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Review

Living Collections of Threatened Plants in Botanic Gardens: When Is Ex Situ Cultivation Less Appropriate than Quasi In Situ Cultivation?

Sergei Volis

Tashkent Botanical Garden, Tashkent 100053, Uzbekistan; sergeivolis@yahoo.com

Abstract: Botanic gardens play an increasingly important role in the conservation of global biodiversity. However, although botanical gardens periodically report the results of introducing certain species of native flora, they rarely attempt to summarize existing knowledge to make general recommendations regarding ex situ collections. The aim of this study was to analyze the many years of experience of the Tashkent Botanical Garden in creating and maintaining living collections of threatened species of Uzbekistan (the majority of which are endemic to the country or Central Asia) in order to identify species whose cultivation ex situ is advisable, and whose cultivation will not result in meaningful conservation. Careful analysis of the species introduction history revealed that a simple dichotomy of the introduction results (success/failure) appears to be an oversimplification. In terms of the cultivation success, the introduced plant species can rather be classified into three categories: success, failure, and dubious success. For many species whose introduction was earlier considered successful, the introduction success is questionable and further efforts to conserve these species ex situ should be abandoned. A decision tree and classification of threatened perennials for possible ex situ introduction are proposed and the species in TBG collections are tabulated according to the latter. Species considered unsuitable for ex situ conservation are recommended for quasi in situ conservation. Both approaches, ex situ and quasi in situ, should be intensively used as a part of an integral conservation strategy for preserving plant biodiversity.

Keywords: decision tool; ex situ conservation; integrated plant conservation; threatened species; Uzbekistan flora

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1. Introduction

Plant living collections created and maintained by botanical gardens have traditionally been a resource for public education and scientific (mostly taxonomic) research. With botany as a driving force, the cultivated plants were used to describe, name, and place the species into taxonomic groups. Today, 107,340 accepted species are represented in botanic gardens collections, representing 31% of vascular plant species [1]. With time, some gardens started to specialize on local flora. For example, the subjects of Rancho Santa Ana Botanic Garden and National Tropical Botanical Garden are the flora of California and Hawaii, respectively. Then, due to biodiversity crisis caused by wide scale destruction or transformation of natural habitats by humans [2–5], some gardens recognized as their objectives not only taxonomic and botanical research but also conservation, i.e., the preservation of threatened plant species [6–14]. The number of such gardens grows, as does the intensity of their focus on living conservation collections [12,15–19].

Unfortunately, among the existing approximately 3000 botanical gardens worldwide [20], a few have ex situ collections with significant in situ conservation value, although notable exceptions exist and they should encourage the other botanical gardens [21–27]. It is known that keeping plants in space-limited gardens and arboreta introduces numerous genetic and demographic problems associated with their small population sizes. These small populations are subject to founder effects, genetic drift, and inbreeding, and can experience selective pressure from artificial conditions in the ex situ environment (reviewed in [18,28]). However, although these factors can compromise utility of ex situ collections for reintroduction, they can be curated (for example [29]). Another problem is that some species do not grow ex situ because it is impossible to provide them with a garden with the appropriate conditions for growth and reproduction. Threatened species are usually species with narrower environmental requirements than common species, and for some species, these requirements are simply not possible to meet in a garden. Govaerts [30] reports that of 844 plant taxa identified as extinct in the wild in 2010, 5% had been in collections but subsequently lost. Although some of these losses could be due to the small population size problems, others went extinct because the botanical gardens could not, in principle, provide them with the necessary conditions. The botanical gardens periodically report the results of introduction success for particular species of native flora, and there are publications trying to summarize the available knowledge to predict a probability of introduction success for plant species of the native flora representing different eco-climatic or soil types (e.g., [31,32]). Unfortunately, such studies are scarce and much more effort is required to make regional flora lists of rare and threatened species that can and cannot be maintained in botanical garden living collections. Species for which the creation of living collections in botanical gardens makes no sense include not only those which die within a few years after planting but also those which can survive in a garden for many years but do not produce seeds and cannot be propagated vegetatively. Of course, there can be exceptions; when collections are created for studying species biology, genetics, or methods of their propagation, the latter is impossible without planting individuals in a garden.

The Tashkent Botanical Garden (hereafter TBG), founded in 1950, is one of a few botanical gardens that exist in Central Asia; therefore, it is impossible to overestimate its role for preserving unique regional biodiversity. By 1989, the garden preserved in its living collections more than 2500 species of Central Asian flora, of which many were rare and threatened species. Regretfully, the majority of these collections were lost in the years following the Soviet Union's collapse, and only a small fraction of them were re-created in the last 20 years. Fortunately, the knowledge gained by the botanical garden personnel has been documented and preserved. Although the living collections were created in TBG without the aim of supporting in situ actions (reinforcement and translocation), the above knowledge can be used for the creation of collections specifically dedicated to these purposes.

In this study, I analyzed the experience at TBG of creating and maintaining living collections of rare and threatened species of Uzbekistan to identify those species which can and cannot be grown ex situ. Earlier, this was conducted by Belolipov [31,33]; however, in comparison with the data in [31,33], the present study makes an important further step by creating two species lists: one for ex situ and another for quasi in situ living collections. The concept of quasi in situ living collections was introduced by Volis and Blecher [34]. This concept proposes the creation of living collections in natural or semi-natural environmental settings within legally protected areas with a close match of these settings to those of the target species' natural populations. Because of the close match of the environmental conditions to those of the natural populations, the potentially large physical space being occupied and the lack of danger of interspecific hybridization, these collections have much better prospects for the successful introduction of plant species than collections in botanic gardens. More details on the quasi in situ methodology can be found in [35,36].

It is important to stress that in this paper, both types of living collections (ex situ and quasi in situ) are considered in terms of the role they can play in the conservation of threatened species by preserving them and providing material for in situ actions (reinforcement and translocation). Other aspects, such as education, public awareness, recreation, etc., are not considered here. The specific objectives of this study include the following: (i) a thorough analysis of cases previously considered to be species cultivation successes in order to identify those in which success is doubtful; (ii) the development of a classification and decision tree based on a set of criteria for determining the appropriate type of living collection for a given species.

2. Materials and Methods

Tashkent Botanical Garden is located at an altitude of 480 m above sea level on a plain, but very close to the foothills that border the Western Tian Shan mountains. The climate is continental, with significant daily temperature fluctuations, hot summers, dry and warm autumns, and moderately cold winters. The recorded absolute minimum and maximum temperature is −25.8 °C and +44.6 °C, respectively. The average number of days with temperature above 0 °C, 5 °C, and 10 °C is 327, 263, and 213, respectively. The average annual rainfall amount is 380 mm, which falls mainly in the autumn—winter—spring period. The average annual humidity is 59%, which, during summer, decreases to 22% [37]. The FAO soil type is Xk (calcic xerosoils) [38].

In creating a dataset for analysis, I used the previously published literature [31,33,39] and the data from local reports and PhD theses [40–43]. According to this literature, the living collections were created with plants grown from seeds or adults collected in natural populations. Seeds were sown in the open ground. The adult plants were planted in late autumn or early spring. The planted individuals did not receive any special care except for weeding. The rare/threatened species with known histories of cultivation in TBG have been classified into the following life form categories: annual, biannual, perennial, subshrub, and shrub (Table A1). In addition, they were classified according to the Raunkier classification [44] and provided with additional information on the type of underground organs and reproduction processes (monocarpic or polycarpic) (Table A2). For each species listed, I provide information on whether it was introduced as seed or adult and whether or not it reproduced during cultivation. When the data were available, I provided the information on the species' life duration in the garden and at what age it started flowering in TBG. The above information was used to develop a proposed categorization of ex situ introduction success and to create an ex situ vs. quasi in situ decision tree.

3. Results and Discussion

In total, since 1950, 100 threatened species have been introduced in TBG (Appendix A), of which 83 are listed in the Red Book of Uzbekistan [45]. The other 17 species not listed in the current Red Book were listed in the previous editions and reasons for their exclusion have never been explained. In general, the Red Book of Uzbekistan appears to underestimate the number of threatened species—rather than the opposite—because species categorization in Uzbekistan has never involved the formal IUCN criteria. The latter is due to the lack of data on population dynamics and even population sizes for many species. Therefore, many species not included in the Red Book can be truly threatened. From the introduced species, 47 are endemic to Uzbekistan and 87 species are endemic to Central Asia. The distribution of introduced species among the five life forms was highly dissimilar. Most introduced species were herbaceous perennials (78), followed by subshrubs (13). Only five introduced species were shrubs, three were annuals, and one was biannual. More detailed description of the species life forms is presented in Table A2.

Of the 100 species introduced during 1950–2022, the cultivation of 26 failed. These species never flowered and could not be propagated vegetatively. Of these, 17 died the same year, and four, two, one, and one lived in the garden for 1–2, 3–4, 8–9, and 10–11 years, respectively. For two of these 26 species, there are no data on their life duration in the garden.

Large number of species whose cultivation was successful confirms the high potential of TBG to create and maintain living collections that can be used for obtaining large quantities of these species' propagules. One of surprising findings of this study was that for several of the most critically endangered species of Uzbekistan (as well as of the whole Central Asia), living collections in which plants produce seeds every year can be created in TBG with only minimal care (i.e., weeding). For example, *Fritillaria eduardii* (Figure 1), *Ostrowskia magnifica*, and *Incarvillea olgae* can be sown in the open ground; plants start flowering and fruiting when 5, 4, and 2 years old, respectively, and produce seeds every year and live in the garden for more than 10 years. *Paeonia intermedia* plants (Figure 2) start producing seeds when they are 2–3 years old and live in the garden for 15–20 years. Individuals of *Dianthus uzbekistanicus* (Figure 2) start producing seeds when they are 2 years old and live in the garden for 10–15 years. Among the threatened woody species, *Malacocarpus crithmifolius* starts reproducing when 2 years old and lives in the garden for up to 30 years. *Rhus coriaria* also starts producing seeds when it is two years old and lives up to 18 years.

Figure 1. Living collections in TBG. (**A**) *Fritillaria eduardii*; (**B**) *Allium stipitatum*; (**C**) *Eremurus aitchisonii*; (**D**) *E. stenophyllus* subsp. *ambigens*; (**E**) *E. robustus*; (**F**) *E. baissunensis*; (**G**). *E. suworowii*; (**H**) *E. luteus*. Photos by Natalya Beshko.

All the above examples fall into a category of unequivocal introduction success. However, a simple dichotomy of the introduction results (success/failure) appears to be an oversimplification. In terms of the cultivation success, the introduced plant species can rather be classified into three categories: success, failure, and dubious success. Traditionally, a cultivation is considered successful if a species survives in a garden for some time and produces viable seeds or can be propagated vegetatively. Success may have ranks defined based on whether a species produces seeds every year, requires special care, lives a certain number of years under the garden conditions, etc. A closer look at the list of species whose cultivation can be considered successful using the above definition reveals a group of species whose cultivation success seems to be dubious and whose living collections in a garden make little sense.

For some species, success seems to be highly dubious after a closer look at the species cultivation data. For example, the cultivation of *Eremurus luteus* (Figure 1) was considered by the garden personnel to be a success. However, the examination of this species' cultivation data revealed that of the 25 adults that were dug out in a natural population and planted in the garden, only 7 survived by the fourth year; flowering/fruiting was observed only once during six years of cultivation; and the average germination percentage of produced seeds was 1.9%. Similarly, the reported success of the cultivation of *Eremurus stenophyllus* subsp. *ambigens* and *Eremurus suworowii* (Figure 1) is dubious because of the introduced 35 and 10 adults, only 5 and 2, respectively, survived by the fourth year. With such poor survival of the introduced adults, any further attempts to relocate plants of these species from natural populations to the garden must be stopped unless the introduction trials utilize new methods of their cultivation (e.g., another soil type).

Figure 2. Species cultivated in TBG. (**A**) *Acantholimon nuratavicum*; (**B**) *Acantholimon ekatherinae*; (**C**) *Paeonia intermedia*; (**D**) *Nanophyton botschantzevii*; (**E**) *Salvia submutica*; (**F**) *Anemone narcissiflora*; (**G**) *Dianthus uzbekistanicus*; (**H**) *Aconitum talassicum*; (**I**) *Corydalis sewerzowii*. Photos by Natalya Beshko.

Cultivation success is dubious in cases when seed production is low, irregular, or infrequent. Of the large number of cushion semishrubs that are threatened in Uzbekistan (five species of *Acantholimon* and two species of *Acanthophylum* are red listed), three species have been tested (*Acantholimon ekatherinae*, *Acantholimon nuratavicum*, and *Acantholimon margaritae*) (Figure 2). In all three species, seed production was very limited and did not last for more than several years. Although the potting and transplanting of *Acantholimon* seedlings usually posed no problems, the adults of these species lived in the garden for only 8–10 years, or a maximum 15 years, while they live up to 100 and more years in the wild [31,33].

Cultivation success is also dubious in cases where seed production is relatively abundant, but plants die soon after their first flowering. Geophytes *Anemone baissunensis* and *Anemone bucharica* start flowering when they are 3–4 years old and die when they are only 4–5 years old. Although they can be propagated vegetatively from bulbs, keeping them in garden living collections does not make sense. To my knowledge, keeping these species in TBG living collections did not provide any useful horticultural knowledge or serve as a source for breeding.

Two life forms for which the creation and maintenance of living collections in botanical gardens may look like a success, but in fact make little sense, are annuals/biannuals and monocarpic perennials. For the first group, keeping a collection means that every year the seeds must be collected and, repeatedly re-sown, year by year. Any neglect may result in a sudden collection loss as happened, for example, with a population of *Bromus bromoideus* created and maintained at Meise BG during 1985 and 1990 and again between 2006 and 2012. As a result, because no attempt was made to create any population in situ, the species currently exists only in the seed banks [46].

The collections of monocarpic perennials pose another similar problem. These species have to be maintained for many years before they set seeds (e.g., *Dorema microcarpum* and *Ferula gigantea* reproduce when they are 10 years old) and then they die, which means there is a need to start all over again. This problem can partly be solved by creating a collection of plants of different ages, but this means that species should be repeatedly collected in nature or sown every year.

The creation of botanical garden living collections is problematic for species that have many congeners which are maintained in proximity in a botanical garden, and with which spontaneous hybridization is highly probable. Examples are species from such genera as *Tulipa*, *Allium*, *Iris*, *Eremurus*, and *Astragalus*. For these species, measures against possible spontaneous interspecific hybridization should be taken to ensure that the produced seeds are not of a hybrid origin.

With a large number of plant species that are threatened due to the tremendous and only growing anthropogenic pressure on natural vegetation throughout the country, the active involvement of the only Uzbek botanical garden (i.e., TBG) in the conservation of these species is necessary. The knowledge of how to grow and propagate rare and threatened species in Uzbekistan obtained during the last 70 years by the garden personnel will help to create garden living collections specifically dedicated to the propagation of these species and their introduction into protected areas of Uzbekistan. However, it is important to communicate to the authorities responsible for nature protection in Uzbekistan that for certain species, ex situ conservation is not an option. For example, in the critically endangered shrub, *Molucella bucharica*, populations are under severe anthropogenic pressure; there is no protected area within the species range; and the seed production in natural populations of this species is virtually absent [47]. Thus, ex situ conservation seems to be the most appropriate option for this species. However, the numerous attempts of the cultivation and vegetative propagation of this species in TBG failed, evidencing that the ex situ approach, to date, have been inapplicable to this species. This kind of species must be protected in situ, which means the creation of new protected territories in an area where they currently grow, grew in the past, or can grow, according to expert knowledge. If the number and sizes of their extant populations are critically low and/or they experience regeneration problems, quasi in situ collections can mitigate these problems. The latter collections will be created within the current species range with an exact match of their natural ecological niche (climate, soil, vegetation community, and associated biota). The seeds collected from the plants in these collections will be used for in situ actions.

Quasi in situ collections have numerous advantages over ex situ collections, but they are not entirely better than the latter. The ex situ collections are a better option if the plants can be easily maintained for many years, do not require much space, and produce numerous seeds that can be easily germinated and grown to the required plant size/age. Ex situ cultivation is especially advantageous if seed production requires assistance (e.g., hand pollination), or when quasi in situ collections are not within easy reach.

Thus, both ex situ and quasi in situ cultivation should be intensively used for the conservation of local flora. However, the experience of TBG in the creation of living collections suggests that the individuals maintained ex situ should not remain in cultivation too long; periodically, they should be replaced by the new generations grown from seeds. This is especially important for perennials with underground storage organs. After successful cultivation for 3–5 years, they should be returned to nature (together with young plants obtained from the seeds they produced) as a part of the species reintroduction/translocation programs. This recommendation is based on the fact that for many species cultivated in

TBG (e.g., many representatives of *Eremurus*, *Iris*, and *Tulipa*), after 3–5 years of cultivation, plant mortality increased exponentially. The other reasons for the periodic renewal of the living collections are to prevent the loss of genetic diversity and to prevent artificial selection [28,48].

All of the above considerations can be summarized in a decision tree (Figure 3). As the proposed decision tree is based on data limited to a single botanical garden, it should be considered preliminary and subject to future amendments. Moreover, I propose a classification based on plant lifespan and reproduction potential for possible ex situ introduction, as presented in Table 1. This classification is pertinent for non-monocarpic perennials only. Annuals/biannuals and monocarpic perennials in general do not suit ex situ conservation, but can be an option for severely threatened species. Maintenance of living collections of these life forms requires the periodic renewal of a collection, which is logistically challenging, but can be justified if the goal is the production of large number of seeds. Therefore, both ex situ and quasi in situ collections can be useful for them depending on a species.

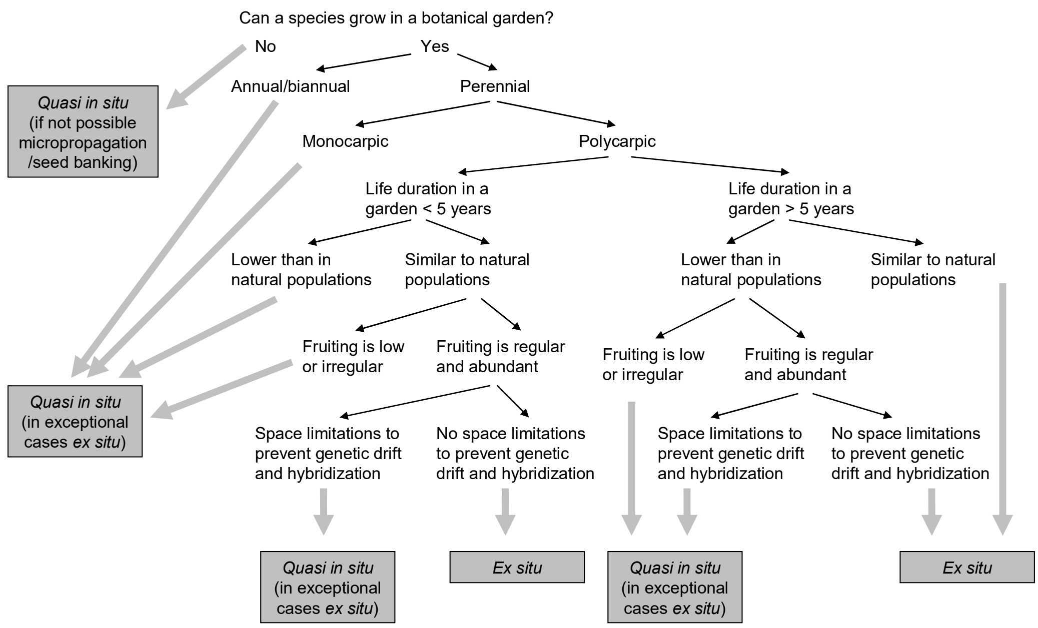

Figure 3. A decision tree for creation of ex situ vs. quasi in situ living collections.

Table 1. The classification of threatened species for possible ex situ introduction.

Category	Description	Suitability for Ex Situ Cultivation
0	Majority of the introduced plants die within a few years after introduction, or a species does not produce seeds and cannot be propagated vegetatively; it does not matter for how long it can survive with or without care	No
1	A species does not produce viable seeds but can provide small quantity of cuttings/underground vegetative propagules	YES if their life duration in the garden does not principally differ from their life in nature and they are not represented in situ by critically small populations
2	A species produces a limited quantity of viable seeds and survives with care after reaching maturation for less than 5 years	
3	A species produces a limited quantity of viable seeds and survives with care after reaching maturation for more than 5 years	
4	A species produces abundant viable seeds and survives after reaching maturation with or without care for less than 5 years	YES given precautions against hybridization with congeners
5	A species produces abundant viable seeds and survives without care after reaching maturation for more than 5 years	

In the proposed classification, plant species of the category 0 are not suitable for ex situ conservation in botanical garden living collections. Species of the categories 4–5 can be grown in botanical garden living collections given precautions against hybridization with congeners. Species of the categories 1–3 can be grown in botanical garden living collections only if their life duration in the garden does not principally differ from their life in nature and they are not represented in situ by critically small populations. For species from the categories 1–3 that do not satisfy the above criteria, only quasi in situ living collections can be created. Some species from 0 category can be grown in quasi in situ living collections but apparently not all. The species in TBG collections are tabulated according to this classification in Table A1.

4. Conclusions

Although ex situ conservation is extremely important for threatened plant species, it is impossible or problematic for many species. In the latter cases, quasi in situ conservation can be an alternative solution.

It must be noted that although the quasi in situ concept was introduced more than a decade ago and is often cited in the conservation literature, applications of this approach—other than that in [49]—are lacking. I would like to encourage the readers of this paper to put my recommendations to the test by creating two types of living collections for the same species and comparing the outcomes.

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Appendix A

Table A1. Rare and threatened species introduced in Tashkent botanical garden, the information about the species, their introduction history, suggested ex situ introduction success category, and recommended form of introduction.

Species	Introduced Material	Life Form	Seed Production/ Vegetative Propagation	Years to First Fruiting	Life Duration in Botanical Garden (Years)	Category	Recommended Form of Introduction
Acantholimon ekatherinae *	seeds/adults	subshr	+low/−	3	4–8	2	quasi in situ
Acantholimon margaritae *	seeds/adults	subshr	+low/−	2	12–18	3	quasi in situ
Acantholimon nuratavicum *	seeds	subshr	+low/−	?	10–15	3	quasi in situ
Acantholimon subavenaceum *	seeds	subshr	+low/−	2	15	3	quasi in situ
Aconitum talassicum *	seeds/adults	per	+low/−	?	3	2	quasi in situ
Aconitum seravschanicum	adults	per	−/−	-	3	0	quasi in situ?
Adonis chrysocyathus	adults	per	−/−	8	?	0	quasi in situ?
Allium decoratum *	seeds/adults	per	−/−	-	-	0	quasi in situ?
A. giganteum *	seeds/adults	per	+/+	5–6	?	4 or 5	ex situ
A. praemixtum *	seeds/adults	per	+/+	3–4	?	4 or 5	ex situ
A. pskemense *	seeds/adults	per	+/+	3–4	?	4 or 5	ex situ
A. isakulii *	seeds/adults	per	+/−	4–5	?	4 or 5	ex situ
A. stipitatum	seeds/adults	per	+/?	?	?	?	quasi in situ
A. oshaninii	adults	per	−/−	-	-	0	quasi in situ?
Acanthophyllum gypsophiloides *	seeds	per	+/−	2	12	5	ex situ
Acanthophyllum tadshikistanica	seeds	per	+/−	4	12	5	ex situ
Andrachne vvedenskyi *	seeds/adults	subshr	+/−	?	?	?	quasi in situ
Anemone baissunensis *	seeds/adults	per	+low/−	4	4–5	2	quasi in situ
Anemone bucharica *	seeds/adults	per	+low/−	4	4	2	quasi in situ

Table A1. *Cont.*

Species	Introduced Material	Life Form	Seed Production/ Vegetative Propagation	Years to First Fruiting	Life Duration in Botanical Garden (Years)	Category	Recommended Form of Introduction
Anemone narcissiflora (=Anemonastrum protractum)	seeds/adults	per	−/−	-	-	0	quasi in situ?
Astragalus belolipovii *	seeds	per	+/−	3	8–10	5	ex situ
Astragalus bucharicus *	adults	per	−/−	-	-	0	quasi in situ?
Astragalus rhacodes *	seeds	subshr	+/−	2	8–9	5	ex situ
Astragalus terrae-rubrae *	seeds	per	−/−	-	8–9	0	quasi in situ?
Astragalus willisii *	seeds	per	−/−	-	-	0	quasi in situ?
Aulacospermum popovii *	seeds	per	−/−	-	-	0	quasi in situ?
Bryonia melanocarpa *	seeds/adults	per	−/−	-	10–11	0	quasi in situ
Bunium vaginatum *	seeds/adults	per	+/−	3	8	5	ex situ
Argyrolobium aegacanthoides *	adults	subshr	−/−	-	-	0	quasi in situ?
Capparis spinosa var. herbacea	seeds	per	−/−	-	-	0	quasi in situ?
Cephalopodum hissaricum *	seeds	per	−/−	-	-	0	quasi in situ?
Cleome gordjaginii *	seeds	ann	+/−	1	1	-	quasi in situ
Colchicum kesselringii *	adults	per	+/−	?	?	?	quasi in situ?
Corydalis sewerzowii	seeds/adults	per	+/+	4	10–12	5	ex situ
Crambe gordjaginii *	seeds	per	−/−	-	2	0	quasi in situ?
Crocus alatavicus	adults	per	+low/+	3–4	?	2 or 3	quasi in situ
Crocus korolkovii	seeds/adults	per	+/−	?	?	?	quasi in situ?
Dianthus uzbekistanicus *	seeds	per	+/−	2	10–15	5	ex situ
Dipcadi turkestanicum *	adults	per	−/−	-	-	0	quasi in situ?
Dorema microcarpum *	seeds	per	+/−	10	10	-	quasi in situ
Eremurus aitchisonii *	seeds/adults	per	+/−	5–6	>10	5	ex situ
E. alberti *	seeds/adults	per	+/−	4–5	>10	5	ex situ
E. stenophyllus subsp. *ambigens*	seeds/adults	per	+/−	4	>10	0	quasi in situ
E. baissunensis *	adults	per	−/−	-	-	0	quasi in situ?
E. lactiflorus *	seeds/adults	per	+/+	4–5	>10	5	ex situ
E. korolkowii *	adults	per	−/−	-	-	0	quasi in situ?
E. luteus *	seeds/adults	per	+low/−	4–5	>10	3	quasi in situ
E. nuratavicus *	seeds/adults	per	+low/−	4–5	>10	3	quasi in situ
E. robustus *	seeds/adults	per	+/−	4–5	>10	5	ex situ
E. stenophyllus	seeds/adults	per	+/+	4	>10	5	ex situ
E. suworowii *	seeds/adults	per	+low/−	4–5	>10	3	quasi in situ
Eversmannia botschantzevii *	seeds	shrub	+/−	?	?	?	quasi in situ?
Ferula gigantea	seeds	per	+/−	10	10	-	quasi in situ
Fritillaria eduardii *	seeds/adults	per	+/−	5–6	>10	5	ex situ
Gladiolus italicus *	seeds/adults	per	+/+	3–4	?	?	ex situ
Heliotropium bucharicum *	seeds	ann	+/	1	1	-	quasi in situ
Incarvillea olgae *	seeds	per	+/	2	15	5	ex situ
Iris hippolyti *	adults	per	−/−	-	4	0	quasi in situ?
I. magnifica *	seeds/adults	per	+low/+	4–5	11	2	quasi in situ
I. orchioides *	seeds/adults	per	+low/+	4–5	10	2	quasi in situ
I. svetlanae *	seeds/adults	per	+low/+	4–5	10	2	quasi in situ
Lagochilus inebrians *	seeds	subshr	+low/−	2	3–4	2	quasi in situ
Lepidolopha fedtschenkoana *	seeds	subshr	+low/−	?	3–4	2	quasi in situ
Lipskya insignis *	seeds	per	+low/−	2	6–18	2	quasi in situ
Malacocarpus crithmifolius *	seeds	shrub	+/+	2	up to 30	5	ex situ
Molucella bucharica *	seeds/adults	subshr	−/−	-	?	0	quasi in situ?
Nanophyton botschantzevii	seeds	shrub	−/−	-	-	0	quasi in situ?
Onobrychis tavernierifolia *	seeds	ann	+/−	1	1	-	quasi in situ
Ostrowskia magnifica *	seeds/adults	per	+/−	4	18	5	ex situ
Oxytropis tachtensis	seeds	per	+/−	2	6–10	5	ex situ
Oxytropis seravschanica	seeds	per	+/−	2	4–6	4	ex situ
Paeonia intermedia	seeds/adults	per	+/−	3	7–17	5	ex situ
Physochlaina alaica *	adults	per	+low/−	3	8–10	3	quasi in situ
Prangos tschimganica	seeds	per	+/−	7	20	5	ex situ
Primula hissarica *	seeds	subshr	−/−	-	-	0	quasi in situ?
Rhus coriaria *	seeds/adults	shrub	+/−	3	up to 18	5	ex situ
Rubia laevissima *	seeds	subshr	−/−	-	1–2	0	quasi in situ?
Salvia korolkowii *	seeds/adults	subshr	+/−	3	up to 25	5	ex situ
Salvia lilacinocoerulea *	seeds/adults	per	+/−	2	6	4	ex situ
Salvia submutica *	seeds	per	+/−	2	8	5	ex situ
Spirostegia bucharica *	seeds	biann	−/−	-	1	0	quasi in situ?
Sternbergia lutea *	adults	per	−/−	-	-	0	quasi in situ?

Table A1. *Cont.*

Species	Introduced Material	Life Form	Seed Production/ Vegetative Propagation	Years to First Fruiting	Life Duration in Botanical Garden (Years)	Category	Recommended Form of Introduction
Tulipa affinis *	seeds/adults	per	+/−	4–5	5–6	4	ex situ
T. bifloriformis	seeds/adults	per	+/+	4–5	5–6	4	ex situ
T. buhseana	seeds/adults	per	+/+	5–6	10	4	ex situ
T. carinata *	seeds/adults	per	+/+	4–5	10	5	ex situ
T. ferganica *	seeds/adults	per	+/−	4–5	5–6	4	ex situ
T. fosteriana *	seeds/adults	per	+/+	4–5	10	5	ex situ
T. greigii *	seeds/adults	per	+/−	4–5	5–6	4	ex situ
T. ingens *	seeds/adults	per	+/−	4–5	5–6	4	ex situ
T. kaufmanniana *	seeds/adults	per	+/+	4–5	10	5	ex situ
T. korolkowii *	seeds/adults	per	+/−	4–5	10	5	ex situ
T. lanata *	seeds/adults	per	+/−	4–5	10	5	ex situ
T. micheliana *	seeds/adults	per	+/−	4–5	10	5	ex situ
T. orythioides *	seeds/adults	per	+/−	4–5	10	5	ex situ
T. scharipovii *	seeds/adults	per	+/−	4–5	5–6	4	ex situ
T. tschimganica	seeds/adults	per	+/+	4–5	5–6	4	ex situ
T. tubergeniana *	seeds/adults	per	+/−	4–5	10	5	ex situ
T. turkestanica	seeds/adults	per	+/+	4–5	5–6	4	ex situ
T. sogdiana	adults	per	−/−	-	-	0	quasi in situ?
T. uzbekistanica *	seeds/adults	per	+/−	4–5	5–6	4	ex situ
T. vvedenskyi *	seeds/adults	per	+/+	4–5	5–6	4	ex situ
Zeravschania regeliana *	seeds	per	+/−	?	?	?	quasi in situ?
Zygophyllum bucharicum *	seeds/adults	shrub	−/−	-	2	0	quasi in situ?

Abbreviations: * included in the latest edition of Red Book of Uzbekistan [45]. ? Not known. Life form—ann: annual; biann: biannual; per: perennial; subshr: subshrub; shr: shrub.

Table A2. Description of the life forms of the threatened species cultivated in TBG.

Species	Life Form According to Raunkiaer [44]	Description
Acantholimon ekatherinae *	chamaephyte	Pulvinate subshrub, polycarpic
Acantholimon margaritae *	chamaephyte	Pulvinate subshrub, polycarpic
Acantholimon nuratavicum *	chamaephyte	Pulvinate subshrub, polycarpic
Acantholimon subavenaceum *	chamaephyte	Pulvinate subshrub, polycarpic
Aconitum talassicum *	cryptophyte	Geophyte with tuberous root, polycarpic
Aconitum seravschanicum	cryptophyte	Geophyte with tuberous root, polycarpic
Adonis chrysocyathus	hemicryptophyte	Perennial forb with taproot, polycarpic
Allium decoratum *	cryptophyte	Bulbous geophyte, polycarpic
A. giganteum *	cryptophyte	Bulbous geophyte, polycarpic
A. praemixtum *	cryptophyte	Bulbous geophyte, polycarpic
A. pskemense *	cryptophyte	Bulbous geophyte, polycarpic
A. isakulii *	cryptophyte	Bulbous geophyte, polycarpic
A. stipitatum	cryptophyte	Bulbous geophyte, polycarpic
A. oshaninii	cryptophyte	Bulbous geophyte, polycarpic
Acanthophyllum gypsophiloides *	hemicryptophyte	Perennial forb with taproot and caudex, polycarpic
Acanthophyllum tadshikistanica	hemicryptophyte	Perennial forb with taproot and caudex, polycarpic
Andrachne vvedenskyi *	chamaephyte	Subshrub, polycarpic
Anemone baissunensis *	cryptophyte	Geophyte with tuberous root, polycarpic
Anemone bucharica *	cryptophyte	Geophyte with tuberous root, polycarpic
Anemone narcissiflora (=Anemonastrum protractum)	hemicryptophyte	Perennial forb with taproot and caudex, polycarpic
Astragalus belolipovii *	hemicryptophyte	Perennial forb, polycarpic
Astragalus bucharicus *	hemicryptophyte	Perennial forb, polycarpic
Astragalus rhacodes *	chamaephyte	Subshrub, polycarpic
Astragalus terrae-rubrae *	hemicryptophyte	Perennial forb, polycarpic
Astragalus willisii *	hemicryptophyte	Perennial forb, polycarpic
Aulacospermum popovii *	hemicryptophyte	Perennial partial rosette forb with taproot, monocarpic
Bryonia melanocarpa *	-	Perennial herbaceous liana, polycarpic
Bunium vaginatum *	cryptophyte	Geophyte with tuberous root, polycarpic
Argyrolobium aegacanthoides *	chamaephyte	Subshrub, polycarpic
Capparis spinosa var. herbacea	hemicryptophyte	Perennial forb, polycarpic
Cephalopodum hissaricum *	cryptophyte	Geophyte with thickened taproot (?), monocarpic
Cleome gordjaginii *	therophyte	Annual

Table A2. *Cont.*

Species	Life Form According to Raunkiaer [44]	Description
Colchicum kesselringii *	cryptophyte	Bulbotuberous geophyte, polycarpic
Corydalis swerzowii	cryptophyte	Geophyte with tuberous root, polycarpic
Crambe gordjaginii *	cryptophyte	Geophyte with thickened taproot (?), polycarpic
Crocus alatavicus	cryptophyte	Bulbotuberous geophyte, polycarpic
Crocus korolkowii	cryptophyte	Bulbotuberous geophyte, polycarpic
Dianthus uzbekistanicus *	hemicryptophyte	Perennial forb with taproot and caudex, polycarpic
Dipcadi turkestanicum *	cryptophyte	Bulbous geophyte, polycarpic
Dorema microcarpum *	cryptophyte	Geophyte with thickened taproot (?), monocarpic
Eremurus aitchisonii *	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. alberti *	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. stenophyllus subsp. *ambigens*	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. baissunensis *	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. lactiflorus *	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. korolkowii *	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. luteus *	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. nuratavicus *	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. robustus *	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. stenophyllus	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
E. suworowii *	cryptophyte	Geophyte with short rhizome and tuberous roots, polycarpic
Eversmannia botschantzevii *	nanophanerophyte	Shrub
Ferula gigantea	cryptophyte	Geophyte with thickened taproot and caudex, monocarpic
Fritillaria eduardii *	cryptophyte	Bulbous geophyte, polycarpic
Gladiolus italicus *	cryptophyte	Bulbous geophyte, polycarpic
Heliotropium bucharicum *	therophyte	Annual
Incarvillea olgae *	hemicryptophyte	Perennial forb with taproot, polycarpic
Iris hippolyti *	cryptophyte	Bulbotuberiferous geophyte, polycarpic
I. magnifica *	cryptophyte	Bulbotuberiferous geophyte, polycarpic
I. orchioides *	cryptophyte	Bulbotuberiferous geophyte, polycarpic
I. svetlanae *	cryptophyte	Bulbotuberiferous geophyte, polycarpic
Lagochilus inebrians *	chamaephyte	Subshrub, polycarpic
Lepidolopha fedtschenkoana *	chamaephyte	Subshrub, polycarpic
Lipskya insignis *	hemicryptophyte	Perennial forb with taproot and caudex, monocarpic
Malacocarpus crithmifolius *	nanophanerophyte	Liana-like shrub
Molucella bucharica *	chamaephyte	Subshrub, polycarpic
Nanophyton botschantzevii	chamaephyte	Prostrate subshrub, polycarpic
Onobrychis tavernierifolia *	therophyte	Annual
Ostrowskia magnifica *	cryptophyte	Geophyte with tuberous root, polycarpic
Oxytropis tachtensis	hemicryptophyte	Perennial partial rosette forb with taproot and thickened caudex, polycarpic
Oxytropis seravschanica	hemicryptophyte	Perennial forb, polycarpic
Paeonia intermedia *	cryptophyte	Geophyte with tuberous roots, polycarpic
Physochlaina alaica *	hemicryptophyte	Perennial forb with taproot, polycarpic
Prangos tschimganica	hemicryptophyte	Perennial partial rosette forb with taproot, polycarpic
Primula hissarica *	chamaephyte	Subshrub, polycarpic
Rhus coriaria *	nanophanerophyte	Shrub
Rubia laevissima *	chamaephyte	Subshrub, polycarpic
Salvia korolkowii *	chamaephyte	Subshrub with a long vertical root and branching caudex, polycarpic
Salvia lilacinocoerulea *	hemicryptophyte	Perennial partial rosette forb with taproot, polycarpic
Salvia submutica *	hemicryptophyte	Perennial partial rosette forb with taproot, polycarpic
Spirostegia bucharica *	therophyte	Biennial forb, monocarpic
Sternbergia lutea *	cryptophyte	Bulbous geophyte, polycarpic
Tulipa affinis *	cryptophyte	Bulbous geophyte, polycarpic
T. bifloriformis	cryptophyte	Bulbous geophyte, polycarpic
T. buhseana	cryptophyte	Bulbous geophyte, polycarpic
T. carinata *	cryptophyte	Bulbous geophyte, polycarpic
T. ferganica *	cryptophyte	Bulbous geophyte, polycarpic
T. fosteriana *	cryptophyte	Bulbous geophyte, polycarpic
T. greigii *	cryptophyte	Bulbous geophyte, polycarpic
T. ingens *	cryptophyte	Bulbous geophyte, polycarpic
T. kaufmanniana *	cryptophyte	Bulbous geophyte, polycarpic
T. korolkowii *	cryptophyte	Bulbous geophyte, polycarpic
T. lanata *	cryptophyte	Bulbous geophyte, polycarpic
T. micheliana *	cryptophyte	Bulbous geophyte, polycarpic
T. orythioides *	cryptophyte	Bulbous geophyte, polycarpic
T. scharipovii *	cryptophyte	Bulbous geophyte, polycarpic

Table A2. *Cont.*

Species	Life Form According to Raunkiaer [44]	Description
T. tschimganica	cryptophyte	Bulbous geophyte, polycarpic
T. tubergeniana *	cryptophyte	Bulbous geophyte, polycarpic
T. turkestanica	cryptophyte	Bulbous geophyte, polycarpic
T. sogdiana	cryptophyte	Bulbous geophyte, polycarpic
T. uzbekistanica *	cryptophyte	Bulbous geophyte, polycarpic
T. vvedenskyi *	cryptophyte	Bulbous geophyte, polycarpic
Zeravschania regeliana *	cryptophyte	Geophyte with thickened taproot and caudex, polycarpic
Zygophyllum bucharicum *	nanophanerophyte	Shrub

Abbreviations: (?) disputed, * included in the latest edition of Red Book of Uzbekistan [45].

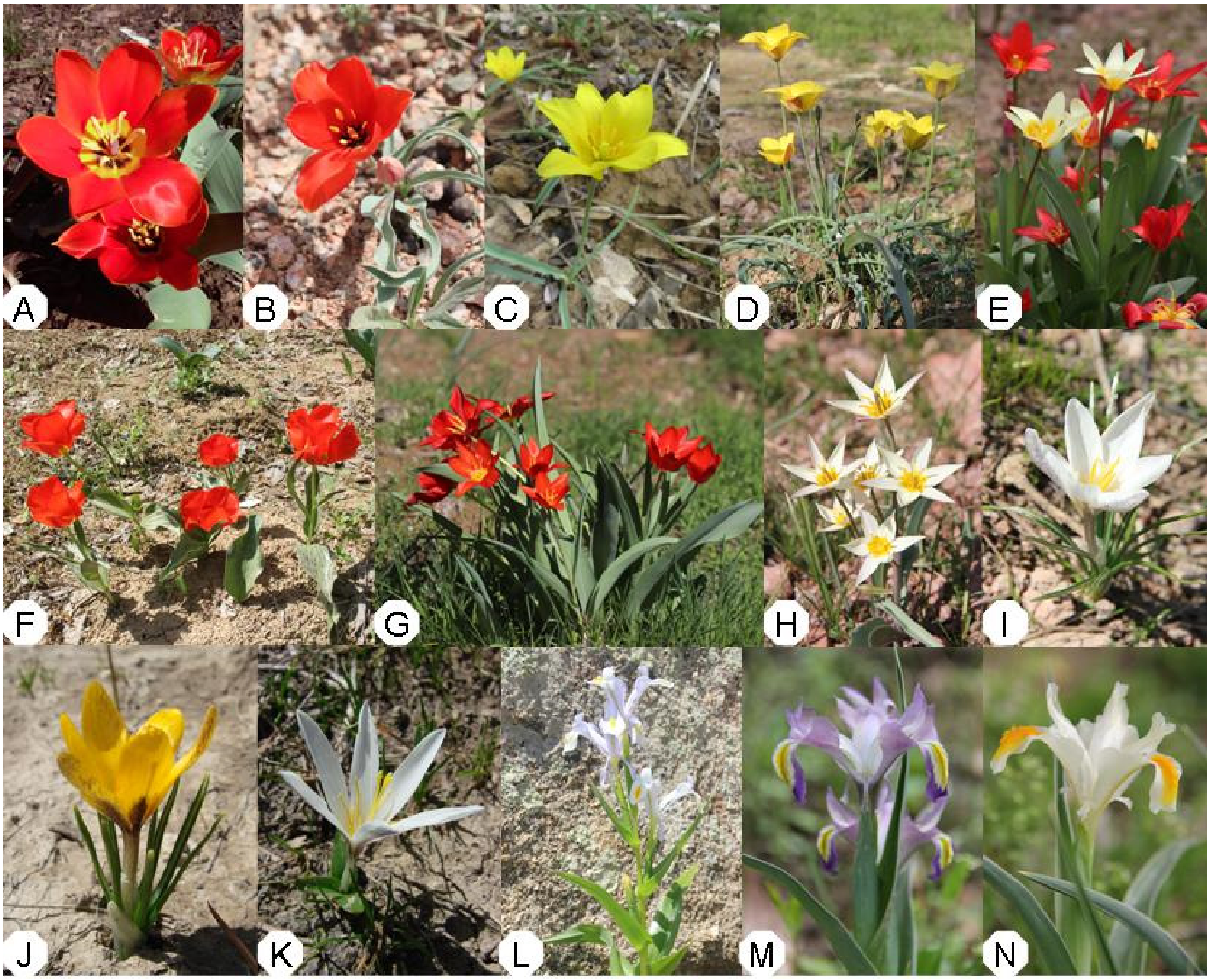

Figure A1. Photos of some species cultivated in TBG. (**A**) *Tulipa uzbekistanica*; (**B**) *Tulipa korolkovii*; (**C**) *Tulipa scharipovii*; (**D**) *Tulipa ferganica*; (**E**) *Tulipa kaufmanniana*; (**F**) *Tulipa greigii*; (**G**) *Tulipa vvedenskyi*; (**H**) *Tulipa bifloriformis*; (**I**) *Crocus alatavicus*; (**J**) *Crocus korolkovii*; (**K**) *Colchicum kesselringii*; (**L**) *Iris magnifica*; (**M**) *Iris hippolyti*; (**N**) *Iris orchioides*. Photos by Natalya Beshko.

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