure. These textural properties influence water retention and may partially explain the spatial differences in soil moisture and, consequently, vegetation cover. Understanding these soil parameters is critical for interpreting the ecological responses of Primula boveana and other associated species under varying habitat conditions.

Table 3. Soil physicochemical properties and texture variability across four enclosures in the St. Catherine Protectorate at which *Evotrochis involucrata* was recorded. 1, First record in1999; 2, second record in 2001; 3, third record in 2007 and 4, fourth record in 2023

Enclosure No.	Recording time	pH	Electric conductivity (mhos/cm)	Moisture content (%)	Organic matter (%)	Gravel %	Fine soil texture (%)				
							Total sand	Corse sand	Fine sand	Silt	Clay
3 Kahf El-Ghola	1	7.75	6.95	32.51	12.52	68.36	79.67	0	79.67	13.64	8.86
	2	7.72	6.99	28.51	15.6						
	3	7.75	15.6	27.3	16.7						
	4	7.79	19.7	33.61	23.57						
	5	7.73	20.5	34.71	20.21						
	6	7.75	20.8	30.43	24.6						
13 Shaq Musa (Ain Shinnara)	1	7.95	1.4	16.86	7.53	32.54	84	29.48	54.52	11	5
	2	7.01	2.9	14.23	7.9						
	3	7.12	11.3	13.12	15.31						
	4	7.19	21.4	15.01	19.4						
	5	7.15	15	16.4	12.25						
	6	7.23	21.7	21.7	21.18						
14 South of Wadi Garagnia	1	8.05	0.23	2.24	6.87	51.4	71.28	35.95	35.34	21.54	7.18
	2	8	2.25	5.56	16.21						
	3	7.7	2.92	7.76	16.9						
	4	7.8	11.3	12.51	22.3						
	5	8.12	15.32	10.3	13.5						
	6	8.17	18.4	12.1	23.71						
16 East of Wadi Garagnia	1	8.06	2.42	1.96	6.7	26.03	93.44	50.12	43.32	4.36	2.2
	2	7.4	15.5	2.51	5.5						
	3	7.9	19.78	12.51	3.5						
	4	7.5	19	13.5	12.5						
	5	7.6	210	15.3	14.5						
	6	8.17	260.1	16.4	16.7						

DISCUSSION

The primary objective beyond the establishment of thirty-seven enclosures in the Saint Catherine area was to monitor long-term changes in plant populations, particularly those that are endemic to Egypt. Many of these endemic species are classified as threatened due to various anthropogenic and environmental pressures;. Given the ecological, medicinal, and economic importance of these species (Khedr et al., 2025), the enclosures were designed as a conservation strategy to protect their natural habitats, minimize external disturbances, and facilitate regular scientific monitoring over time. These protected microhabitats provide valuable insights into population dynamics, habitat preferences, and the resilience of rare plant species under changing environmental conditions.

Evotrochis involucrata has been classified by the International Union for Conservation of Nature (IUCN) as facing an extremely high risk of extinction in the wild. Among the most significant and pressing threats to this critically endangered plant is climate change, which directly influences life style (Moustafa et al., 2024) and key stages of plant life cycles, and its phenological stages.. Shifts in temperature and precipitation patterns may alter habitat suitability, disrupt food and nutrient availability, and increase the likelihood of population declines due to physiological stress or habitat loss. Climate change can also indirectly affect *Evotrochis involucrata* through its impact on ecosystem processes, leading to changes in species interactions, increased competition, and reducing biodiversity (Hui, 2013). Over the past century, global average temperatures have increased by approximately 0.6°C, with projections indicating a continued and potentially accelerated warming trend (Serag et al., 2018; Moustafa et al., 2024). In the Saint Catherine region, this warming is often accompanied by prolonged droughts, erratic rainfall patterns, and occasional flash floods, all of which contribute to habitat fragmentation and physical damage to fragile plant populations, including uprooting of *P. boveana* individuals during extreme events. In addition prolonged drought may lead to increase salt content like Na ions which will be accumulated by plant and decrease its growth and survival rate (Serag et al., 2025). Moreover, elevated atmospheric CO_2 levels have been shown to alter plant morphology, affect physiological functions, and contribute to soil acidification. These changes, combined with rising temperatures, can significantly influence species distribution, biophenological patterns (flowering and fruiting times), and overall vegetation structure (Moustafa et al., 2024). These combined stressors underscore the urgent need for in situ conservation strategies, such as the enclosure system in St. Catherine, to safeguard *Evotrochis involucrata* and other vulnerable endemic species under changing climatic conditions.

In addition to climate change, human activities represent a major threat to the survival of *Evotrochis involucrata* and other endemic plant species in the St. Catherine region. These anthropogenic pressures include water extraction for domestic use from nearby valleys, unregulated grazing by livestock such as sheep and goats, and biotic stress from insect herbivores. Grazing can lead to significant physical damage, reduced reproductive capacity, and soil compaction, all of which adversely affect seedling establishment and long-term plant survival. Furthermore, insect pests, particularly those that consume vegetative parts, can reduce plant vigor, photosynthetic capacity, and overall fitness. Seed predation by ants may also interfere with the reproductive success of these species, either by removing seeds before dispersal or by reducing seed viability through desiccation or damage (Iqbal, 2023). In some cases, ant activity has been associated with altered soil properties and decreased water availability, further stressing native flora in arid environments. Interestingly, previous studies have demonstrated that restricting grazing pressure is more effective than supplemental water in enhancing the survival and recovery of desert plant species, particularly those of high forage or medicinal value (Ali, 2025). Notably, the study found that the density and total cover of chamaephytes, a growth form adapted to harsh, dry conditions, were significantly higher within protected enclosures compared to surrounding open areas. This highlights the critical role of exclusion zones in mitigating the combined impacts of biotic and abiotic stressors on sensitive plant communities.

In recent years, the growing global interest in traditional and herbal medicine has led to an over harvesting of medicinal plants from their native habitats. This increased demand has placed significant pressure on wild populations, leading to the overexploitation of many valuable species. As a result, several of these plants are now at risk of extinction, especially those with limited natural distributions. Alarmingly, some of these threatened species are listed in official pharmacopoeias, underscoring both their medicinal importance and the urgency of their conservation (Moustafa

et al., 2019). Beyond direct exploitation, another critical threat to these species is the loss of genetic diversity, particularly among small or geographically restricted populations. Reduced genetic variation can compromise a species' ability to adapt to environmental changes and may result in lower reproductive success and individual fitness. In severe cases, it can lead to inbreeding depression and even complete extinction (Wikipedia: Genetic erosion, 2025). Therefore, assessing and monitoring genetic diversity is a fundamental component of plant conservation programs, as it informs strategies for maintaining population viability and enhancing resilience to environmental stressors (Moustafa et al., 2016). Effective conservation efforts must integrate both ecological and genetic assessments to ensure the long-term survival of endangered medicinal plants, especially in arid and semi-arid ecosystems where environmental pressures are intensifying.

Between 2003 and 2014, the St. Catherine Protectorate (SKP) received approximately four million visitors from 51 countries, averaging around 335,000 tourists annually. Most tourism activity was concentrated in the northern part of the protectorate, a designated World Heritage Site. Safari tourism, which often involves multi-day trips with overnight stays in remote areas, was particularly common in ecologically sensitive zones such as Wadi Tenia, Wadi Gebal, Shaq Mousa, and Sad Abu Hebik. Although tourism has had minimal direct impact on five of the nine known subpopulations of *Evotrochis involucrata*, localized disturbances have been documented. Trampling, climbing, and repeated foot traffic compact the soil, reducing its permeability and leading to a decline in vegetation cover. In some cases, garbage accumulation and physical disturbance hinder seed germination and seedling establishment. Additionally, the diversion of water from high-elevation, water-rich wadis to drier, lower-elevation areas for human use has led to over extraction from wells, further degrading habitat quality and reducing available moisture for endemic plant populations (IUCN, 2014). Furthermore, recent assessments quantitatively link rising tourism activity with increased biodiversity risks, illustrating that intensified tourism pressure correlates with higher threat indices in sensitive ecosystems (Chen et al., 2025). This aligns with observations at SKP, where the fragile balance between tourism and conservation is increasingly strained. Of particular concern is the Ain Shinnara site, where one of the most suitable microhabitats for *Evotrochis involucrata* has recently been damaged due to structural failure of protective enclosures. This incident highlights the need to reinforce *in situ* conservation infrastructure and to integrate *ex situ* strategies. Conservation efforts should include propagation and cultivation programs within the affected study areas, along with seed banking and controlled cultivation under greenhouse conditions to safeguard the species for future restoration efforts (Moustafa & Mansour, 2020b).

Several conservation strategies can play an effective role in mitigating threats to Egypt's endemic and endangered plant species. One such strategy involves the development of genome resource banks and seed banks, which act as reservoirs of genetic variation. These *ex situ* conservation tools are essential for preserving the evolutionary potential of plant populations and preventing irreversible genetic erosion (Zaghloul, 2008). Alternatively, regular monitoring of population size, distribution, and long-term trends is critical to inform adaptive management decisions. Equally important is raising public awareness about the ecological and cultural significance of vulnerable plant species such as *Evotrochis involucrata*. Educational programs tailored to schools, universities, and research institutions can foster a conservation-minded community. Furthermore, engaging local Bedouin communities through targeted initiatives is vital. Promoting their participation in conservation and protection efforts not only increases program success but also supports community-based stewardship of natural resources (Moustafa & Mansour, 2020b). *In situ* conservation efforts should include the restoration and rehabilitation of existing *P. boveana* populations, as well as the construction of new protective enclosures in priority areas of the Saint Catherine Protectorate. Expanding the protected area network, regulating uncontrolled harvesting by Bedouins and botanists, and encouraging the sustainable use of native plant resources are also essential components.

In addition, effective conservation requires institutional and policy support. This includes the development of a tax or financial mechanism to fund conservation activities, regulation of unorganized tourism practices, and the formulation of public policies and environmental laws that safeguard plant diversity. Together, these coordinated actions can significantly enhance the

long-term conservation of endemic flora in arid and vulnerable ecosystems (Moustafa & Mansour, 2020b).

This account represents a key in situ conservation action aimed at preserving *Evotrochis involucrata* within the St. Catherine Protectorate. Monitoring results from enclosures containing *Evotrochis involucrata* over a 25-year period (1998–2023) revealed variable trends in plant population dynamics, with some enclosures showing increases and others decreases in individual numbers and total vegetation cover. In general, the establishment of protective enclosures has positively influenced vegetation characteristics, improving plant cover, diversity indices, and biovolume, particularly for endemic and threatened species such as *Evotrochis involucrata*. The success of these enclosures, however, has varied by site. Notably, significant population growth of *Evotrochis involucrata* was observed in enclosures at Kahf El-Ghola, South of Wadi Garagnia, and East of Wadi Garagnia, where protection measures appear to have effectively mitigated environmental stressors. In contrast, a marked decline in plant individuals and cover was recorded in the Shaq Mousa site (Enclosure No. 13), where enclosures were less effective. This decline is attributed to ongoing threats such as climate-induced flash floods, continued human disturbance, and grazing pressure. These findings underscore the importance of site-specific factors in determining the success of conservation interventions.

The outcomes observed in Saint Catherine are consistent with findings from similar enclosure-based studies. For instance, research conducted in the *Hulunbeier sandlands* of China demonstrated that longer enclosure durations led to substantial vegetation recovery and structural shifts in plant communities. Biomass in 5-year and 10-year enclosures was significantly higher, by 134.35gm² and 312.25g/m² respectively, compared to non-enclosed sites (Park et al, 2013). Additionally, vegetation cover in the 10-year enclosure was nearly ten times greater than in the open areas and 23% greater than in the 5-year enclosure (Park et al., 2013). These results support the conclusion that long-term protection within enclosures can facilitate the regeneration of degraded habitats and the persistence of endangered plant species, including *Evotrochis involucrata* However, variability in outcomes across different sites within the SKP highlights the need for further ecological research at the population level to better understand the mechanisms driving plant recovery or decline. Adaptive management strategies that incorporate both ecological monitoring and local environmental conditions are essential for ensuring the long-term conservation of these unique endemic species (Moustafa et al, 1999).

Our findings are also compatible with another study by Guang-xiong et al. (2023), which investigated the impact of fenced enclosure on interactions between species in a Savanna grassland plant community. Fencing enclosures and disturbed areas were constructed and kept up for twenty years to facilitate research into vegetation, water, and soil conservation techniques in the arid-hot valley region surrounding the Jinsha River. The study discovered that fencing enclosures have an important effect on the interaction of dominant species in Savanna grassland from the arid-hot valley zone, influencing the plant community's species composition and functional group structure. The increased contact between dominating species appears to be biologically important (Guang-xiong et al*.,* 2023). On the other hand, the results of previous research made by Belgacem et al. (2013) were not completely in line with our research results. This may explain why enclosures did not fully protect the plant in some areas, such as Shaq Mousa, resulting in a decrease in the number of individuals of this endemic plant. They found that providing full protection against overgrazing and other human activities for an extended period did not benefit natural vegetation. Partial protection by rotation-grazing should be explored as an effective conservation method. The results on the effect of livestock grazing on plant cover and species diversity in Qatar desert rangelands demonstrated that protection had a significant positive influence on vegetation parameters. However, their findings highlighted the harmful effects of long-term protection. Short-term protection with light grazing outperformed long-term protection for plant cover, species richness, and biovolume (Shaltout & El-Ghareeb, 1985).

Desert, above-ground biomass increased by 36% while below-ground biomass decreased by 10%.

CONCLUSION

Sinai hosts numerous important endemic plant species that are threatened by various factors and require protection. The implementation of enclosures to prevent excessive grazing and vegetation cutting in the mountainous areas of South Sinai, particularly in Saint Catherine, over approximately twenty-five years has resulted in

significant improvements in vegetation density, cover, and species diversity at most monitored sites. Variations in vegetation observed during the study period may be attributed to uncontrolled factors such as meteorological variability, exacerbated by the lack of on-site climatic data. In mountainous regions characterized by diverse landforms and microhabitats, local climate fluctuations strongly influence natural vegetation patterns. Overall, enclosures play a critical role in enhancing species cover and diversity, thereby increasing vegetation resilience in arid environments. Monitoring and evaluation of these enclosures will continue in the coming years. This study underscores the importance of integrated conservation strategies for *Evotrochis involucrata*, a rare and endangered endemic species restricted to the high-altitude habitats of the St. Catherine Protectorate (SKP), South Sinai. Long-term monitoring across multiple enclosures from 1998 to 2023 revealed variable population trends driven by site-specific environmental conditions, climate variability, and human disturbances. Sites such as Kahf El-Ghola and the Garagnia region exhibited encouraging increases in population size and vegetation cover, whereas Shaq Mousa experienced declines, likely due to inadequate protection from flash floods, grazing, and anthropogenic impacts.The success of enclosures in promoting *Evotrochis involucrata* recovery aligns with international studies. To ensure the long-term survival of *Evotrochis involucrata* and other threatened endemic plants, conservation efforts must be multifaceted. These should include strengthening *in situ* protection measures (e.g., enclosure maintenance and expansion), implementing ex situ strategies such as seed banking and propagation, and incorporating genetic monitoring to preserve evolutionary potential. Engaging local communities, particularly the Bedouin population, through education, awareness campaigns, and incentives for sustainable land use is equally vital. Finally, robust institutional support, coordinated environmental policies, and sustained scientific monitoring are essential to mitigate escalating threats from climate change and human activities. Only through such an integrated framework can the unique biodiversity of St. Catherine be effectively conserved for future generations. This study reveals that the protection led to an increase in overall phytomass (as measured by total plant cover).

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REFERENCES

Abd El-Ghnai, M., Hussein, E. (2024). Exploring Ruderal vegetation dynamics and site factors in managed habitats of North East Cairo, Egypt. *Catrina: The International Journal of Environmental Sciences*, 29(1): 25-38.

Abd El-Ghani, M.M., Hosni, H., Shamso, E., Ellmouni, F. (2024). New perspectives, additions, and amendments to plant endemism in a North African flora. *Botanical Studies,* 65: 21. https://doi.org/10.1186/s40529-024-00428-w

Abdullah, M., Abdullah, M., Al-Ali, Z., Almousa, M. (2024). Plant-soil Interlinkage Indicates Functional Green Water Areas in an Arid Ecosystem. *Catrina: The International Journal of Environmental Sciences*, 31(1): 99-108.

Al Wadi, H. (1993). *Primula boveana* and Jebel Katarina. *Bulletin of the Alpine Garden Society,* 61: 68-70.

Ali, F. (2025). The inhibiting impact of extracts of medicinal plants as natural fungicide on the growth of phytopathogenic fungi. *Catrina: The International Journal of Environmental Sciences,* 34(1): 1-10.

Ayyad, M.A., Fakhry, A.M., Moustafa, A.R.A. (2000). Plant biodiversity in the Saint Catherine area of the Sinai Peninsula, Egypt. *Biodiversity and Conservation*, 9: 265–281.

Badr, A., El-Shazly, H. (2024). Climate change and biodiversity loss: Interconnected challenges and priority measures. *Catrina: The International Journal of Environmental Sciences*, 29(1): 69-78.

Belgacem, A., Al-Kaabi, N., Al-Wawi, H., Louhaichi, M. (2013). Effect of livestock grazing on plant

cover and species diversity in desert rangelands: A case study of Musawar Al Ottoria in Qatar. *Range Management and Agroforestry,* 34: 88–92.

Boulos, L. (1995). "*Flora of Egypt (Checklist)*". Al-Hadara Publishing, Cairo, Egypt, 283p.

Guang-xiong, H.E., Zheng-tao, S.H.I., Bang-guo, Y.A.N., Hao-zhou, Y.A.N.G., Sun, Y., et al. (2023). Effects of fencing enclosure on interspecific associations in a Savanna grassland community in China's arid-hot valley region[J]. *Acta Prataculturae Sinica,* 32(2): 1-14.

Chen, Y. , Wu, F., Zhang, D., Ji, Q. (2025). International tourism and global biodiversity risks. *Annals of Tourism Research,* 113: 103982.

El-Khalafy, M.M., Al-Sodany, Y.M., Ahmed, D.A., et al. (2024). Evaluation of conservation status of the Egyptian endemic plants along the Mediterranean coastal strip region. *Journal of Coastal Conservation,* 28(16). https://doi.org/10.1007/s11852-023-01007-0

Hui. D. (2013). Global climate change and biodiversity: issues and future research. *Journal of Biodiversity & Endangered Species,* 1: 1-2. DOI: 10.4172/2332-2543.1000e105.

IUCN (International Union for the Conservation of Nature) (2014). *Primula boveana*. The IUCN Red List of Threatened Species. https://www.iucnredlist.org/species/163968/1015883.

Iqbal H. (2023). Seed germination: An overview. *Journal of Plant Biochemistry & Physiology,* 11: 274. doi: https://doi.org/10.35248/2329-9029.23.11.274

Fouad, M.A., Moustafa, A., Zaghloul, M., Arnous, M. (2023). Unraveling the impact of global warming on *Phragmites australis* distribution in Egypt. *Catrina: The International Journal of Environmental Science*s, 27(1): 59-73.

Khedr, N., Ibrahim, A., EL-Metwally, M., Eldakroory, S., Soliman, M. (2025). Phytochemical screening of *Echium angustifolium* and *Anchusa aegyptiaca* extracts and their cytotoxic, antitoxic, and antimicrobial activities. *Catrina: The International Journal of Environmental Sciences*, 34(1): 75-91.

Mansour, H.M. (2010). Genetics basis for polymorphic floral morphology of Sinai Primrose (*Primula boveana*), *Ph.D. Thesis*, Botany Department, Faculty of Science, Suez Canal University, Ismailia, 171p.

Moustafa, A. (2001). "*Botanical Conservation Measures and Ecological Monitoring Program Book*". Egyptian Environmental Affairs Agency (EEAA). (SEM 04/220/016 A – Egypt).

Moustafa, A., Mansour, S. (2020a). Impact of climate change on the distribution behavior of *Alkanna orientalis* in Saint Catherine, south Sinai, Egypt. *Catrina: The International Journal of Environmental Sciences,* 22(1): 29-34.

Moustafa, A., Mansour, S. (2020b). Climate change cause extinction for *Primula boveana* from its natural habitats in South Sinai, Egypt. www.mutagens.co.in/jgb/vol.09/12/091204.pdf.

Moustafa, A., Ghowail, L. (2022). Exploring climate change mitigation: Innovative technologies and strategies for carbon dioxide removal. *Catrina: The International Journal of Environmental Sciences,* 26(1): 75-81.

Moustafa, A.A., Ramadan, A.A., Zaghloul, M.S., Mansour, M.A.H. (1999). Environmental factors affecting endemic species, species richness and species diversity in Saint Catherine Protectorate South Sinai Egypt. https://www.researchgate.net/publication/281438429

Moustafa, A.A., Ramadan, A.A., Zaghloulol, M.S., Helmy, M.A. (2001). Characteristics of two endemic and endarged species (*Primula boveana* and *Kickxia macilenta*) growing in South Montains, Egypt. Egyptian Journal of Botany, 41(1). https://www.researchgate.net/publication/281438454_Characteristics_of_two_endemic_and_endangered_species_Primula_boveana_and_Kickxia_macilenta_growing_in_south_Sinai.

Moustafa, A.A., Zaghloul, M.S., Mauricio, R., Mansour, H.M.H. (2016). Evolution and conservation of Sinai's primrose (*Primula boveana*): An endangered pre-glacial relict species growing on Sinai Mountain, Egypt. *Biogenetics Journal,* 4: 56-72.

Moustafa, A.A., Zaghloul, M.S., Mansour, S.R., Alsharkawy, D.H., Alotaibi, M. (2017). Long term monitoring of *Rosa arabica* populations as a threatened species in South Sinai, Egypt. *Journal of Biodiversity & Endangered Species*, 5: 197. doi: 10.4172/2332-2543.1000197.

Moustafa, A., Zaghloul, M., Mansour, S., Alotaibi, M. (2019). Conservation strategy for protecting *Crataegus x sinaica* against climate change and anthropologic activities in South Sinai Mountains, Egypt. *Catrina: The International Journal of Environmental Sciences,* 18(1): 1-6.

Moustafa, A., Salman, A.A., Elrayes, A.E., Bredemeire, M. (2020). Classification of Wadi system based

on floristic composition and edaphic conditions in South Sinai, Egypt. *Catrina: The International Journal of Environmental Sciences,* 20(1): 9-21.

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: The International Journal of Environmental Sciences,* 28(1): 43-51.

Moustafa, A., Elganainy, R., Abdelghnai, M., Mansour, S. (2024). Scorching records: The hottest may in history and its impact on our planet, breaking records and intensifying the climate crisis. *Catrina: The International Journal of Environmental Sciences*, 33(1): 29-42.

Müller, A., Ganzera, M., Stuppner, H. (2006). Analysis of phenolic glycosides and saponins in *Primula elatior* and *Primula veris* (*Primula* root) by liquid chromatography, evaporative light scattering detection and mass spectrometry. *Journal of Chromatography A,* 1112: 218-223.

Park, K.H., Qu, Z.Q., Wan, Q.Q., Ding, G.D., Wu, B. (2013). Effects of enclosures on vegetation recovery and succession in Hulunbeier steppe, China. *Forest Science and Technology*, 9(1): 25–32.

Pearson, L.C. (1965). Primary production in grazed and ungrazed desert communities of Eastern Idaho. *Ecology*, 46: 278–285.

Ramadan, A., Moustafa, A.R., Zaghloul, M., Helmy, M. (2009). Conservation of three endangered species at St. Catherine Protectorate, South Sinai, Egypt. *Catrina: The International Journal of Environmental Sciences,* 4(1): 53-64.

Richards, A.J. (2003). "*Primula"*. Timber Press, Portland, Oregon, USA, 346p.

Said, R. (1962). "*The Geology of Egypt*", Elsevier Sci. Pub. Co., Amsterdam, 377p.

Said, R. (1990). The geology of Egypt. Elsevier, Publ., Amsterdam. 734 pp.

Salah, H., (1995). "*Egypt Country Study on Biological Diversity*". Publication of National Biodiversity Unit, No. 3, 217p.

Sallam, A., Tagyan, A., Mahmoud, E., Hozayen, W., Alkhalifah, D., Hozzein, W. (2025). Comparison of actinobacterial rhizosphere communities in agricultural soil of Beni-Suef, Egypt, using cultural and non-cultural methods. *Catrina: The International Journal of Environmental Sciences*, 35(1): 17-28.

Serag, M., Moustafa, A., Qiqa, S. (2018). Impact of climate change on surviving of *Phlomis aurea* as an endemic species growing in Southern Sinai, Egypt. *Catrina: The International Journal of Environmental Sciences,* 17(1): 33-39.

Serag, M., Khedr, A.H., Abdulsamad, H., Nada, R. (2025). Growth performance of *Cakile maritima* Scop and *Brassica tournefortii* Gouan in relation to the regulation of some sodium-inducible genes at salt affected lands in the Nile Delta coast', *Catrina: The International Journal of Environmental Sciences*, 34(1): 53-59.

Shaltout, K.H., El-Ghareeb, R. (1985). Effect of protection on the Phyto-mass and primary production of ecosystems of the Western Mediterranean Desert of Egypt. I- Ecosystem of non-saline depressions. *Bulletin of the Faculty of Science, Alexandria University,* 25: 109–131.

Weather Atlas (2024). Climate and monthly weather forecast Saint Catherine, Egypt. https://www.weather-atlas.com/en/egypt/saint-catherine-climate.

Wikipedia: Genetic erosion (2025). https://en.wikipedia.org/wiki/Genetic_erosion.

Zaghloul M.S. (1997). Ecological studies on some endemic plant species in South Sinai, Egypt. *M. Sc. Thesis*. Department of Botany, Faculty of Science, Suez Canal University.

Zaghloul, M.S. (2008). Diversity in soil seed bank of Sinai and implications for conservation and restoration. *African Journal of Environmental Science and Technology,* 2(7): 172-184.

Zaghloul, M., Abd El-Wahab, R., Alsharkawy, I. Salman, A. (2016). Ecological prominence of *Juniperus phoenicea* L. growing in Gebel Halal, North Sinai, Egypt. *CATRINA,* 15(1): 11-23.