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Conservation of Three Endangered Species at St. Catherine Protectorate, South Sinai, Egypt

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ABSTRACT

The present paper aims to characterize some biological and ecological traits of three threatened species, namely; *Phlomis aurea*, *Pterocephalus sanctus*, and *Thymus decussatus* inhabiting the mountains of Southern Sinai, in Saint Catherine Protectorate. The study included aspects of phenology, seed germination, and restoration of species from the soil seed bank. The effect of short-term fencing on productivity and annual growth rate was tested. The results of seed germination showed the highest ratio (66%) by *Phlomis aurea* in dark incubator at constant temperature without pretreatment. Non-treated seeds of *Pterocephalus sanctus* showed a comparable ratio (64%) in room conditions. However, *Thymus decussatus* seeds showed lower ratio (up to 36%) after washing seeds by dripping water for 24 hrs. Seedlings of *Phlomis aurea* had been succesfully recruited from the soil seed bank. The mean productivity values of *P. sanctus* showed a positive response under a short-term fencing, while *Ph. aurea* and *T. decussatus* showed *a* negative response. On the other hand *Phlomis aurea* populations showed a positive trend in the annual grouth rate, under short-term fencing, however, *T. decussatus* populations remained almost steady. On the other hand, *P. sanctus* showed a growing trend in open localities more than under fenced ones. Concerning the reproductive effort, the highest value (16%) was obtained by *T. decussatus,* while the lowest value (10 %) was obtained by *Ph. aurea,* and *P. sanctus* was intermediate (13%). The study recommended for application of the soil seed bank techniques, as effective tools for restoration of target plant species and for nature conservation.

Key words: St. Catherine Protectorate, endangered species, phenology, conservation, seed germination, soil seed bank, population ecology, productivity, growth rate, reproductive effort.

INTRODUCTION

St. Catherine area has a unique location and environment; it has a rich flora including many endangered rare and endemic species. It harbors 26 species of the endemic species (42.6% of endemic species in Egypt). These endemic species are mainly found in four main mountains namely: Mountain Catherine, Mt. Serbal, Mt. Musa, and Mt. Umm Shaumer. It has been noticed that many plant species are endangered due to the severe impact of human activities (Moustafa *et al.*, 2001a). The continuous overgrazing, over-cutting and uprooting (for fuel and medicinal uses) resulted in disappearance of many pastoral plants, paucity of trees and shrubs. This misusing and depletion of natural resources caused an environmental depletion and gene loss or erosion. For these reasons and in the view of both the national and international interests for environmental conservation, the Egyptian Government had issued the decree No. 613 in 1988 which declared an area of about 40 km radius around the town of St. Catherine, and expanded it in 1994 to encompass 4330 km^2 of the mountainous area of southern Sinai granitic massif as a natural protectorate.

The conservation of plants within their natural ecosystems falls within the framework of conservation of the ecosystems themselves. Fundamental to the conservation of ecosystems is the maintenance of their definitive physical and biological conditions. One of the priorities is to carry out an analytical study on the existing conditions in the ecosystem. In short, the autecology of each taxon of interest should be sufficiently known so that one can deal with its conservation under optimal conditions (Ruiz de la Torre, 1985). The studied species were chosen as representatives of the endangered plant species in desert mountainous ecosystem in Sinai.

The present study aims at characterizing some biological and ecological traits for three endangered rare species that are essential in planning for a long-term conservation program in 'St. Catherine Protectorate'. Also it aims at restoring threatened species from the soil seed bank as considerable and a reliable recent technique of rehabilitation of vegetation ecosystems (Batanouny *et al*. 1991; Ramadan and Shabana 2002). The studied traits should be re-evaluated, for the studied species, after implementing the long-term conservation, which started already in 1998.

MATERIALS AND METHODS

Study area

The study species are restricted to an area between latitudes and longitudes 28° 25' - 28° 50' N and 33° 55' - 34° 10' E, respectively and between altitudes 1300 and 2640 m a.s.l. The mean annual precipitation is about 60 mm. In frequent years, snowy winters may happen in St. Catherine (Fig. 1). Melted snow may increase the precipitation up to 3-4 folds. More climatic details were previously measured and an ombrothermic diagram was constructed for St. Catherine (Ramadan and Gamal El-Din 1998). The mean minimum temperature, in 1983 for example in St. Catherine Province, ranged from about

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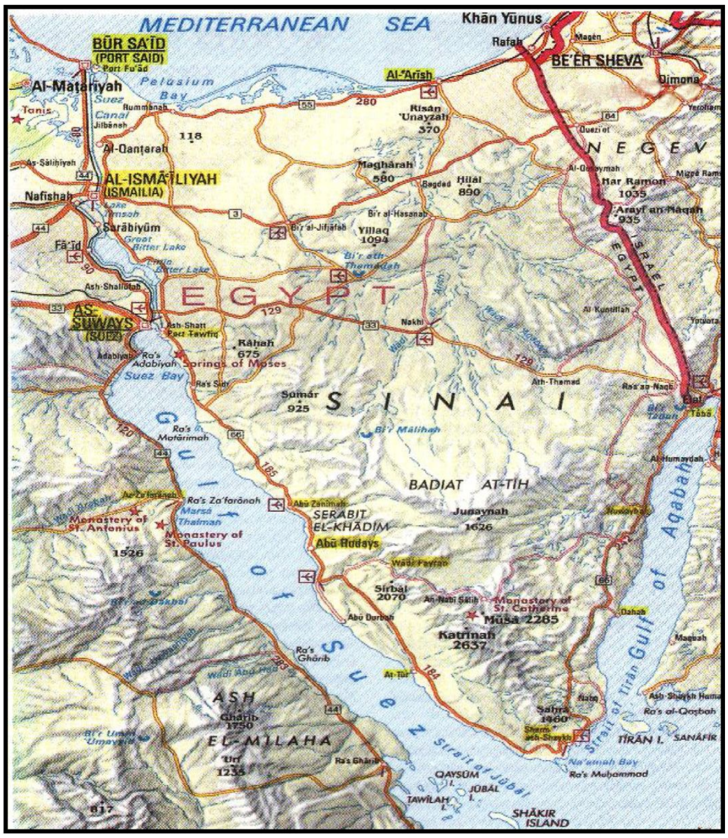

Figure (1): Location map of the study area (St. Catherine).

-2.2^{o} C in winter to 17^{o} C in summer, while the mean maximum temperature ranged from about 9.7^{o} C in winter to 32^{o} C in summer.

Study species

(1) *Phlomis aurea* Decne. (Labiatae): English name is Wick weed and Arabic names are Awarwar or Zeheira) is a suffrutescent shrub mostly found in stony crevices and ravines and is usually used by Bedouins (as boiled leaf extract) for curing of sore throat.

(2) *Pterocephalus sanctus* Decne. (Dipsacaceae): Arabic names are Essele and Megeineena. It is a suffrutescent undershrub mostly found on rocky slopes and is heavily grazed.

(3) *Thymus decussatus* Benth. (Labiatae): English name is Thyme and Arabic names are Z'atar and Za'tran. It is a clonal suffrutescent undershrub, that can perform vegetative reproduction by ramets, in addition to the sexual reproduction. It is mostly found in gravel crevices and ravines and is usually used by Bedouins (as boiled leaf extract) for curing colic.

Identification was according to T?ckholm (1974) and updated nomenclature was according to Boulos (1995; 2002). The three species belong to the Irano-Turanian flora (Zohary, 1935) and their distribution boundaries are in upper and lower Sinai massif (Danin, 1983; and Moustafa *et al.*, 2001).

Studied plots

A total of thirty two stands belonging to the three species were studied. Some populations were subjected to short-term fencing and the rest were not fenced as follows: *Phlomis aurea*: (6 fenced and 12 non-fenced stands). *Pterocephalus sanctus*: (2 fenced and 7 non-fenced stands). *Thymus decussatus*: (1 fenced and 4 non-fenced stands). Few populations were fenced from the last two species due to their extreme rarity in the study area. The size of fenced plots was variable depending on the available number of individuals of the target species.

Environmental variables

The altitude, slope degree, landform type (eg. gorge, slope, wadi and outcrop. The human interference (present/absent), grazing intensity (severe, moderate, low) were determined. The nature of the soil surface was classified into five visual categories: fine (< 2 mm), gravel (2-75 mm), cobbles (75-250 mm), stones (250-600 mm) and boulders (> 600 mm) (Hausenbiuller 1985).

Soil analysis

Soil physical analysis was performed by sieving, and pipette methods. Organic matter content is determined by the loss in weight after ignition. The pH-value was measured in 2 water: 1 soil extract solutions, using a low voltage AC-Wheatstone bridge (pH-meter) as described by Wilde *et al.* (1972). Total carbonate content was determined according to Jackson (1958) and Bascomb (1961) using calcimeter. The available phosphorus content and total nitrogen content (by Kjeldahl) were determined according to Wilde *et al.* (1972).

Phenology

Six stages of phonological aspects were recorded as percentages of marked individuals (≥ 10) and abbreviated according to Braun-Blanquet system (1964) as follows: G = Germinant, S = Seedling, V = Vegetative, B = Budding, Fl = Flowering, Fr = Fruiting, SD = Seed Dispersed, Sp = Sprouting, W = Weathered (almost dying), F = Foliage shedding, D = Dead aerial shoot, Sd = found as seeds only.

Untreated seeds were tested for germination at two constant temperatures, T1: 20 ± 2˚C and T2: 15 ± 2˚C in dark incubator. However, seed treatments included light/dark conditions and dry/wet chilling for five months (at 2-5˚C). In case of wet-chilling, seeds were spreaded over filter papers moistened with distilled water in Petri dishes and kept in a cold fridge. A set of alternations and combinations of the two factors (light and chilling) were applied. Three different levels of light intensity were adopted: light (300-880 lux), shade (60-80 lux) and dark (zero lux) using two white florescent lamps (20 watts each) which were turned on, in combination with T1: 25˚C±2, at day time (for 12 hrs.) and turned off in combination with T2: 15˚C±2, at night (for 12 hrs.). Petri dishes (containing 50 seeds, each) were randomly distributed inside the incubator. Seeds were considered germinated when the radical first emerged.

Soil seed bank

Soil samples of the seed bank experiments were collected from the upper three centimeters, as recommended by Williams et al. 1974 and Frease & Kemp 1983). A total of fifty two soil samples were collected from twenty six permanent stands (two samples, 25 x 25 cm each, per stand). Seedling emergence method was adopted (for details see Roberts 1981; Ramadan, 1988; and Batanouny *et al.* 1991). The 26 stands represented six assemblages of vegetation types in the study area (Moustafa *et al.*, 1999) in the following rates: *Kickxia macilenta* - *Varthemia montana* (two stands, four samples), *Tanacetum santolinoides* - *Artemisia herba-alba* (seven stands, fourteen sample)., *Origanum syriacum* (six stands, twelve samples), *Nepeta septemcrenata* (four stands, eight samples), Biological crust - *Primula boveana* (two stands, four samples) and *Primula boveana* (five stands, ten samples).

Both of Spearman and Pearson correlation coefficient tests were carried out between each pair of soil samples per stand.

Grazing elimination (short-term species conservation *in situ*)

Seven stands including populations of the three target species were fenced against grazing animals and human interference to assess the effect of the short-term protection on the mean values of productcivity and annual growth rate (net reproductive rate). Also comparisons were done between adjacent (and homogeneous) twins of fenced and non-fenced stands concerning the absolute values of productivity and annual growth rate of the studied species.

Productivity

This trait was estimated by dimension analysis, based on the assumption that plant volume (proportional to the dry weight) can be correlated with the standing crop biomass (Barbour *et al.*, 1987). In the beginning, few individuals, representing different size classes of each study species were harvested in order to construct and determine the slope of the regression curve, which was then used to predict plant biomass from the plant volume (at frequent intervals). At least five permanent-marked individuals, of each population, were tested for non-destructive assessment of productivity in either fenced or open stands. The simple linear regression model (1) (Barbour *et al.*, 1987) and the log-regression model (2) (Kittridge 1944, as cited in Barbour *et al.*, (1987) were applied in all the studied stands as follows:

(1) $Y = \alpha + \beta X$ (2) $\text{Log } Y = a + b \text{ Log } X$

Where Y= estimated standing crop, X= the measured parameter (plant volume), α (a) = the point at which the regression line crosses Y axis and β (b) = slope of the regression line. The simple regression model proved to be more fitter than log-model.

Reproductive effort (RE %)

This trait was estimated as mean percentage values of at least three individuals per population and five populations per species, according to the following simplified equation (Bazzaz & Ackerly, 1992): RE % = (Rr + Rv + Sr) x 100 / (Tr + Sv), Where Rr= reproductive pool, Rv= vegetative biomass attributable to reproduction, Sr= Structural losses from reproductive organs, Tr= total standing pool and Sv= structural losses from vegetative organs. The proportional allocation to different structures is used as a measure of investment in corresponding functions (Bazzaz & Reckie, 1985; and Bazzaz & Ackerly, 1992). The reproductive effort is used in referring to the investment of a resource in reproduction that result in its diversion from vegetative activity (Reckie & Bazzaz, 1987).

Annual growth rate (= net reproductive rate)

The trait of annual growth rate of each species, expressed as 'net reproductive rate' (R_o), is used to decide whether it is developmental (> 1), steady (=1) or declining (<1). It is simply the ratio between the population size in a generation (Nt + 1) to the population size in the previous generation (Nt) according to the following equation: R_o = Nt + I / N t

Statistical Evaluation

Pearson correlation coefficient test was carried out between species cover values (%) and the environmental factors to inspect species behavior towards each single environmental factor. Also the simple and backward stepwise linear regression equations were applied to find out the final equation including only the significant effective factor(s), as follows:

$$Y = \alpha + \beta X, \qquad Y = \alpha + \beta X1 + \beta X2 + \ldots \beta i\, Xi$$

Where Y= dependent variable, α= constant, β= partial regression coefficient, X= independent variable and i = the number of independent variables.

RESULTS

Species behaviour along environmental gradients

The application of Pearson correlation coefficient analysis between the cover % of each species and the environmental factors (Table 1), showed a positive correlation between *Phlomis aurea* cover %, stones (P= 0.3247) and cobbles (P= 0.5431), in the surface soil and the soil phosphorus content (P = 0.7056) according to the next equation of multiple - regression analysis (Table 2):

Ph. aurea cover% = -3.178 + 8.044 x phosphorus% + 0.214 x cobbles %.

Simple regression analysis revealed a high positive correlation between *Pterocephalus sanctus* cover % and cobbles % of the surface soil (*P* = 0.008) according to the equation (Table 2):

P. sanctus cover % = -0.049 + 0.069 x cobbles %

Simple regression analysis revealed also a positive correlation between *Thymus decussatus* cover % and gravel % of the surface soil (P= 0.022) according to the equation (Table 2):

T. decussatus cover % = -0.504 + 0.082 x gravel %

Phenological aspects

Phenology depends generally on the combination between the climatic variables and the inherited characters of each species, providing that there is no abnormal environmental stress.

Table (1): Pearson simple linear correlation coefficient (r) between three studied species, from south Sinai, Egypt and the environmental factors. (* = Significant)

Variable / Species	*Phlomis aurea*	*Pterocephallus sanctus*	*Thymus deccusatus*
Habitat features			
Landform type	0.2103	0.0831	0.2885
Exposure degree	-0.0191	-0.1457	0.1749
Slope degree	-0.3419	0.0223	-0.1734
Elevation (m a.s.l.)	0.1729	0.0415	0.125
Human interference	-0.0928	-0.0161	0.0954
Grazing intensity	-0.0378	0.0902	-0.094
Management (fenced/not)	-0.0197	0.2465	-0.132
Nature of soil surface			
Bare rock %	-0.2906	-0.1795	-0.1271
Boulders %	0.1971	0.0157	-0.1122
Stones %	0.3247*	0.2274	-0.0863
Cobbles %	0.5431*	0.4237*	-0.0316
Gravel %	0.0695	-0.1449	0.3699*
Fine fraction %	-0.1934	0.0725	-0.0855
Soil texture (sieving)			
Gravel %	0.0076	-0.0811	0.0467
Coarse sand %	-0.2512	-0.2852	0.2592
Medium sand %	0.2333	0.204	-0.0993
Fine sand %	0.1779	0.3157*	-0.2028
Silt+Clay %	0.0995	-0.0222	-0.2134
Soil texture (pipette)			
Sand %	-0.0872	0.0108	0.1107
Clay %	0.1166	-0.2007	-0.0061
Silt %	0.0513	0.0501	-0.1082
Organic matter %	-0.0555	0.1516	-0.1584
Moisture content %	-0.2549	-0.1749	-0.0263
Chemical analyses			
pH	0.0189	-0.171	-0.052
EC (2000 uS/cm)	-0.1343	-0.0776	-0.1037
Carbonate content %	-0.2077	-0.09	-0.0992
Phosphorus (ppm)	0.7056*	-0.0394	-0.0631
Nitrogen %	0.1352	0.0952	-0.113

Table (2): Regression of the plant cover (%) on some edaphic variables supporting three endangered species from Sinai, Egypt and the analysis of variance including F-ratio and their significance values

Species	Most fit equation	Analysis of variance df	Sum squares	Av squares	F-Ratio	Sig. F.
Phlomis aurea	Cover % = -3.178 + 8.044 x phosphorus + 0.214 x cobbles%	2 35	1630.119 998.618	815.060 28.532	28.567	0.000
Pterocephalus sanctus	Cover % = -0.049 + 0.069 x cobbles%	1 36	36.955 168.891	36.955 4.691	7.877	0.008
Thymus decussatus	Cover % = -0.504+ 0.082 x gravel %	1 36	263.317 1661.558	263.317 64.154	5.705	0.022

Table (3): Soil seed bank output for the endangered species *Phlomis aurea*, from south Sinai, Egypt in 26 stands (six assemblages).

Species	*Phlomis aurea*					
Parameter	Assembly					
	I	II	III	IV	V	VI
No of stands	2	7	6	4	2	5
*G.R.%/ Assembly	0	0	15	0	0	5
Total mean	3.3					
G.R.% / stand	0	0	2.5	0	0	1.0
No spp./ Assembly	19	24	30	22	11	24
Total mean	21.7					
Species richness	8.0	3.43	5.0	5.5	5.5	4.8
Total mean	5.37					
Presence % / 26 stands	11.5					

G.R. = Germination ratio (seedling / *l* soil).

(a) Phenology of Phlomis aurea

Vegetative growth starts slowly in October, maximizes in April and declines in June. Flower budding starts slowly in April, then maximizes and declines in May. Flowering starts slowly in May, maximizes and declines in June. Seed shedding starts extensively in July and declines gradually in August through November (Fig. 2). starts and increases progressively through July – August but maximizes in September, then plants keep vegetative from October through March. It is noticed that leaves sprouting in winter are larger in size, thinner and carrying stellate hairs on both sides. However, leaves sprouting in Spring are smaller in size and covered on both sides with a thick layer of stellate hairs This observation might be interpreted as a biological strategy of *Phlomis* to overcome hot and dry summer conditions.

(b) Phenology of Pterocephalus sanctus

Vegetative growth starts in October, maximizes in April and declines in June. Flower budding starts high in May, maximizes in July and declines in August. Flowering starts with maximum rate in June then declines in August. Fruiting starts with a maximum rate in June, then decreases gradually and declines in December. Seed shedding starts high in August, decreases gradually and declines in December. Dryness starts slowly in July, maximizes in September and declines in April (Figure 3).

(c) Phenology of Thymus decussatus

This species reproduces sexually and vegetatively during the same year. Vegetative growth starts slowly in September, increases in two peaks. The first peak is in November, followed by a gradual decrease till March giving new vegetative ramets, forming adventitious roots which show a geotropism. The second peak is in April giving vegetative branches developed as modules from the previous ramets. The modular structures afterwards carry the sexual organs. Fragmented ramets may give new cloning individuals. Flowering starts in May, maximizes in June and declines in July. Seed shedding starts in July, maximizes in August and declines in September. Dryness is permanently evident all the year round since *T. decussatus* branches often carry dry parts (Figure 4).

Seed germination

(a) Phlomis aurea seeds

The shape and size (8x4 mm) of *Phlomis aurea* seeds (5A). The average seed weight is about 0.00315 g and one gram includes about 317.5 seeds. Each fruit contains four seeds (nutlets). Based on naked eye-examination and the Tetrazolium viability test, two different types of seeds were recognized, the first type is large, fat and mature, while the second type is thin and immature (just as seed testa). Immature ratio amounts to about 98% of the total seed setting in some populations.

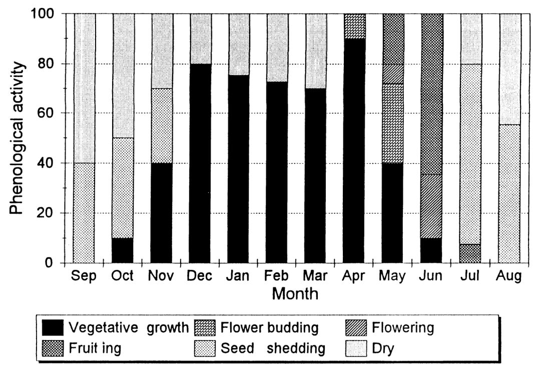

Figure (2): Phenological aspects of *Phlomis aurea.*

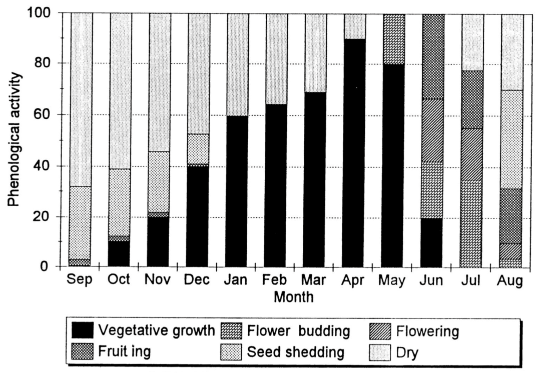

Figure (3): Phenological aspects *Pterocephalus sanctus.*

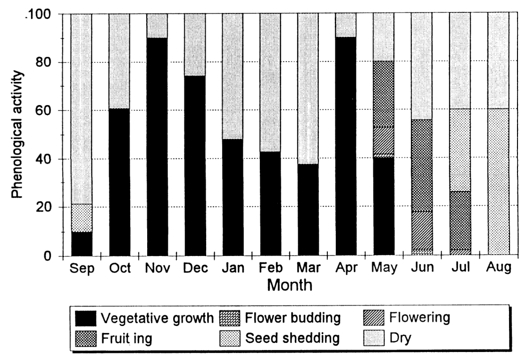

Figure (4): Phenological aspects of *Thymus decussatus.*

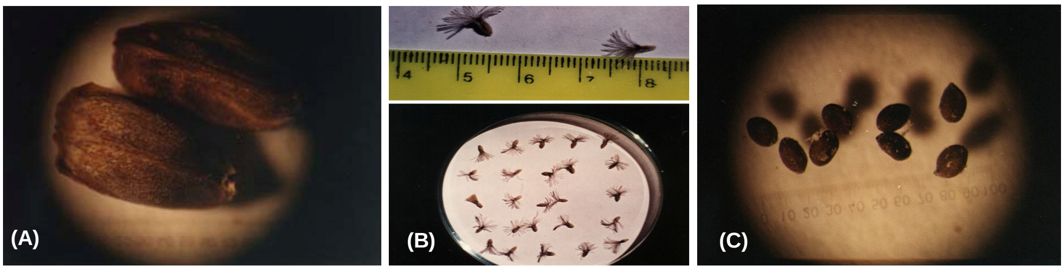

Figure (5): seeds of *(A) Phlomis aurea,* (B) *Pterocephalus sanctus,* and *(C) Thymus decussates*.

Such a behavior of inefficient seed setting (2% mature seeds) is the direct result of the inbreeding depression which is likely to be considered as one of the major factors of rarity and hence the endemic status of *Phlomis aurea.* In fact the number of mature seeds / gram would be rather low (317.5 x 2% = 6.35).

The germination behavior of *Phlomis aurea* seeds showed its highest ratio (66%) in dark incubator at a constant temperature (15˚C±2), without seed pretreatment. It was evident also that the germination ratio (32%) under light condition was relatively better than those under shade (19%) and in darkness (12%).

(b) Pterocephalus sanctus seeds

As a member of Dipsacaceae each head of *P. sanctus* includes about 9 fruits with 9 achenes, having pappus. The shape and size (8x2 mm) of *P. sanctus* seeds are shown (Fig. 5B). The average seed weight is about 0.1097 gm and one gram includes about 9.12 seeds in average. Due to the wind-borne capability of seeds and their fast shedding, as soon as they become mature, it was extremely difficult to collect mature seeds of *P. sanctus* for germination experiments. The available seeds were only tested for germination at room conditions in Petri-dishes on moistened filter paper, and they showed about 64% germination ratio.

(c) Thymus decussatus seeds

Unlike most of other members of Labiatae, each fruit of *T. decussatus* was found to set one seed only with an average weight of 0.0037 gm and one gram includes about 270.27 seeds in average. The shape and size (about 2x1.5 mm) of the seeds are shown (Fig. 5C). Seeds of this species may have innate dormancy which suppresses their germination physiologically. Washing of seeds with dripping water for 24 hours proved to be the only successful pre-treatment for seed germination of *T. decussatus* in a ratio of 36%. The other treatments showed either no or negligible germination ratio (2%).

Soil seed bank

As depicted from the results, 26 stands were studied, representing six groups (assemblies) of vegetation types in the study area. *Phlomis aurea* was the only one of the studied three species recruited from the soil seed bank (Table 4). The presence value of *Phlomis aurea* seeds was about 11.4 % of the total number of stands and the mean germination ratio was low (3.33 seedling/l soil / assembly). The highest absolute germination ratio (15 seedling/l soil) was in assembly III and the lowest absolute ratio (5 seedling/l soil) was in assembly VI. The range of mean germination ratio was narrow (1-2.5 seedling/l soil / stand). No seedlings of *Pterocephalus*

Table (4): The regression analysis output of productivity expressed as dry weight (dependent variable) against size (S) and height (H) (independent variables) for three endangered species from Sinai, Egypt.

Species	Rgression equation	Indp. Var.	Constant	Std Err of Y est	Root Square	X Coeff.	Std Err X Coeff
Phlomis aurea	Y= a + bX	S	- 12.253	159.836	0.866	0.002	0.000
		H	- 102.029	390.029	0.201	8.129	6.121
	LogY= a + b LogX	S	- 1.687	0.306	0.734	0.792	0.180
		H	- 0.363	0.530	0.202	1.534	1.115
Pterocephalus sanctus	Y= a + bX	S	- 13.454	105.732	0.652	0.002	0.000
		H	- 16.083	175.094	0.046	4.888	7.394
	LogY= a + b LogX	S	- 0.388	0.412	0.329	0.483	0.230
		H	0.533	0.491	0.047	0.922	1.388
Thymus decussatus	Y= a + bX	S	29.326	38.931	0.627	0.002	0.000
		H	- 6.879	53.504	0.295	5.255	2.170
	LogY = a + b LogX	S	- 0.522	0.357	0.542	0.549	0.135
		H	- 0.072	0.437	0.314	1.528	0.604

Table (5): Mean and absolute values of productivity in fenced and non-fenced localities and loss by grazing (g/yr) for three endangered species from Sinai, Egypt.

Species	Mean productivity (g/yr)			Absolute productivity (g/yr)			*Trend for conservation
	Fenced	Non-Fenced	Loss in grazing	Fenced	Non-Fenced	Loss in grazing	
Phlomis aurea	706.5 (N=6)	1684.5 (N=12)	- 978.0	256.9	30.0	227.0	-
Pterocephalus sanctus	403.0 (N=2)	157.7 (N=7)	246.0	943.7	235.9	707.8	+
Thymus decussatus	14.0 (N=1)	75.0 (N=4)	- 61.0	14.0	28.1	- 14.1	-

* The trend for conservation was detected based on the mean productivity values only.

sanctus or *Thymus decussatus* were recruited. This implies critical question marks about seed dissemination behavior, demography and their specific requirements for germination.

The present results showed that a total of 50 species have recruited from the soil seed bank experiment, 26 of them couldn't be identified due to their death in young stages. The total no of species per assembly ranged from 11 to 30 (mean= 21.7 species) and the species richness ranged from 3.43 to 8 (mean= 5.37).

Based on the present as well as previous seed bank studies there is a great need for wider application of the soil seed bank techniques and exploiting it for restoring endemic, endangered and may be even some extinct species.

Productivity

The effect of short-term protection (fencing) on both productivity and the loss from primary productivity (by grazing and/or collection) was the target of this part of study. Table (5) shows the models used in regression analysis of the dry weight biomass (dependent variable) of productivity, against the size (volume) and/or height of the individuals (independent variables). The most fitting model with the studied species was the simple linear equation. Comparing the mean values of productivity from fenced and open stands (Table 5) it is noticed that: the mean annual productivity (706.5 g/yr) of *Phlomis aurea* in fenced stands was unexpectedly lower than that in open stands (1684.5 g/yr). The same negative trend was encountered by *Thymus decussatus* giving mean values (14.0 and 74.9 g/yr) in both fenced and open stands, respectively. However, *Pterocephalus sanctus* showed a positive trend in the mean productivity value (403.7 g/yr) in fenced stands which is much higher than in open ones (157.7 g/yr). The absolute productivity values (Table 5) showed similar positive trends by *Pterocephalus* and *Thymus*, but showed a negative trend by *Phlomis*.

The negative mean values in loss for grazing from *Phlomis* and *Thymus* (Table 5), indicate that the short-term protection was not effective enough for both species and the application of grazing regime may stimulate their productivity. The positive mean values in loss for grazing from *Pterocephalus* indicate that short-term protection was effective (positive trend).

For *Phlomis* and *Thymus*, it is important to remark that the above results of productivity may not be highly reliable, since we think that the number of observed stands should have been increased; and the protected stands should have been firmly fenced, to insure more reliable and confirmed conclusions. However, due to the extreme rarity of the studied populations, the stand numbers were limited and the fenced stands may be subjected to disruption by Bedouins and grazing animals.

Reproductive effort

As depicted from the results, there are differences between the studied species regarding their reproductive effort. They showed mean values of (10%, 13 % and 16%) for *Ph. aurea, P. sanctus* and *T. decussatus*, respectively. There is no doubt that if long-term assessments had been carried out the values of reproductive effort would have been modified and give more reliable results.

Annual growth rate

The annual growth rate (= net reproductive rate) was estimated for the studied stands under a short-term protection and in open conditions, in order to evaluate the significance of short-term conservation. A comparison was held considering that populations with net reproductive rates, $R_o \geq 1$, as growing populations and those with rates ≤ 1, as declining, while those of rates = 1 as steady. *Phlomois aurea* showed net reproductive rates of (1.27 and 1.06) in fenced and open stands, respectively, indicating a positive response (population growth) under short-term conservation, while it is almost steady in open stands. In contrast *Pterocephalus sanctus* behaved adversely, showing rates of (1.16 and 1.05) in open and fenced stands, respectively, indicating slight growth in open habitats more than under short-term protection (almost steady). On the other hand *Thymus decussatus* showed net reproductive rates close to one (1.0 and 0.98), indicating a steady behavior under short-term protection and a slow declining rate in open stands, respectively. Such a behavior of reproduction and the criticism of seed germination of *T. decussatus*, in addition to being collected as a folk-medicinal plant, are considered among the causal factors of its extreme rarity and the threat of extinction from its unique ecosystem.

DISCUSSION

The present study is dealing with quantifying the relationships between three endangered and rare species, namely *Phlomis aurea, Pterocephalus sanctus* and *Thymus decussatus*, living in restricted localities at southern Sinai mountainous area. These species are supposed to be protected as components of the natural vegetation in the famous "Saint Catherine Protectorate". Concerning *Phlomis aurea*, it was previously described as a dominant species of a community type in the study area (Ramadan, 1988; Ramadan, 1995; Ramadan and Gamal El-Din, 1998). The regression analysis revealed that correlations exist between some soil physical and chemical variables and the cover percentage of the studied species are as follows: A positive correlation between *Phlomis aurea* cover and stones and cobbles % in the surface soil and the soil phosphorus content, Similarly, a positive correlation is found between *P sanctus* and cobbles as well as fine sand percentage. A high positive correlation exists between *Pterocephalus sanctus* cover and cobbles % of the surface soil and also a positive correlation exists between *Thymus decussatus* cover and gravel % of the surface soil.

The phonological aspects of the studied species were recorded for one year in order to be referred to in future following up. All phases of the life cycles are recorded for the three species. The flowering dates of Sinai and Palestine's floras were given in (Zohary, 1966; 1972; and Feinbrun-Dothan, 1978; 1986).

Seed germination

Although it is known that chilling treatment (cold stratification) has been found to enhance germination of seeds of many species at the temperate regions (Thompson, 1971), it is not a suitable treatment for every species. Seed chilling absolutely suppressed germination of *Ph. aurea* seeds (up to 2 %). This indicates that under natural chilling conditions, during deep cold and snowy winters, we might not see new seedlings of *Ph. aurea* in south Sinai, otherwise, they may be seen after moderate winter and precipitation (Ayyad, 1973; Ayyad & El-Ghonemy, 1996; and El-Keblawy *et al.*, 1997).

Dormant seeds of *T. decussatus* proved that they require intensive and excessive washing by running water (dripping) in order to remove what is known as 'furanocoumarins (psoralens)' which are physiological inhibitors for embryonic germination (Zobel & Brown, 1991; and Zobel *et al.*, 1991). The role of the seed coat in germination behavior needs also to be assessed, since it may play a significant role in determining the timing of germination (Ferasol *et al.*, 1995); it may act as a permeability barrier to water, oxygen, and carbon dioxide (Toole *et al.*, 1956).

Such a behavior in germination of *T. decussatus* seeds may explain the extreme rarity or absence of *T. decussatus*, even as seedlings in its habitats and why it is declining and threatened by extinction. Historically, It was known that since long time *T. decussatus* has been subjected to extensive collection as a medicinal herb (Bailey and Danin, 1981).

In conclusion, it might be argued that seed germination is not related to the population size (Kery *et al.*, 2000). Meanwhile, we emphasize that the studied species are not only very rare and endangered, but also their populations are restricted in small patches which may be less attractive to pollinators (Sih & Baltus, 1987). It was suggested that insufficient pollen quantity or quality may be the cause of reduced fecundity in small populations of several species (Menges, 1991; Petanidou *et al.*, 1991; Lamont *et al.*, 1993; Aizen & Feinsinger, 1994; and Fischer & Matthius, 1997). However, an opposite conclusion suggests that pollen limitation is not likely to be an important factor regulating seed production of plants e.g. *Vallisneria americana*: (Lokker, Lovett-Doust and Lovett-Doust 1997). The same finding is assured by Lovett-Doust and LaPorte (1991), who observed high seed production and viability, despite frequent pollen infertility in *V. americana.*

Although the long-term, loss of genetic variability may decrease the potential of a population to persist in the face of environmental change (Huenneke, 1991), Similar studies have shown either that it is triggered by small population size or that it leads to reduced plant fitness (Oostermeijer *et al.*, 1994; and Fischer & Matthies, 1998a, b).

Soil seed bank

The present results showed that a total of 50 species have recruited from the soil seed bank experiment, 26 of them couldn't be identified due to their death in young stages. Based on the present as well as previous seed bank studies there is a great need for wider application of the soil seed bank techniques and exploiting them for restoring endemic, endangered and extinct species as we have recommended before (Ramadan & Shabana, 2002; and Ramadan *et al.*, 2002). Several studies in different countries (e.g. Hayashi *et al.*, 1978; Ryser & Gigon, 1985; Willems, 1983; Ramadan, 1988; and Leck *et al.*, 1989) proved that there is no similarity (or there is a very low) similarity between the output of the soil seed banks and the components of the above ground vegetation. The stages between seed production and the subsequent seed germination are generally very dynamic, with dispersal, mortality, and predation as likely regulating factors (Lokker *et al.*, 1997).

Based on the present as well as previous seed bank studies there is a great need for wider application of the soil seed bank techniques and exploiting them for restoring endemic, endangered and extinct species as we have recommended before (Ramadan & Shabana, 2002; and Ramadan *et al.*, 2002).

Productivity

Comparing the mean values of productivity from fenced and open stands it is noticed that: the mean annual productivity of *Phlomis aurea* in fenced stands was unexpectedly lower than that in open stands. The same negative trend was encountered by *Thymus decussates*. However, *Pterocephalus sanctus* showed a positive trend in fenced stands which is much higher than in open ones. Negative trends were followed by some species (*Cyperus conglomerates* and *Hammada elegans*) as shown towards conservation in UAE (El-Keblawy, unpublished).

The negative mean values in loss for grazing from *Phlomis* and *Thymus* (Table 5), indicate that the short-term protection was not effective enough for both species and the application of grazing regime may stimulate their productivity. A similar negative trend was also shown by the endemic species *Origanum syriacum* subsp *sinaiticum* (Ramadan *et al.*, 2002) and *Primula. boveana* (Moustafa *et al.*, 2001). The loss for grazing from *Pterocephalus* indicate that short-term protection was effective (positive trend). The same trend was shown also by the endangered species *Nepeta septemcrenata* (Ramadan *et al.*, 2002) and *Kickxia macelenta* (Moustafa *et al.*, 2001).

For *Phlomis* and *Thymus*, it is important to remark that the above results of productivity may not be highly reliable, since we think that the number of observed stands should have been increased; and the protected stands should have been firmly fenced, to insure more reliable and confirmed conclusions. However, due to the extreme rarity of the studied populations, the stand numbers were limited and the fenced stands may be subjected to disruption by Bedouins and grazing animals.

Reproductive effort

As depicted from the results, there are differences between the studied species regarding their reproductive effort, showing mean values of (10%, 13 % and 16%) for *Ph. aurea, P. sanctus* and *T. decussatus,* respectively. Monitoring the reproduction in populations of rare species may provide important indicators of future population trends (Kery *et al.,* 2000). There is a possibility that reproductive effort, as a natural function, show "opportunistic reproduction", as in case of *Thymelaea hirsuta* (Ramadan *et al.*, 1994) and in many other species. This means that a hardly-reproducing species, in one year/season, may compensate the shortage in its reproduction during preceding years. Nevertheless, the timing of such "opportunistic reproduction"it seems difficult to forecast or to predict its output. The effect of favorable habitat was argued to increase the reproductive effort of different sex forms of *T. hirsuta* by approximately three - eleven folds than in less favorable habitats (Ramadan *et al.*, 1994). There is no doubt that if long-term assessments have been carried out the above values would have been modified and would give more reliable results.

Annual growth rate

A comparison was held considering that populations with net reproductive rates, $R_o \geq 1$, as growing populations and those with rates ≤ 1, as declining, while those of rates = 1 as steady (Ramadan *et al.*, 2002; and El-Keblawy *et al.*, 1997). A little fluctuation in R_o between years as well as among species is characteristic of the long-lived species (Nault & Gagnon, 1993; and Svensson *et al.*, 1993). As quoted by Kery *et al.* (2000), the negative consequences of small population size and isolation may not become obvious for a long time, because the mortality of established perennial plants is often very low (Summerfield, 1972; Tamm, 1972; and Harper, 1983), even though reproduction may be affected much sooner than survival (Lamont *et al.*, 1993; and Oostermeijer *et al.*, 1994).

Phlomois aurea showed net reproductive rates of (1.27 and 1.06) in fenced and open stands, respectively, indicating a positive response (population growth) under short-term conservation, while it is almost steady in open stands. In contrast *Pterocephalus sanctus* behaved adversely, showing rates indicating slight growth in open habitats more than under short-term protection (almost steady). On the other hand *Thymus decussatus* showed net reproductive rates close to one indicating a steady behavior under short-term protection and a slow declining rate in open stands, respectively. This was also the case with the endemic *Primula boveana* (Moustafa *et al.*, 2001). Such a behavior of reproduction and the criticism of seed germination of *T. decussatus,* in addition to being collected as a folk-medicinal plant, are considered among the causal factors of its extreme rarity and the threat of extinction from its unique ecosystem.

Generally speaking, species having population growth rates close to one, tend to be ‘interoparous’ perennial herbs or trees, mainly inhabiting stable environments, while species with variable rates of population growth are ‘semelparous’ short-lived herbs or shrubs growing mainly in disturbed and/or unstable environments (El-Keblawy *et al.,* 1997). To a great extent, that is the case of most of the studied species, which grow in disturbed habitats and may be considered in critical cases, on the border of being either threatened by declination / extinction or being hardly growing.

In spite of the above results, it might be expected that the reproduction of steady and declining species, for several successive years, may be occasionally compensated during unpredictable favorable years, which might result in sharp and sudden increase in the growth rates of their populations (Crawley, 1990; Gutterman, 1994; and Ramadan *et al.*, 1994). The fundamental role of microhabitat conditions should also be considered and critically evaluated. Gradient in microhabitat, from favorable to non-favorable conditions, was suggested to be associated with pattern of lower seedling emergence, survival and a lower population growth rate and greater mortality (El-Keblawy *et al.*, 1997). Some opinions suggest that the apparent decline in species growth rate may be referring to that invesgators who may examined too small areas or monitoring too few quadrates, also some favorable quadrates may be dismissed (El-Keblawy *et al.*, 1997). On the other hand, underestimation of germinating seeds in quadrates lacking adult individuals may also happen by some investigators (Telenius, 1993).

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