Chapter 9

GIS and *ex situ* Plant Conservation

Nikos Krigas, Kimon Papadimitriou and Antonios D. Mazaris

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/50525

1. Introduction

In the frame of the global efforts to halt the biodiversity loss by 2010 and with the aim to develop effective conservation strategies extending beyond 2010, stakeholders have recognized as a priority the *in situ* conservation (on site conservation) of target plant species.

Still, the rapid environmental changes including climate change, habitat loss and alteration, could pose some limitations on our ability to conserve target species effectively *in situ* (Sharrock & Jones, 2009). As a result, conservation biologists, policy makers and managers acknowledge the importance of *ex situ* conservation of target plants in botanic gardens and seed banks as an essential back-up solution (Convention on Biological Diversity [CBD], 1992; Glawka et al 1994; Global Strategy for Plant Conservation [GSPC], 2002; European Strategy for Plant Conservation [ESPC], 2009; Sharrock & Jones, 2009).

For the *ex situ* plant conservation, target species mainly refer to plant taxa (species and subspecies) presenting a narrow distribution in the wild (see Krigas & Maloupa, 2008). This category of plants usually includes:

i. Local endemics (endemics of a single mountaintop e.g. *Viola cephalonica* (Katsouni et al., 2009), or endemics of a single island e.g. *Allium samothracicum* (Krigas, 2009), or endemics of a group of nearby areas or islands e.g. *Thymus holosericeus* (Krigas et al. 2010),
ii. Regional endemics (endemics to small parts of a single country, e.g. endemics of southern Spain, endemics of Peloponnese, southern Greece),
iii. National endemics or single-country endemics (e.g. Greek endemics, Italian endemics, Spanish endemics),
iv. Endemics to specified small geographical areas e.g. local Balkan endemics transcending the borders of neighbouring Balkan countries such as *Ranunculus cacuminis* (Krigas & Karamplianis, 2009).

Other target species significant for the *ex situ* plant conservation may include plants which are rare in a certain area (e.g. Europe, Sharrock & Jones, 2009) or plants that are currently threatened with extinction at local, regional or global level i.e. taxa characterized as "Near Threatened", "Vulnerable", "Endangered" or "Critically Endangered" according to the IUCN (2001) criteria. However, given that almost 90% of the Europe's threatened plants are single-country endemics, it should be noted that most of the endemic plants are also threatened with extinction (Sharrock & Jones, 2009). Last but not least, other groups of socioeconomically valuable plants (e.g. saffron) and their progenitors (e.g. plants in the genus *Crocus*) may also be considered as target plants for the *ex situ* conservation (Fernández et al., 2011).

GIS has be given a role in analyzing potential and current spatial distribution of target species, locating and assessing the populations of target plant species and assemblages, measuring biodiversity, monitoring biodiversity patterns and identifying priorities for conservation and management (Iverson & Prasad, 1998; Salem, 2003; Powel et al., 2005; Pedersen et al., 2004).

Habitat evaluation or habitat modeling with the use of GIS has the potential to make a substantial contribution to conservation management of target species within an integrated approach and is suitable for setting conservation priorities at multiple spatial scales (Store & Jokimäki, 2003; Powel et al., 2005). GIS have also been used as a tool for specific conservation programmes including comparisons of ecological patterns between local and regional scales, selection of protected areas according to habitat suitability, analysis of the impact of alien species on endemic plants and selection of sites for representative seed collections of target species (Draper et al., 2003). Flexible GIS-based tools have also been developed to exploit static information of botanical collections in an attempt to evaluate species distributional ranges (Schulman et al., 2007; Loiselle et al., 2008), accounting for potential effect of climate change to predicted models (Loiselle et al., 2008). Other GIS-tools and distribution modeling methods have been applied to examine the hypothesis that wild and cultivated plants of certain species may occur in the same types of habitats (Allison et al., 2006).

Currently, the GIS technology has increasingly been used for predictive purposes in species re-introductions. Combining historical information from specimen labels with up-to-date environmental data, GIS can be used to identify the range of environmental conditions in which plants grow, offering an understanding of the ecological requirements of different species. The relevant environmental conditions can then be used to delimit areas of high, moderate or low survival probability (Sawkins, 1999 as cited in Moat & Smith, 2003; Powel et al., 2005). Recent GIS applications further include studies on the assessment of the importance of landscape connectivity, structure and configuration for native and non-native plant communities, dispersal and invasiveness abilities (Minor et al., 2009). Nevertheless, the most frequently encountered obstacle to the use of GIS technology in conservation planning is lack of data, especially distribution data of target species and digital vegetation maps of areas with conservation interest (Sawkins, 1999 as cited in Moat & Smith, 2003).

The GIS technology has also an enormous potential in seed conservation, particularly in targeting collecting needs for botanic gardens and conservation institutes and in identifying what, where and when to collect (Moat & Smith, 2003). Although concerns are raised regarding limitations and biases (Store & Kangas, 2001), some of the GIS applications have been used for their power to pinpoint by spatial niche modeling, new probable locations where rare endemic species may be found in the wild, thus permitting the search for new populations (Jarvis et al., 2005). The GIS could also be used for assessing the sensitivity of target species to climate change identifying potential distributions as well as vulnerable habitats and species (Vanderpoorten et al., 2006). In this way GIS may deliver important information that can drive seed banking priorities and design (Godefroid & Vanderborght, 2010).

Lately, a new application of GIS has been launched for the *ex situ* plant conservation; GIS was used to describe quantitatively and qualitatively the natural habitats of target plants in order to facilitate their propagation and transfer from the wild habitats to man-made habitats like botanic gardens (Krigas et al., 2010).

2. GIS used for the description of the natural habitats of target species

The geographical data associated with plant collections may be considered as a set of facts about the places in which the plants thrive. In the wild, target plants for *ex situ* conservation could thrive literally anywhere. Given the spatial and temporal heterogeneity of the environmental factors and the dissected topography of the landscape, the target plants may well originate in a variety of quite different habitats in which they are adapted to grow naturally. Hence, it seems quite difficult to be able to emulate their preferable conditions when trying to cultivate them in restricted man-made habitats such as botanic gardens (Krigas et al., 2010). A deeper understanding of the ecology and life cycle of such target species has been considered as a key issue towards a species-specific successful propagation and cultivation method (Baskin & Baskin, 1988).

In this framework, the GIS can be used to offer a reliable, quantitative and qualitative description of the *in situ* habitat conditions preferred and/or tolerated by different target plant species in the wild. This novel GIS application is both ecologically meaningful and useful in horticulture and *ex situ* plant conservation (Schulman & Lehvävirta, 2010).

To demonstrate this application a dataset was chosen including target plants originating from sites of varied landscapes that are also subjected to different climatic conditions (Fig. 1): the Aegean Archipelago, Crete, Ionian Islands, and Peloponnese (Greece, Southern Europe). The target plants included in this dataset fall into the conservation priorities of the Balkan Botanic Garden of Kroussia (BBGK, Krigas & Maloupa, 2008, Krigas et al., 2010). To date, the BBGK has organized several botanic expeditions all over Greece in order to collect appropriate plant material for propagation and *ex situ* conservation. All this plant material is currently maintained under *ex situ* conservation (ca. 25% of the known Greek flora which includes at least 6.300 species and subspecies, Krigas et al., 2010).

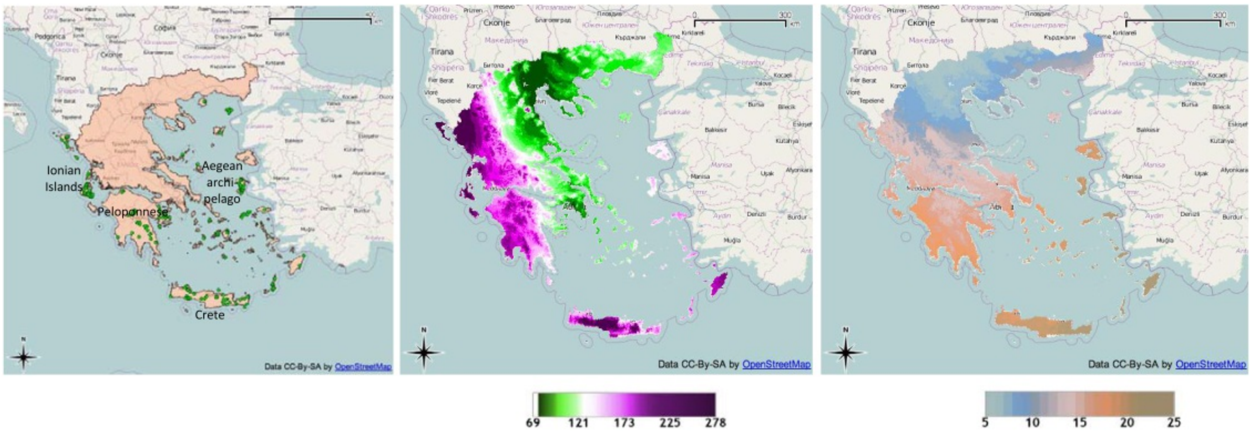


Figure 1. Different target plants (n=256, each dot represents at least one botanic expedition and at least one target plant collected) from various sites originating from the selected area of Greece including the Aegean Archipelago, the Ionian Islands, Crete and Peloponnese (left). All plant material is currently maintained under *ex situ* cultivation at the Balkan Botanic Garden of Kroussia (BBGK). Raster maps displaying the variations of climatic conditions in Greece as expressed by the Emberger Pluviothermic Quotient (middle) and Precipitation Seasonality (right). All values have resulted from map algebra calculations after point sampling for the Greek territory regarding the collection sites of the selected target plants (n=256).

The positions of the collection sites of target plant species were captured in the wild using handheld GPS trackers. The obtained geographic coordinates were consequently imported as point layer into a Geographical Information System (GIS) and point sampling was performed for each one on multiple raster and polygon layers. In order to probe values for topography, terrain, soil, climatic, land cover and habitat attributes at the captured sites, the following datasets were selected (Fig. 2):

a. Raster elevation data from SRTM (USGS 2004), with resolution of 1 km^2 (30 arc second) which were used for terrain and topography attributes.
b. Soil data from the European Soil Database (ESDB) v2.0 (EC, 2004), which is composed of the Soil Geographical Database of Eurasia at a scale of 1: 1,000,000 (version 4 beta) and the Pedotransfer Rules Database (v2.0), with a raster resolution of 1 km^2, presenting 72 soil parameters.
c. Temperature and precipitation data from the WorldClim database (Guarino et al., 2002; Hijmans et al., 2005), with a raster resolution of 1km^2, which has been used for the description of climatic conditions (average values of 50 years).
d. Land cover data from CORINE (Coordination of Information on the Environment) comprehensive hierarchical vector geodatabase at a scale of 1: 100,000 (with a minimum mapping unit of 25ha) which present the spatial distribution of different landcover/land-use types (CORINE land cover classification, EC & ETC/LC, 1999) and soil types (CORINE soil classification EC, 1985).

Additionally, part of the initial data was processed to produce more specific attributes for the collection sites of the target plants, as follows:

a. The elevation data (DEM) was used for raster based terrain analysis, which resulted in slope and aspect maps of the Greek territory.

b. The DEM was further used as the base layer for the digitization of the vegetation zones of Greece according to Mavromatis (1980).

c. The rasters describing the spatial variations of precipitation, maximum and minimum temperatures from the WorldClim geodatabase (Guarino et al., 2002), were used in map algebra calculations for the production of a raster map which displays the spatial variation of the Emberger Pluviothermic (Ombrothermic) Quotient as: 2000*P/(Tmax+Tmin)*(Tmax-Tmin), where P: the layer of annual precipitation (mm), T: the layers of mean maximum (Tmax) and minimum (Tmin) monthly temperature of the warmest and coldest month in Kelvin degrees. Precipitation (P) Seasonality was calculated also, using the following map algebra expression: 100* (Pw -Pd) / Py, where Pw and Pd are the raster layers for the spatial variations of precipitation for the wettest and driest quarter of the year respectively, and Py the total annual precipitation (Fig. 1).

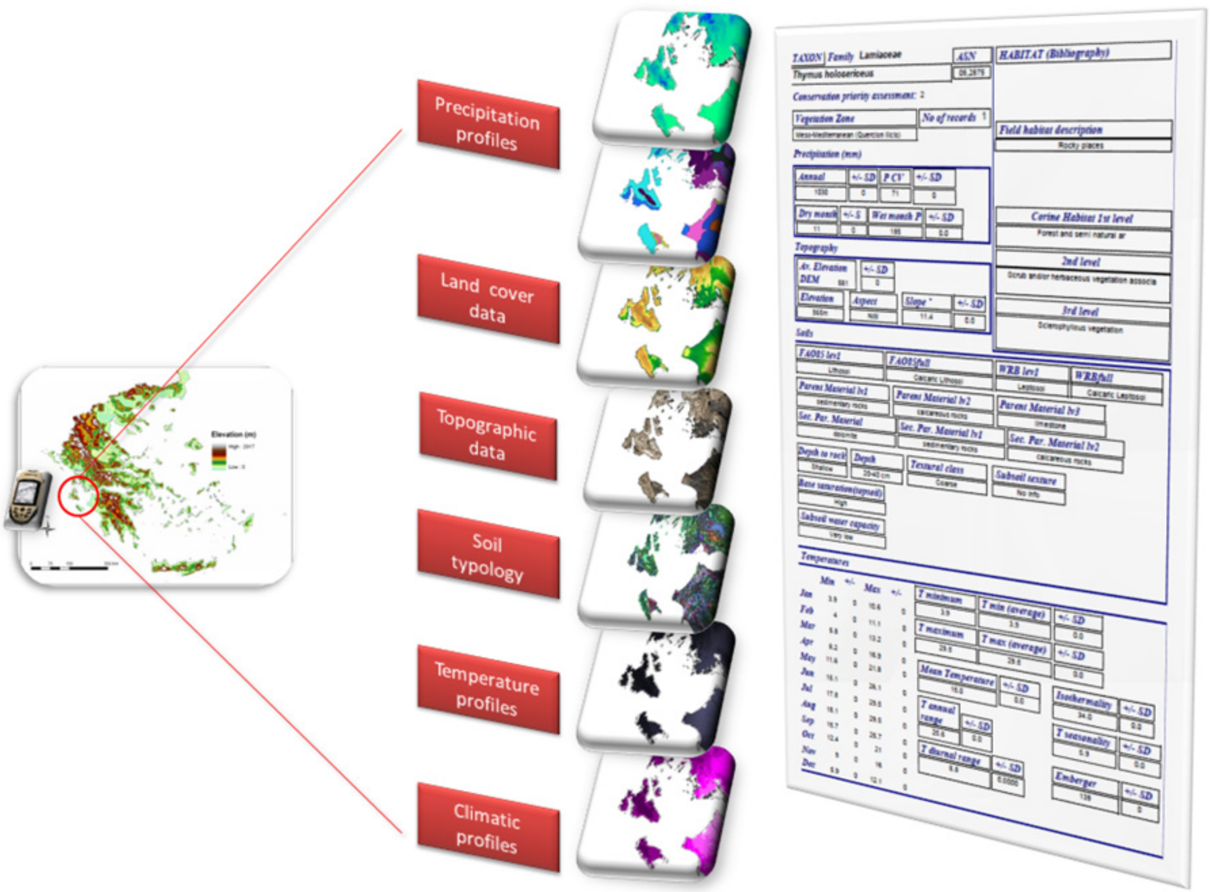


Figure 2. Methodology concept: The GPS data can be used for point sampling in a GIS environment regarding the collection sites of a target species over multiple polygon and raster layers extracted from selected geo-databases. This approach leads to the attribution of selected values regarding precipitation, land cover, terrain, topography, soil typology, temperature and climate to the wild habitats of a target species, resulting in a summarized fact sheet which reflects the ecological preferences of a target species (e.g. *Thymus holosericeus* originating from the Ionian Islands, SW Greece).

Based on this GIS application, simple or advanced ecological fact sheets may be constructed for different target species which actually reveal their preferences in the wild (Fig. 2, 3, 4). An ecological fact sheet illustrates the ecological profile of a wild growing target plant and can be designed in a way to include different kind of information such as: **Vegetation zone** (different types), **Climatic data** which is a combination of **Precipitation and Temperatures** (for the different sites: total annual and annual range of precipitation, driest and wettest month, minimum, mean and maximum temperatures, annual and diurnal temperature range, isothermality and seasonality, Emberger pluviothermic quotient), **Topographic** (for the different sites: elevation, aspect, slope), **Habitat** (bibliographic, field notes), **Land Cover Types** (for the different sites: CORINE classification in three levels) and **Geological-Pedological data** (for the different sites: Food and Agriculture Organization's [FAO] soil classification, World Reference Base Soil classification, dominant parent material in three levels, depth to rock, textural class, topsoil base saturation, subsoil water capacity) (see Fig. 2, 3, 4).

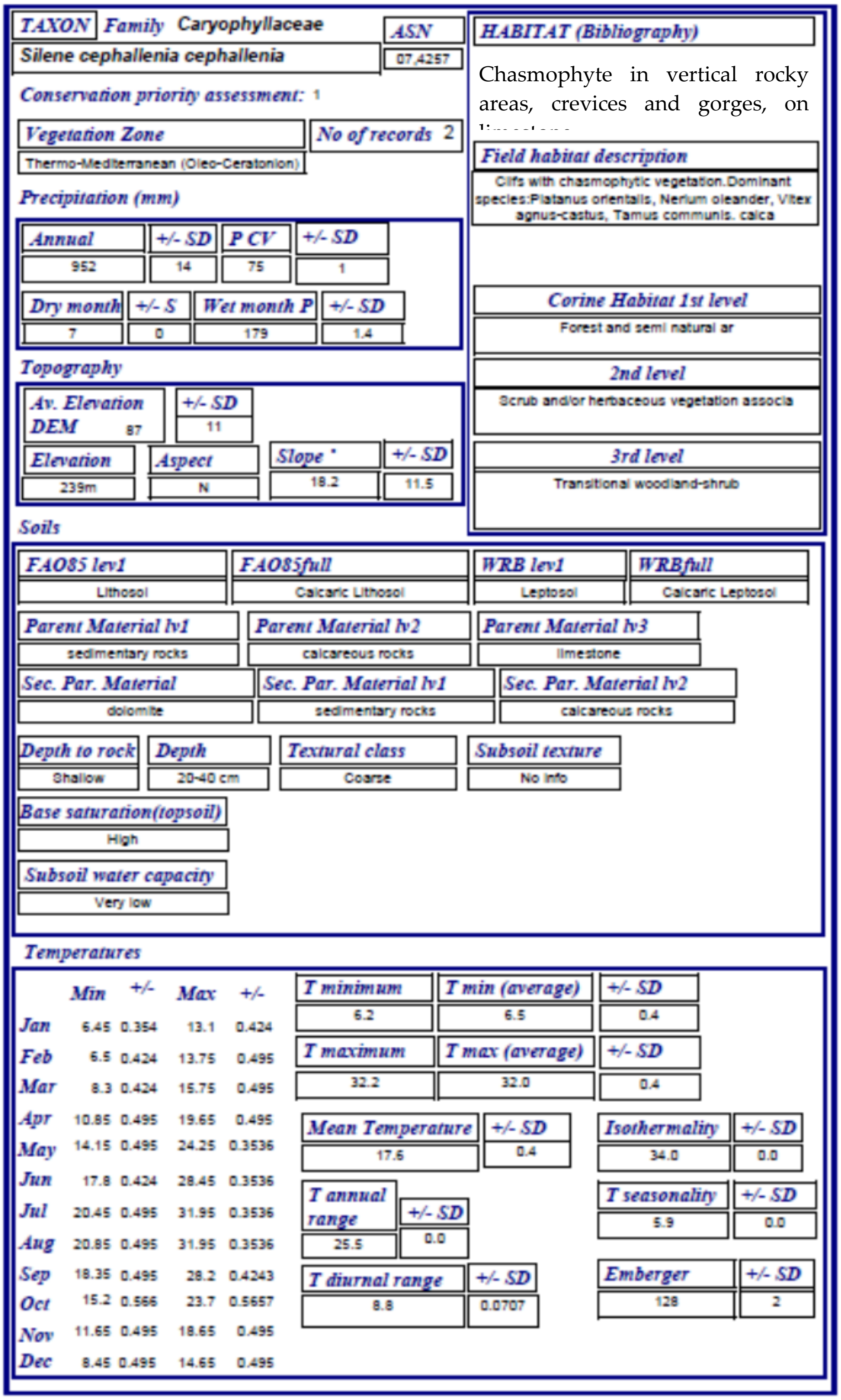
Additionally, other information may also be associated with the ecological description of the wild habitat of target species such as **Taxonomic data** i.e. taxon's name, family, accession number (ASN) given, **Collection data** (e.g. geographical coordinates, description of state, province, exact locality etc), **Conservation assessment** (e.g. ranking according to priorities assigned), and **Mother Plantations** (number of total plant accessions or number of records). It should be mentioned that when the number of records introduced in GIS for a specific information field are >1, then any quantitative information may be described by the mean value and its standard deviation (± SD) (see Fig. 2 and 3).

3. GIS-facilitated development of protocols for *ex situ* conservation of target species

Considering the recent challenges in regional conservation planning, it becomes apparent that there is an urgent need for increased applied research in order to develop propagation and cultivation protocols for target plants threatened with extinction, towards species recovery and populations' reinforcements (Bunn et al. 2011, Maunder et al. 2001 Sarasan et al. 2006). Moreover, the GSPC (2002) and the ESPC (2009) have included this urgent need under their conservation targets at European and global level (Target 8). The GIS may serve such a need and may help at the development of species-specific propagation protocols and *ex situ* cultivation guidelines regarding target species. Such methodologies could also provide basic information and criteria for prioritizing collections of threaten or rare species based on their distributional patterns, population status and the genetic and/or geographic representation of current seed bank collections (Draper et al., 2003; Farnsworth et al., 2006) or even prioritizing sites for seed collections (Jarvis et al., 2005; Ramírez-Villegas et al., 2010).

3.1. GIS and seed germination

The GIS may be used to facilitate the germination of seeds collected from the wild in plant propagation studies as shown by Krigas et al. (2010). This study included plants originating at the Ionian Islands, south-western Greece and provided some example-cases.



TAXON Family: Caryophyllaceae

Silene cephallenia cephallenia

ASN: 07,4257

Conservation priority assessment: 1

Vegetation Zone	No of records
Thermo-Mediterranean (Oleo-Ceratonion)	2

Precipitation (mm)

Annual	+/- SD	P CV	+/- SD
952	14	75	1

Dry month	+/- S	Wet month P	+/- SD
7	0	179	1.4

Topography

Av. Elevation DEM	+/- SD
87	11

Elevation	Aspect	Slope °	+/- SD
239m	N	18.2	11.5

HABITAT (Bibliography)

Chasmophyte in vertical rocky areas, crevices and gorges, on

Field habitat description

Cliffs with chasmophytic vegetation.Dominant species:Platanus orientalis, Nerium oleander, Vitex agnus-castus, Tamus communis. calca

Corine Habitat 1st level: Forest and semi natural ar

2nd level: Scrub and/or herbaceous vegetation associa

3rd level: Transitional woodland-shrub

Soils

FAO85 lev1	FAO85full	WRB lev1	WRBfull
Lithosol	Calcaric Lithosol	Leptosol	Calcaric Leptosol

Parent Material lv1	Parent Material lv2	Parent Material lv3
sedimentary rocks	calcareous rocks	limestone

Sec. Par. Material	Sec. Par. Material lv1	Sec. Par. Material lv2
dolomite	sedimentary rocks	calcareous rocks

Depth to rock	Depth	Textural class	Subsoil texture
Shallow	20-40 cm	Coarse	No info

Base saturation(topsoil)	Subsoil water capacity
High	Very low

Temperatures

	Min	+/-	Max	+/-
Jan	6.45	0.354	13.1	0.424
Feb	6.5	0.424	13.75	0.495
Mar	8.3	0.424	15.75	0.495
Apr	10.85	0.495	19.65	0.495
May	14.15	0.495	24.25	0.3536
Jun	17.8	0.424	28.45	0.3536
Jul	20.45	0.495	31.95	0.3536
Aug	20.85	0.495	31.95	0.3536
Sep	18.35	0.495	28.2	0.4243
Oct	15.2	0.566	23.7	0.5657
Nov	11.65	0.495	18.65	0.495
Dec	8.45	0.495	14.65	0.495

T minimum	T min (average)	+/- SD
6.2	6.5	0.4

T maximum	T max (average)	+/- SD
32.2	32.0	0.4

Mean Temperature	+/- SD	Isothermality	+/- SD
17.6	0.4	34.0	0.0

T annual range	+/- SD	T seasonality	+/- SD
25.5	0.0	5.9	0.0

T diurnal range	+/- SD	Emberger	+/- SD
8.8	0.0707	128	2

Figure 3. Simple ecological fact sheet for a single-area endemic (*Silene cephallenia* subsp. *cephallenia)* produced after linking its collection data with those of geodatabases. *S. cephallenia* subsp. *cephallenia* is found exclusively at Poros gorge in Cephalonia (Ionian Islands, SW Greece), is protected by the Greek Presidential Decree 67/1981 and recently it has been included in the Red Data Book of Rare and Threatened Plants of Greece as ''Critically Endangered'' (Karagianni et al., 2009) and in Annex 2 of the European Threatened Species (Sharrock & Jones, 2009).

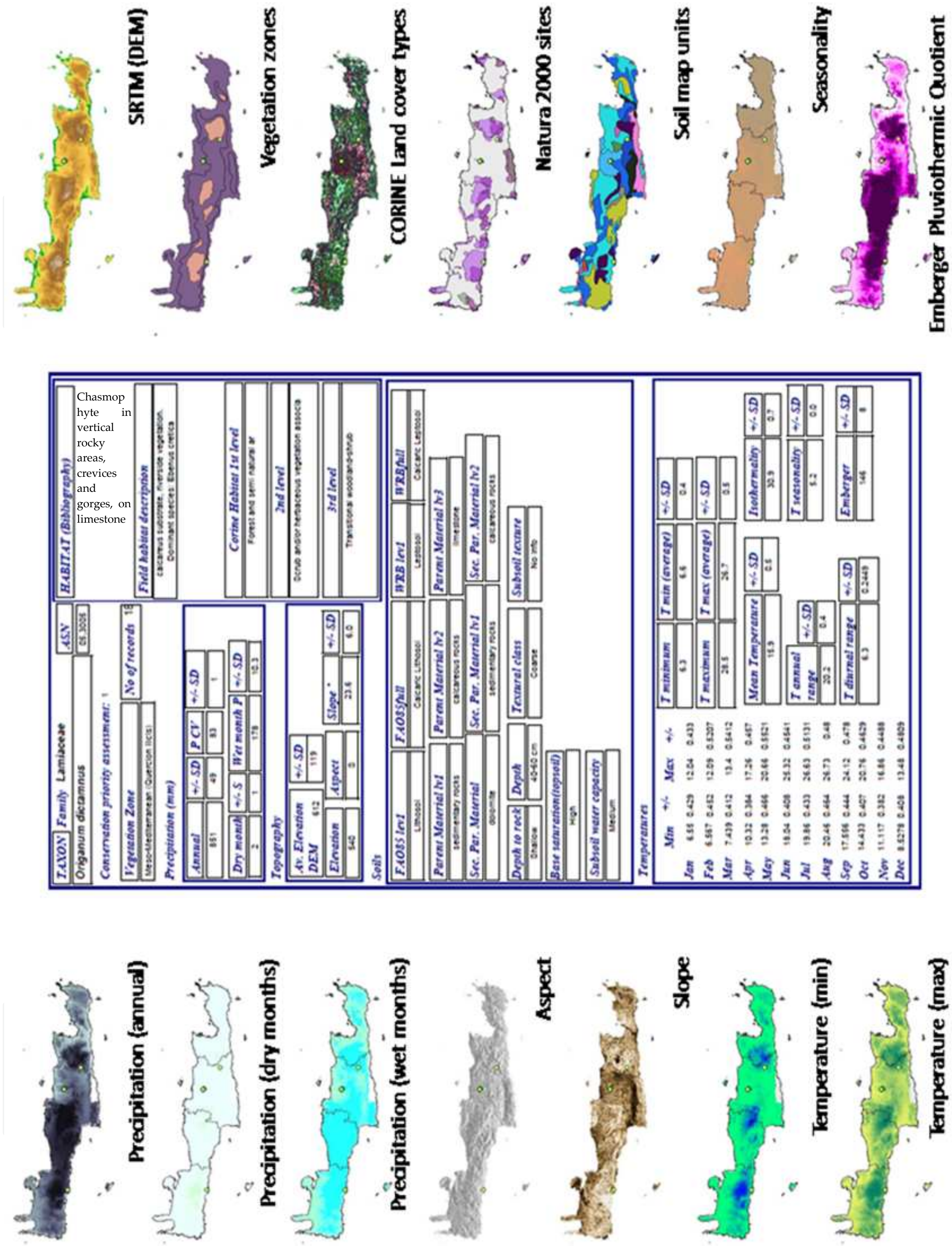


Figure 4. Advanced ecological fact sheet of *Origanum dictamnus* produced after linking data for 18 collection sites with those of geodatabases, enriched with thematic maps displaying the spatial variations of multiple ecological attributes over the area of Crete (the 18 original collection sites are distributed in three main areas shown with yellow circles). *O. dictamnus* is restricted to Crete (endemic), is protected by the Greek Presidential Decree 67/1981, Bern Convention and the European Directive 92/43/EEC, it has been included in the Red Data Book of Rare and Threatened Plants of Greece as ''Vulnerable'' (Turland, 1995) and in Annex 2 of the European Threatened Species (Sharrock & Jones, 2009).

Generally, the appropriate season for germination trials inside the greenhouse was selected by comparing the seasonal temperatures profiles of the local greenhouse used with those of the wild habitat of the target species (Ionian Islands). The season deemed as more appropriate was characterized by temperature ranges that could easily mimic those prevailing in the natural environment of the target species.

To illustrate an example, the GIS-derived temperature profiles for the wild habitat of *Silene cephallenia* subsp. *cephallenia* (Figs. 3, 5) have dictated the selection of temperatures to test for seed germination, leading to a germination success of 64% (Krigas et al., 2010). Additionally, its ecological profile has explain the fact that seed germination was inhibited at 10ºC, whereas seed germination was considerably increased in only 7 days when higher temperature (21ºC±1) was applied, in an attempt to emulate natural conditions.

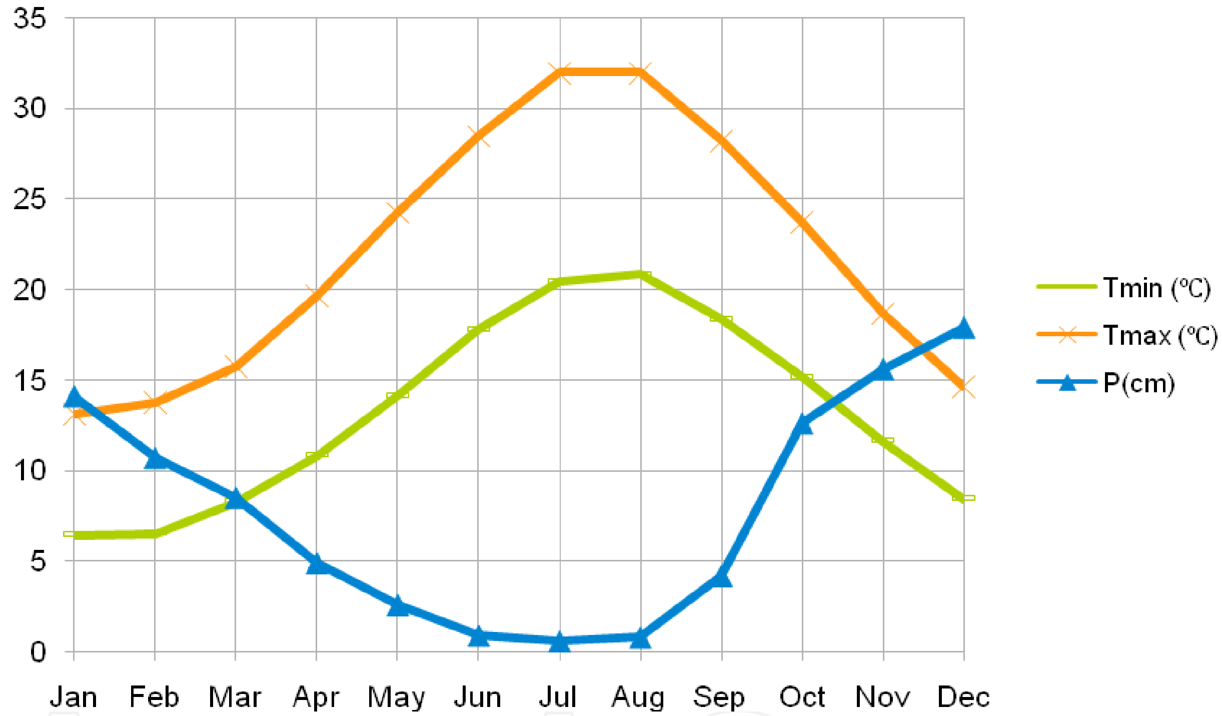


Figure 5. Monthly variations of the climatic conditions (average values of 50 years for precipitation, minimum and maximum temperature) at the original collection sites of *Silene cephallenia* subsp. *cephallenia* derived from its ecological fact sheet.

3.2. GIS and asexual plant propagation by cuttings

Basically, the asexual propagation and the rooting trials of softwood cuttings from plants are performed in greenhouse conditions using a few individuals to produce large amounts of genetically identical plants. Lately, it has been shown that the GIS may also be used to facilitate the asexual plant propagation by cuttings (Krigas et al., 2010). For example, the GIS-derived data for the wild habitat of *Thymus holosericeus* demonstrated that early spring was the most appropriate season for the rooting trials of this target species (Krigas et al., 2010). During early spring, the temperatures of the selected greenhouse in their case have emulated in the best way the temperatures prevailing in the natural habitat of the target plant. In this study, during propagation the rooting substrate's temperature was kept at 18-21°C in order to accelerate rooting as indicated from previous experience (Maloupa et al., 2008). Nevertheless, the air temperature was kept between 18-25°C, in an attempt to emulate as best as possible the original conditions of the natural habitat which were indicated by the GIS. Furthermore, the relative humidity was kept at 80% for the first 7 days and was reduced gradually to 50% during the second week of rooting. This was followed due to the fact that *Th. holosericeus* is a xerophytic species that grows in areas of very low subsoil water capacity, especially during dry months (Fig. 2). In the case of *Th. holosericeus*, the combination of GIS data with previous experience on rooting of other species of the same genus raised propagation success nearly by 90% (from 45% to 80% rooting).

3.3. GIS and *in vitro* plant propagation

The attempts of *in vitro* propagation of rare and threatened plant species are often associated with two inherent problems which may hold back conservation efforts. First of all, there is frequently a lack of published methods regarding the propagation of a certain plant species and secondly, there is often a limited amount of experimental plant material which can be initially available due to scarce populations of limited size found in the wild (Bunn et al., 2011; Krogstrup et al., 2005). Taken these limitations into account, almost every attempt to propagate rare and threatened plants is of great importance but seems difficult to achieve.

Although sophisticated technologies and modern methods have been used to date for the *in vitro* plant propagation (Benson, 1999), the GIS has not been exploited as a tool. Lately, Grigoriadou et al. (2011) have shown how the GIS may also be used to serve the needs and procedures of *in vitro* plant propagation. Using a case-study plant i.e. *Achillea occulta* which is a local endemic of southern Peloponnese (Southern Greece) recently characterized as "Vulnerable" (Constantinidis & Kalpoutzakis 2009), the authors have used GIS in this study for the:

a. Selection of temperatures for both greenhouse cultivation and *in vitro* cultures; the GIS-derived ecological profile for *A. occulta* dictated the selection of 22±2 °C day temperature and 15±2 °C night temperature at 16-h photoperiod to be used as most suitable for the development of the *in vitro* cultures.
b. Selection of appropriate period for acclimatization and transplanting of plantlets produced *in vitro;* after balancing out the temperature profiles of the wild habitat with those prevailing in the man-made site of the botanic garden (BBGK), the GIS revealed that spring temperatures were more suitable for the active growth and acclimatization of plantlets.
c. Selection of growing media and substrates for plantlets produced *in vitro*; the type of commercial peat used with the addition of vermiculite provided a very good imitation of the natural soil conditions as indicated by the GIS-derived ecological profile.
d. Selection of appropriate *ex situ* conservation sites for plants raised *in vitro*; after balancing out the temperature profiles of the wild habitat with those prevailing in the available man-made *ex situ* conservation sites of BBGK, the GIS revealed that specific

sites seemed more favorable than others for the accommodation of *A. occulta* plants (a site with temperature range as close as possible to the natural temperature range of the wild habitat was chosen).

4. GIS-derived ecological profiles and guidelines for the *ex situ* cultivation of target plants

From the above mentioned and when taking into account the associated technical information (see Krigas et al., 2010, Grigoriadou et al., 2011) it becomes apparent that GIS may be used for the development of effective protocols concerning the propagation and initial cultivation of plant material derived from target species.

Regardless the method used for plant propagation (cuttings, seeds or *in vitro* techniques), the young individuals produced (plantlets or seedlings) require hardening and acclimatization before their *ex situ* conservation. In this sense, the GIS-derived ecological profiles of the target plants could be used to provide specific guidelines for their effective *ex situ* cultivation (Table 1).

4.1. Cultivation guidelines regarding soil media, potting volume, texture, pH and drainage

In general, it is known that for the successful *ex situ* cultivation of target plants, the plant medium to be used must be similar to that of the substrate in the plant's natural habitat, providing similar root aeration and drainage conditions. This is quite important since improved drainage conditions during cultivation can actually inhibit fungal disease risks, induce greater rooting depth and enhance general plant health and vigor (Brady & Weil, 2002).

The GIS-derived ecological profile for the wild habitat of *Silene cephallenia* subsp. *cephallenia* (Fig. 3) showed that the plants originally grow on "Calcaric Lithosol" according to the FAO (1985) classification or according to the European Soil Database, on "Calcaric Leptosol (mountainous), shallow (<25 cm) or extremely gravelly soils directly over continuous rock or soils having <20% (by volume) fine earth material" (Krigas et al., 2010). In an attempt to emulate the natural habitat during hardening and acclimatization of plantlets raised from seeds (seedlings), the type of commercial peat used in BBGK for transplantation contained lime and by adding vermiculite, a good approximation of its originally drained soil type was achieved. This fact has actually allowed the plantlets of *S. cephallenia* subsp. *cephallenia* to continue growing without problems observed.

For the further *ex situ* cultivation of *Silene cephallenia* subsp. *cephallenia* and *Thymus holosericeous*, the GIS-derived ecological profiles (Fig. 2, 3) indicated that the basic soil group in which their wild habitats originate from is classified as ''Calcaric Lithosol'' (stony calcareous with a high concentration of MgCO3 and >15% free CaCO3, developed on dolomitic limestone). Such a substratum is characterized by a good drainage capacity, neutral to alkaline soil pH, low depth and a high ratio of stones to fine earth. The above indicated that for the *ex situ* cultivation of these target plants, a potting medium of relative high pH would be required and a fair degree of drainage was deemed essential. To accomplish this, supplementary perlite, sand and/or fragmented stone were added in their growing media. For these plants, medium sized pots (4.5 l) were suggested as suitable and additional Mg dressing was added in order to match the original chemical composition of their natural habitats.

By adopting these guidelines (Table 1), the natural habitat of the target plants was technically emulated with common commercial materials and the plants have adapted well and continued to grow without apparent problems (Krigas et al., 2010).

4.2. Cultivation guidelines regarding temperature range

When cultivating plants from the wild to man-made habitats, the temperature conditions at the plant's growing site (nursery or outdoors) may often be quite different from those prevailing in the plant's original wild habitat. Although it is known that plants usually have a degree of tolerance for a wide range of temperatures, it is important to know the temperature range that a plant species may tolerate, in order to facilitate its growth by maintaining temperatures within these limits during cultivation.

The GIS-derived ecological profile indicated that *Silene cephallenia* subsp. *cephallenia* (Fig. 3, 5) may experience and/or tolerate in its wild habitat mean temperatures ranging from 6.7 ^{o}C to 32.2 ^{o}C throughout the year, while for *Thymus holosericeus* the mean yearly temperatures may range from 3.9 ^{o}C to 29.5 ^{o}C (Krigas et al., 2010 and Fig. 2).

For the acclimatization procedure of the seedlings of *S. cephallenia* subsp. *cephallenia* and of the plantlets of *Th. holosericeous* produced in BBGK, the selection of appropriate sites was achieved after balancing out the temperature profiles of the available areas for *ex situ* conservation in northern Greece with the natural range of temperatures of their wild habitats, as revealed with the use of GIS (Table 1). It was suggested that *Th. holosericeus* may be marginally stressed during hot summer days and short term measures could possibly be taken to avoid heat shock (e.g. periodical shading or translocation of mother plants to cooler conditions). However, high summer temperatures did not seem to be a constraint for *S. cephallenia* subsp. *cephallenia*. Moreover, it was suggested that accommodation in a protected greenhouse would be crucial for the winter survival of both plants in northern Greece (Krigas et al., 2010). Indeed, the propagated plants that were transferred indoors (greenhouse at sea level, with controlled winter indoor temperatures ranging from 5 to 25 ^{o}C), have actually shown increased height, leaf area and number of flowers during cultivation in comparison to those transplanted outdoors (Krigas et al., 2010).

4.3. Cultivation guidelines regarding watering regimes

When transferring wild plants to man-made sites for their *ex situ* cultivation, the amount of water to be offered to them remains largely unknown. The watering regime followed is based merely on observations regarding the natural habitat of the species in question or exploits previous general horticultural experience associated with the cultivation of other species with presumably similar needs. However, it is generally accepted that the design of an irrigation system for the *ex situ* cultivation of target plants should take into account the natural preferences of the species, the medium type and the irrigation frequency requirements. The latter not only depends on the specific plants in question, but it is also influenced by the growing season and the indoor or outdoor temperatures prevailing in the cultivation sites.

The precipitation profiles derived from GIS for the target plants may indicate differences regarding the water requirements preferred and/or tolerated by each one of them in the wild. For example, the GIS-derived ecological profile of *A. occulta* published by Grigoriadou et al. (2011) for its *ex situ* conservation, indicated a watering regime equal to a mean total annual precipitation of 744 mm (7–136 mm per month) which was followed for the proper cultivation of the *in vitro* propagated plants.

Seasonal variation of the watering regime is equally important as the total amount of water offered to plants. To illustrate an example, the GIS-derived ecological profiles of *Thymus holosericeous* and *Silene cephallenia* subsp. *cephallenia* may be taken into account (Fig. 2, 3, 5, 6). It becomes evident that during the wettest and driest quarters of the year, *Thymus holosericeus*'s habitat receives from 40 to 504 mm, while that of *Silene cephallenia* subsp. *cephallenia* from 26 to 476 mm. During autumn, no noticeable differences exist regarding mean monthly precipitation in the natural habitats of these plants. However, from January to August mean monthly precipitation is consistently higher in the intermediate altitude habitats of *Th. holosericeus*, while until autumn *S. cephallenia* subsp. *cephallenia* (which is naturally found close to sea level) receive comparatively lower precipitation (Fig. 5, 6).

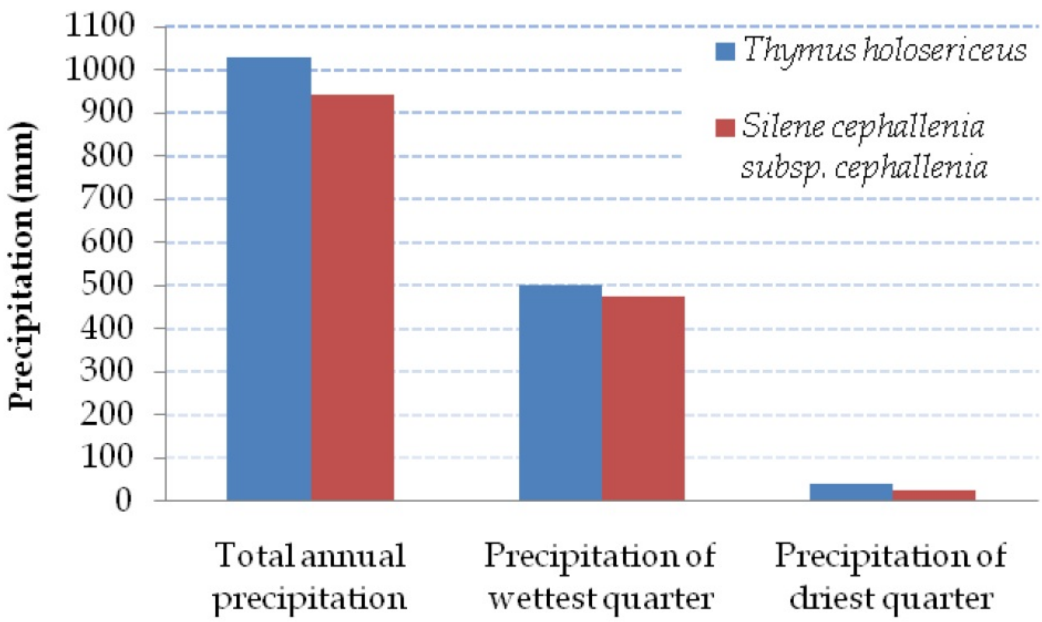


Figure 6. Precipitation profiles for the original collection sites of *Thymus holosericeus* and *Silene cephallenia* subsp. *cephallenia* derived from their ecological fact sheets.

Hence, the GIS-derived precipitation profiles suggest that the watering need (both in terms of water amount received and frequency of watering) is not the same for these plants (Table 1), although both should be under a rather low water regime (regardless of whether it is winter or summer). *S. cephallenia* subsp. *cephallenia* has comparatively lower water demands both annually and seasonally which should result in a more restricted watering schedule, while *Th. holosericeus* has somewhat intermediate watering needs, although a relatively low water regime seems to be equally suitable since it is considered as a xerophytic species (Krigas et al., 2010).

4.4. Guidelines regarding positioning of target plants in displays

The qualitative and quantitative description of the natural habitat of a target species may offer information for appropriate spatial and temporal positioning in plant displays of botanic gardens. Different vegetation types where a target plant is naturally found (deciduous or evergreen i.e. depending on the canopy cover of the vegetation) or land cover types (e.g. rock formations, woodland, pastures etc) from which the target species originate from, are attributes that can be exploited as important ecological information. Such attributes (a) may indicate appropriate or unsuitable sites for the *ex situ* cultivation of target plants, (b) could be useful for the selection of the amount of light or shading needed for the plants or to be avoided by them, and (c) could define the species assemblages with common requirements for specific indoors or outdoors plant displays (Table 1).

To illustrate an example, the GIS-derived ecological profile of *Achillea occulta* published by Grigoriadou et al. (2011) for its *ex situ* conservation indicated that (semi-) shady limestone cracks and rock bases with calcaric lithosols should be used as habitats in order to host the propagated plants and a natural positioning at south, south-eastern and south-western exposures of rock formations was chosen as more favorable for plant growth.

5. Potential and implications for the management of living plant collections

The novel GIS-facilitated application presented here is a powerful tool able to extract ecologically meaningful environmental information from geodatabases regarding the collection sites of different target plants which are useful in applied research and horticulture. This application is able to identify important ecological differences that can contribute to the development of species-specific baseline plant propagation and cultivation protocols. Given the impracticality and lack of on-the-spot field temperature and precipitation measurements and proper soil sampling followed by laboratory analysis, the nothing (just delete the words) geodatabases with the use of GIS can be used to extract at a fraction of time, information crucial for the success of *ex situ* conservation of target species. This application can be used to (Table 1):

- Understand the amplitude of the *in situ* ecological conditions of different target plants both quantitatively and qualitatively (Fig. 1, 2, 3, 4),

<table>
<tr><th>Variable / Source used</th><th>Selected attributes used</th><th>Conservation guidelines produced</th><th rowspan="10">Potential to rank or filter plants in terms of different quantitative or qualitative variables or to group target plants sharing common requirements</th></tr>
<tr><td>Soil moisture / ESDB v.2 (EC, 2004)</td><td>Available topsoil and subsoil water capacity</td><td>Calculation of different watering regimes for different groups or target species</td></tr>
<tr><td>Soil classes and types / ESDB v.2 (EC, 2004), CORINE Soil Classification (EC, 1985)</td><td>Textural class
Different soil classes
Dominant parent material</td><td>Selection of different growing media (regarding texture, pH, drainage) for different groups or target species</td></tr>
<tr><td>Soil nutrient / ESDB v.2 (EC, 2004)</td><td>Topsoil and subsoil base saturation
Cation exchange capacity</td><td>Selection of different growing media and development of fertilization regimes for different groups</td></tr>
<tr><td>Soil limitations / ESDB v.2 (EC, 2004)</td><td>Depth to a gleyed horizon
Depth to rock
Depth of an obstacle to roots
Volume of stones</td><td>Selection of different growing media (regarding texture, drainage) and potting volume for different groups or target species</td></tr>
<tr><td>Climate / WorldClim Database (Guarino et al., 2002, Hijmans et al., 2005)</td><td>Temperatures
Mean minimum or maximum temperatures of the coldest or the warmest month
Annual mean temperature range
Temperature seasonality
Mean diurnal temperature range

Precipitation
Precipitation of the driest month or the wettest month
Mean monthly precipitation
Annual precipitation
Mean precipitation of driest, wettest, coldest or warmest quarter</td><td>Selection of appropriate sites and conditions both in greenhouse and in ex situ cultivation sites for different groups or target species

Selection of temperatures for seed germination and asexual propagation for different groups or target species

Shading and ventilation for temperature regulation

Calculation or watering regimes, calibration of different watering regimes in different seasons and/or in different months for different groups or target species</td></tr>
<tr><td>Topography / Digital Terrain Model created</td><td>Aspect, Slope,
Altitude (elevation from sea level)</td><td>Customization of microclimate in ex situ cultivation sites and appropriate positioning in plant displays</td></tr>
<tr><td>Vegetation zones / Mavromatis (1980)</td><td>11 different vegetation types identified for the Greek territory</td><td rowspan="2">Selection of the ex situ conservation sites for different groups or target species

Selection of shading regime for different groups (seasonal, if originating from deciduous vegetation or all year round, if originating from evergreen vegetation)
or for target species

Creation of species assemblages

Selection of sites for specific plant assemblages and displays</td></tr>
<tr><td>Land cover classes and types/ CORINE Land cover (EC & ETC/LC, 1999)</td><td>45 different land-use classes and types</td></tr>
</table>

Table 1. Guidelines for the *ex situ* conservation of target plants based on links of their collection data with geodatabases (from Krigas et al., 2010, with modifications).

- Indicate the preferable *ex situ* growing conditions for each target plant (linking the *in situ* natural conditions with the *ex situ* cultivation regimes) and provide guidelines regarding species-specific treatments (Fig. 2, 3, 5, 6),
- Rank or filter included target species in terms of different quantitative variables or group target plants sharing common preferences or requirements (Fig. 7, 8),

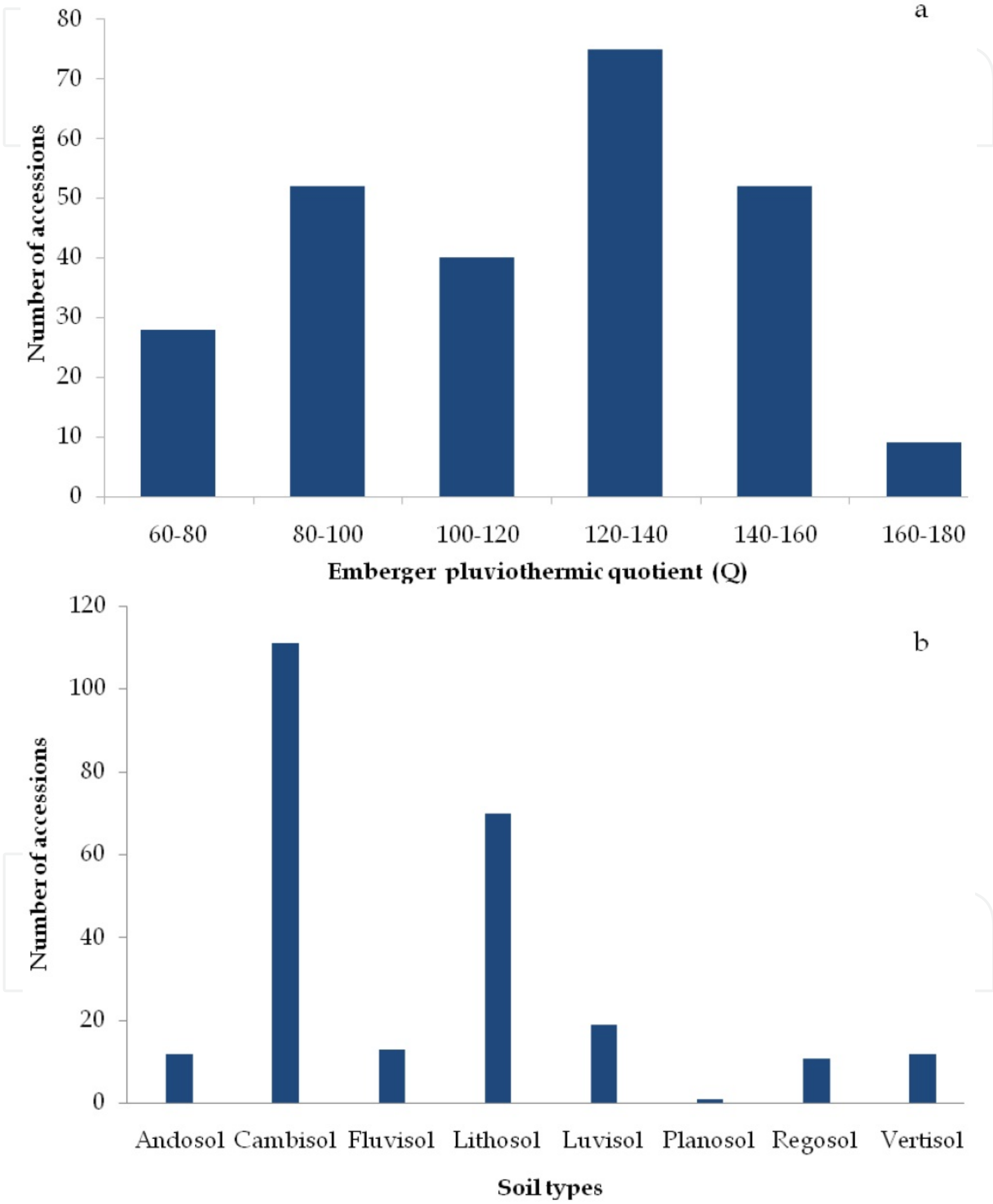


Figure 7. Groupings of target plants based on GIS-derived ecological criteria: Number of accessions of target plants (n=256) originating from the Aegean Archipelago, the Ionian Islands, Crete and Peloponnese, southern Greece grouped into different Emberger's Pluviothermic Quotient classes (a) and according to basic soil types (b). For each class or type specific plant lists can also be generated.

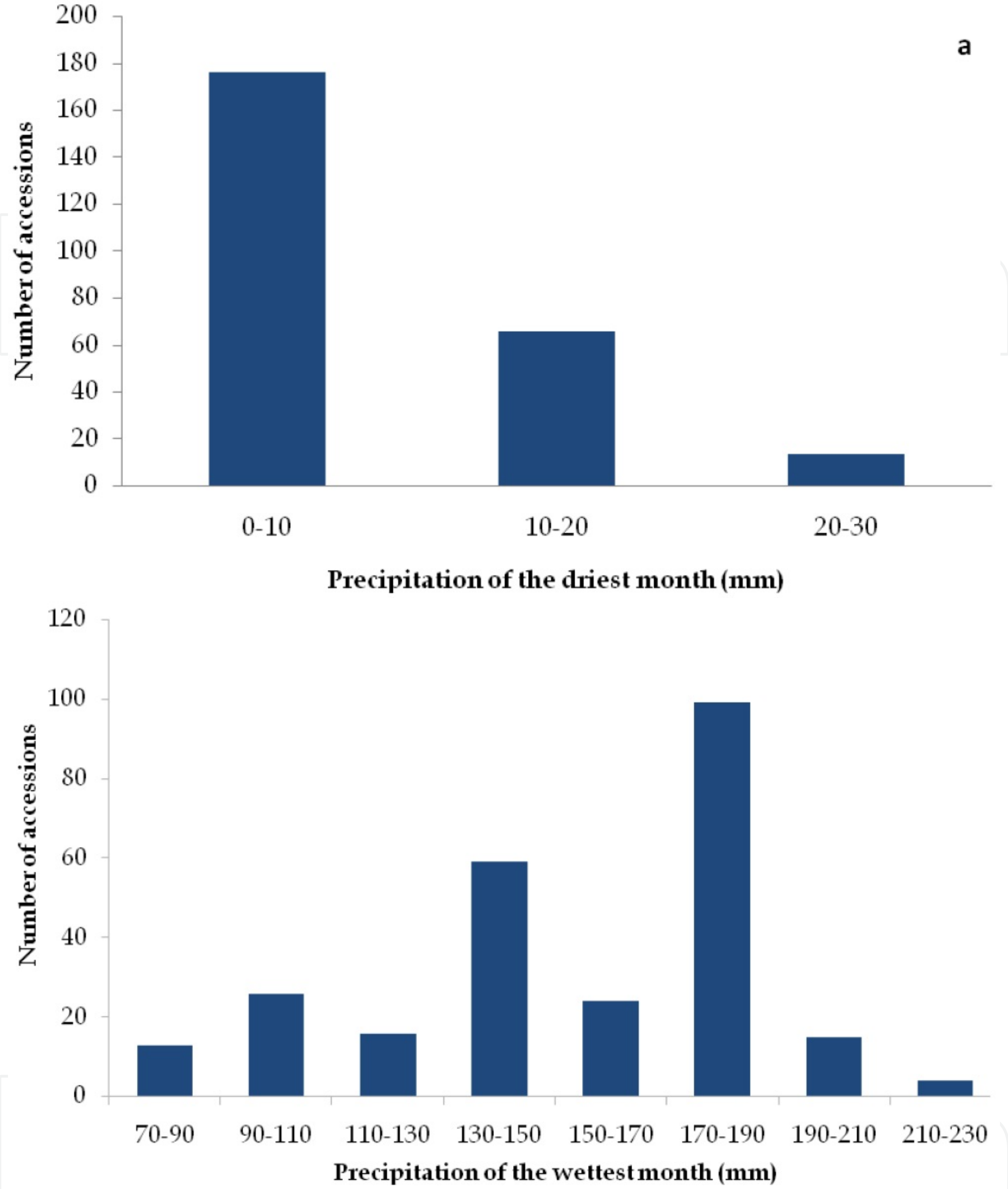


Figure 8. Groupings of target plants based on GIS-derived ecological criteria: Number of accession numbers of target plants (n=256) originating from the Aegean Archipelago, the Ionian Islands, Crete and Peloponnese (Greece) grouped according to precipitation classes during the driest (a) and wettest (b) months of the year. For each class specific plant lists can also be generated.

- Produce lists of species or frequency graphs within specified ranges of environmental variables or combinations thereof (Fig. 7, 8),
- Organize groupings of target plants based on ecological criteria (groups of plants with similar preferences or requirements), thus possibly improving their growing conditions as well as saving human-hours and space in *ex situ* conservation areas (Fig. 7, 8),
- Pinpoint target plants that may or cannot be accommodated in specific areas,

- Reduce trial-and-error losses during the *ex situ* cultivation of target species which seems to be common in the community of botanic gardens, often due to absence of previous experience (Krigas et al. 2010),
- Formulate and establish species-specific guidelines for the *ex situ* cultivation of target plants in botanic gardens,
- Facilitate the gap analysis of the botanic expeditions organized for the collection of plant material (which may also permit better planning of future ones),
- Reveal gaps in the representation of target plants from different altitudes, vegetation zones, habitat types, phytogeographic and climatic regions of specified geographical areas,
- Pinpoint by spatial niche modelling new probable locations where target species may be encountered, permitting the search for new populations in the wild (Jarvis et al., 2005),
- Assess conservation strategies and actions of institutions related to plant conservation.

By exploiting the GIS-derived ecological information for target plant species, the Balkan Botanic Garden of Kroussia (Greece) was the first to initiate this pilot GIS application dedicated to the *ex situ* plant conservation (Krigas et al., 2010). To date the majority of the target plants collected from the wild and propagated at the grounds of the BBGK are able to grow and flower regularly and produce fruits with no problems reported so far (BBGK, pers. comm.). Additionally, their seeds are regularly collected and deposited in a seed bank for future studies. This valuable material of conservation important target plants -in case of catastrophic events and if deemed necessary- could serve as a means to enrich the wild plant populations with individuals raised *ex situ,* actually reducing the risk of their extinction (Bowes, 1999; Bunn et al., 2011).

This novel GIS application described here presents an invaluable (time and money saving) tool with a broad-scale potential in enhancing the prospects of the *ex situ* plant conservation of target species collected from diverse environmental conditions and transferred to man-made sites such as botanic gardens, nurseries and private gardens.

Author details

Nikos Krigas
Laboratory of Systematic Botany & Phytogeography, Department of Botany, School of Biology, Aristotle University of Thessaloniki, Greece

Kimon Papadimitriou
Office for Sustainability, Aristotle University of Thessaloniki, Greece

Nikos Krigas and Antonios D. Mazaris
Department of Ecology, School of Biology, Aristotle University of Thessaloniki, Greece

Acknowledgement

The authors would like to thank Dr E. Maloupa and the Balkan Botanic Garden of Kroussia (Greece) for funding earlier stages in this research and appreciate access to the plant material conserved *ex situ* in its grounds. The field work of N. Krigas in the Ionian Islands, SW Greece was partially supported by the Stanley Smith Horticultural Trust (UK) in the frame of the Ionian Island Project (Collections of rare, threatened and endemic plants of the Ionian Islands for their ex situ conservation in Greek and British botanic gardens). The work of A. D. Mazaris was partially supported by the EU FP7 SCALES project ('Securing the conservation of biodiversity across administrative levels and spatial, temporal and ecological Scales'; project #226852).

6. References

Allison, J., Miller, A.J. & Knouft, J.H. (2006). GIS-based characterization of the geographic distributions of wild and cultivated populations of the Mesoamerican fruit tree *Spondias purpurea* (Anacardiaceae). *American Journal of Botany,* 93, pp. 1757-1767, ISSN 0002-9122

Baskin, C.C., & Baskin, J.M. (1988). Germination ecophysiology *of* herbaceous plant species in a temperate region. *American Journal of Botany,* 75(2), pp. 286–305, ISSN 0002-9122

Benson, E.E. (1999). An introduction to plant conservation biotechnology, In: E.E. Benson (Ed), *Plant conservation biotechnology,* pp. 3-10, Taylor & Francis, ISBN 0203484193, London, UK & Philadelphia, USA

Bowes, B.G. (1999). *A colour atlas of plant propagation and conservation,* Manson Publishing Ltd, ISBN 9781874545927, London, UK

Brady, N.C. & Weil, R.R. (2002). *The nature and properties of Soils,* Prentice Hall, Upper Saddle River, ISBN 130167630, New Jersey, USA

Bunn, E., Turner, S.R. & Dixon, K.W. (2011). Biotechnology for saving rare and threatened flora in a biodiversity hotspot. *In vitro Cellular & Developmental Biology - Plant.* 47(1), pp. 188-200, ISSN 1054-5476

CBD-*Convention on Biological Diversity* (1992). United Nations Environment Programme, Rio de Janeiro, Retrieved from http://www.cbd.int/doc/legal/cbd-en.pdf

Constantinidis, T. & Kalpoutzakis, E. (2009). *Achillea occulta* Constantin. & Kalpoutz., Vulnerable (VU), In: *The red data book of rare and threatened plants of Greece, vol 1 (A–D),* D. Phitos, T. Constantinidis, & G. Kamari (Eds), pp. 40–42, Hellenic Botanical Society, ISBN 9789609407120, Patras, Greece (in Greek)

Draper, D., Rosselló-Graella, A., Garcia, C., Tauleigne Gomes, C. & Sérgio, C. (2003). Application of GIS in plant conservation programmes in Portugal. *Biological Conservation* 113, pp. 337–349, ISSN 0960-3115

EC & ETC/LC (1999). *CORINE land cover—technical guide,* European Community, European Environment Agency, Retrieved from http://www.eea.europa.eu/publications/tech40add

EC (1985). *Soil Map of the European Communities (CORINE soil geodatabase) at 1:1000000,* The Commission of the European Communities, Directorate General for Agriculture, Coordination of Agricultural Research, Luxembourg, Retrieved from http://www.eea.europa.eu/data-and-maps/data/soil-type

EC (2004). *The European Soil Database distribution version 2.0,* European Commission and the European Soil Bureau Network (CD-ROM) EUR 19945 EN

ESPC (2009). *A sustainable future for Europe: The European Strategy for Plant Conservation 2008–2014,* Planta Europa Network, Council of Europe & CBD, Retrieved from http://www.plantaeuropa.org/assets/New%20European%20Strategy%20for%20Plant%20Conservation%20(2008-2014).pdf

Farnsworth, E.J., Klionsky, S., Brumback, W.E. & Havens, K. (2006). A set of simple decision matrices for prioritizing collection of rare plant species for *ex situ* conservation. *Biological Conservation* 128, pp. 1-12, ISSN 0960-3115

Fernández, J.A., Santana, O., Guardiola, J.L., Molina, R.V., Heslop-Harrison, P., Borbely, G., Branca, F., Argento, S., Maloupa, E., Talou, T., Thiercelin, J.M., Gasimov, K., Vurdu, H., Roldán, M., Santaella, M., Sanchís, E., García-Luis, A., Suranyi, G., Molnár, A., Sramko, G., Gulyas, G., Balazs, L., Horvat, O., Rodríguez, M.F., Sánchez-Vioque, R., Escolano, M.A., Reina, J.V., Krigas, N., Pastor, T., Renau-Morata, B., Raynaud, C., Ibadli, O., Polissiou, M., Tsimidou, M.Z., Tsaftaris, A., Sharaf-Eldin, M., Medina, J., Constantinidis, T., Karamplianis, T., De-Los-Mozos-Pascual, M. (2011). The World Saffron and Crocus collection: strategies for establishment, management, characterization and utilization. *Genetic Resources & Crop Evolution* 58(1), pp. 125-137, ISSN 0925-9864

Glowka, L., Burhenne-Guilman, F., Synge, H., McNeely, J. & Güdling, L. (1994). *Guide to the convention on biological diversity,* Environmental and law paper no 30, International Union for the Conservation of Nature and Natural Resources, ISBN 2831702224, Gland, Switzerland & Cambridge, UK

Godefroid, S. & Vanderborght, T. (2010) Seed banking of endangered plants: are we conserving the right species to address climate change? *Biodiversity and Conservation* 19, pp. 3049-3058, ISSN 0960-3115

Grigoriadou, K., Krigas, N. & Maloupa, E. (2011). GIS-facilitated *in vitro* propagation and *ex situ* conservation of *Achillea occulta. Plant Cell Tissue & Organ Culture* 107(3), pp. 531-540, ISSN 01676857

GSPC-*Global Strategy for Plant Conservation* (2002). Secretariat of the convention of biological diversity in association with Botanic Gardens Conservation International, Montreal, Quebec, Retrieved from http://www.cbd.int/gspc/

Guarino, L., Jarvis, A., Hijmans, R.J. & Maxted, N. (2002). Geographic information systems (GIS) and the conservation and use of plant genetic resources. In: *Managing plant genetic diversity*, J.M.M. Engels, V. Ramanatha Rao, A.H.D. Brown & M.T. Jackson (Eds), pp. 387-404, ISBN 0851995225, CABI Publishing, International Plant Genetic Resources Institute, Rome, Italy

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25, pp. 1965–1978, ISSN 1097-0088

IUCN (2001). *IUCN red list categories and criteria, Version 3.1*, IUCN Species Survival Commission, Gland, Switzerland & Cambridge, UK, Retrieved from http://www.iucn.org

Iverson, L.R. & Prasad, A. (1998). Estimating regional plant biodiversity with GIS modeling. *Diversity and Distributions* 4, pp. 49-61, ISSN 1472-4642

Jarvis, A., Williams, K., Williams, D., Guarino, L., Caballero, P.J. & Mottram, G. (2005). Use of GIS for optimizing a collecting mission for a rare wild pepper (*Capsicum flexuosum* Sendtn.) in Paraguay. *Genetic Resources & Crop Evolution* 52, pp. 671–682, ISSN 0925-9864

Karagianni, V., Kamari, G. & Phitos, D. (2009). *Silene cephallenia* subsp. *cephallenia* Heldr., Critically Endangered (CR), In: *The red data book of rare and threatened plants of Greece, vol 2 (E-Z),* D. Phitos, T. Constantinidis & G. Kamari (Eds), pp. 319–320, Hellenic Botanical Society, ISBN 9789609407120, Patras, Greece (in Greek)

Katsouni, N., Karagianni, V. & Kamari, G. (2009). *Viola cephalonica* Bornm., Critically Endangered (CR), In: *The red data book of rare and threatened plants of Greece, vol 2 (E-Z),* D. Phitos, T. Constantinidis & G. Kamari (Eds), pp. 385-387, Hellenic Botanical Society, ISBN 9789609407120, Patras, Greece (in Greek)

Krigas, N. & Karamplianis, Th. (2009). *Ranunculus cacuminis* Strid & Papan., Vulnerable (VU), In: *The red data book of rare and threatened plants of Greece, vol 2 (E-Z),* D. Phitos, T. Constantinidis & G. Kamari (Eds), pp. 269-271, Hellenic Botanical Society, ISBN 9789609407120, Patras, Greece (in Greek)

Krigas, N. & Maloupa, E. (2008). The Balkan Botanic Garden of Kroussia, Northern Greece: a garden dedicated to the conservation of native plants of Greece and the Balkans. *Sibbaldia* 6, pp. 9–27, ISBN 1872291449

Krigas, N. (2009). *Allium samothracicum* Tzanoud., Strid & Kit Tan, Endangered (EN), In: *The red data book of rare and threatened plants of Greece, vol 1 (A-D),* D. Phitos, T. Constantinidis & G. Kamari (Eds), pp. 68-69, Hellenic Botanical Society, ISBN 9789609407120, Patras, Greece (in Greek)

Krigas, N., Mouflis, G., Grigoriadou, K. & Maloupa, E. (2010). Conservation of important plants from the Ionian Islands at the Balkan Botanic Garden of Kroussia, N Greece: using GIS to link the *in situ* collection data with plant propagation and *ex situ* cultivation. *Biodiversity & Conservation* 19, pp. 3583–3603, ISSN 0960-3115

Krogstrup, P., Find J.I., Gurkov, D.J. & Kristensen M.M.H. (2005). Micropropagation of Socotran fig, *Dorstenia gigas* Schweinf. ex Balf. f.—A threatened species, endemic to the island of Socotra, Yemen. *In vitro Cellular & Developmental Biology - Plant* 41, pp. 81–86, ISSN 1054-5476

Loiselle, B. A., Jørgensen, P.M., Consiglio, T., Jiménez, I., Blake, J.G., Lohmann, L.G. & Montiel, O.M. (2008). Predicting species distributions from herbarium collections: does climate bias in collection sampling influence model outcomes? *Journal of Biogeography* 35, pp. 105–111, ISSN 1365-2699

Maloupa, E., Grigoriadou, K., Papanastassi, K. & Krigas, N. (2008). Conservation, propagation, development and utilization of xerophytic species of the native Greek flora towards commercial floriculture. *Acta Horticulturae* 766, pp. 205–213, ISSN 0567-7572

Maunder, M., Higgens, S. & Culham, A. (2001). The effectiveness of botanic garden collections in supporting plant conservation: a European case study. *Biodiversity & Conservation* 10, pp. 383–401, ISSN 0960-3115

Mavromatis, G. (1980). The Bioclimate of Greece, relationship of climate and natural vegetation, bioclimatic maps, Institute of Forest Research of Athens, Athens, Greece

Minor, E.S., Tessel, S.M., Engelhardt,K. A.D. & Lookingbill, T.R. (2009). The role of landscape connectivity in assembling exotic plant communities: a network analysis. *Ecology* 90, pp. 1802-1809, ISSN 0012-9658

Moat, J. & Smith, P.P. (2003). Applications of Geographical Information Systems in Seed Conservation, In: *Seed Conservation: Turning Science into practice*, R.D. Smith, J.B. Dickie, S.H. Linigton, H.W. Pritchard & R. J. Probert (Eds), Chapter IV, pp. 81-87, Royal Botanic Gardens, ISBN 1842460528, Kew, UK, Retrieved from http://www.kew.org/science-research-data/kew-in-depth/msbp/publications-data-resources/technical-resources/seed-conservation-science-practice/index.htm

Pedersen, Å. Ø., Nyhuus, S., Blindheim, T., & Wergeland Krog, O. M. (2004). Implementation of a GIS-based management tool for conservation of biodiversity within the municipality of Oslo, Norway. *Landscape & Urban Planning* 68, pp. 429–438, ISSN 0169-2046

Powel, M, Accad, A. & Shapcott, A. (2005). Geographic information system (GIS) predictions of past, present habitat distribution and areas for re-introduction of the endangered subtropical rainforest shrub *Triunia robusta* (Proteaceae) from south-east Queensland Australia. *Biological Conservation* 123, pp. 165–175, ISSN 0006-3207

Ramirez-Villegas, J., Khoury, C., Jarvis, A., Debouck, D.G. & Guadrino, L. (2010). A gap analysis methodology for collecting crop genepools: a case study with *Phaseolus* beans. *PloS ONE 5*(10), pp. 1–18, ISSN 1932-6203

Salem, BB. (2003) Application of GIS to biodiversity monitoring. *Journal of Arid Environments* 54, pp. 91–114, ISSN 0140-1963

Sarasan, V., Cripps, R., Ramsay, M.M., Atherton, C., McMichen, M., Prendergast, G., Rowntree, J.K. (2006). Conservation *in vitro* of threatened plants—progress in the past decade. *In vitro Cellular & Developmental Biology - Plant* 42, pp. 206–214, ISSN 1054-5476

Schulman, L. & Lehvävirta, S. (2010) Botanic gardens in the age of climate change. *Biodiversity & Conservation* 20, pp. 217–220 (Editorial note), ISSN 0960-3115

Schulman, L., Toivonen, T. & Ruokolainen, K. (2007). Analysing botanical collecting effort in Amazonia and correcting for it in species range estimation. *Journal of Biogeography*, 34, pp. 1388-139, , ISSN 1365-2699

Sharrock, S. & Jones, M. (2009). *Conserving Europe's threatened plants: progress towards Target 8 of the Global Strategy for Plant Conservation*, Botanic Garden Conservation International, Richmond, UK, ISBN 9781905164301, Retrieved from http://www.bgci.org/files/Worldwide/Publications/euro_report.pdf

Store, R. & Jokimäki, J. (2003). A GIS-based multi-scale approach to habitat suitability modeling. *Ecological Modeling* 169, pp. 1–15, ISSN 0304-3800

Store, R. & Kangas, J. (2001). Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modeling. *Landscape & Urban Planning* 55, pp. 79–93, ISSN 0169-2046

Turland, N. (1995). *Origanum dictamnus* L., Vulnerable (VU), In: *The red data book of rare and threatened Plants of Greece*, D., Phitos, A., Strid, S., Snogerup & W., Greuter (Eds), pp. 394-395, WWF, ISBN 9607506049, Athens, Greece

USGS-United States Geological Survey (2004). Shuttle Radar Topography Mission, 30 Arc Second scene SRTM_GTOPO_u30_mosaic, Unfilled Unfinished 2.0, Global Land Cover Facility, University of Maryland, College Park, Maryland, February 2000, Retrieved from http://glcf.umiacs.umd.edu/data/srtm/

Vanderpoorten, A., Sotiaux A. & and Engels, P. (2006). A GIS-based model of the Distribution of the rare liverwort *Aneura maxima* at the landscape scale for an improved assessment of its conservation status. *Biodiversity and Conservation* 15, pp. 829-838, ISSN 0960-3115