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Conservation-oriented restoration and its application to Central Asia

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ABSTRACT
Continuing wide-scale habitat degradation and species extinctions indicate that existing plant conservation practices are inadequate and new approaches are needed. I briefly summarize the major principles of a previously proposed concept called conservation- oriented restoration and compare it with two other approaches to tackling ecosystems' degradation and biodiversity loss: traditional restoration and species-targeted conservation. I then present my perspective on how this concept can be applied in Central Asia as a possible solution to the regional biodiversity crisis.

Key words: biodiversity; conservation strategy; restoration; threatened species

Challenges of plant conservation in the 21st century

We are witnessing dramatic, in both intensity and geographic scale, effects of landscape alterations, habitat fragmentation, and biodiversity loss. Virtually no ecosystem has remained intact, and for many of them, the alterations at times exceeded their resilience. In the modified environments, which have no analogues in the past conditions, the historically evolved communities have been replaced by new combinations of species. This abiotic and biotic novelty introduced by humans is difficult for conservation biologists to deal with because existing conservation practices have been developed for environments that are not principally different from historic ones. A brief list of conservation practices available today includes: land protection by law; IUCN species categorization and creating lists of threatened species; *ex situ* collections; reinforcement or reintroduction of imperiled species; and minor interventions in protected areas (e.g. eradication of invasive species and prescribed burning).

Neither land protection, by far the most important conservation approach, nor the other approaches applied alone or together with protection, can solve the problems outlined above (Bridgewater 2016; Heywood 2016; Heywood 2017, 2019) for two reasons. One reason is climate change which effects for many species with narrow environmental requirements and limited dispersal capabilities can be lethal unless some efforts to adjust their ranges are taken. For example, it has been predicted that more than 50% of plant species within European protected areas will lose suitable climatic conditions by 2080 (Araújo et al. 2011). The second reason is an anthropogenic disturbance. The habitat fragmentation and deterioration caused by this disturbance has either eliminated the species or reduced their population sizes below the viability threshold, or precluded their natural regeneration. At a given location, the

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reestablishment of an extinct or recovery of a declining population is possible only if the factors that caused population's extinction, decline or failure to regenerate are identified and dealt with. As a rule, the elimination of these factors requires interventions that either maintain crucial ecosystems processes, such as succession or periodic disturbance, or restore the species ontogenetic niche.

In the new world realities, when habitats, including those in protected areas, are far from pristine, the practices listed above can become useful only if integrated into a new, creative and flexible approach that can cope with altered habitats and guarantee the long-term species survival via improving conditions for existing populations and creating new viable populations. Given that many populations of imperiled species are declining even in strictly protected areas, land protection must foster, instead of prohibiting, interventions that help restore a viable population structure. This means that a new approach should be based on the integration of conservation biology and restoration ecology, as was proposed by several authors (Dobson et al. 1997; Young 2000; Burney & Burney 2007). Conservation biology and ecological restoration are inherently linked because a threatened species can be diverted from a path to extinction only by eliminating its threat, which in majority of situations is a man-made disturbance, being it logging, cash crop planting, livestock grazing or invasion by alien species, and the removal of these threats requires the restoration of once existing conditions, that is, ecological restoration.

The conservation-oriented restoration concept

Major principles

Recently, I introduced a novel approach to plant conservation, called conservation-oriented restoration, based on the idea that prevention of biodiversity loss can be achieved only through interventions in partly degraded habitats and that a focus of plant conservation must not be a threatened species but a habitat in which population(s) of this species can persist (Volis 2016a,b, 2017). The concept resembles a particular form of ecological restoration called «restoration *sensu stricto*» (Aronson et al. 1993; Jackson et al. 1995) bur has a number of important differences.

One such difference is the wide utilization of threatened plant species introduced both within and outside their historic range. Because many rare and imperiled species are likely to be «*anthropogenic rarities*» (Fiedler & Laven 1996), i.e. species whose dramatic reduction in range and abundance is due to a higher vulnerability to anthropogenic disturbance, they can exhibit vigorous growth and reproduction after removal of their immediate threats (e.g. invasion of non-native species, livestock grazing, logging or cash crop cultivation). Nowadays so many species are imperiled (Heywood 2017; Pimm & Raven 2017; Raven 2020) that it should be possible to choose species to be used in restoration plantings that not only belong to a functionally important plant category, a category needed to restore the ecosystem integrity, but whose extinction can be prevented by their usage in restoration planting. This consideration and uncertainty about a cause of rareness for many species should stimulate the enrichment of lists of candidate species for habitat restoration with imperiled species. In many restoration projects, threatened species are present among propagated and planted trees, but usually constitute a small fraction of the latter. The major reason is the difficulty in obtaining large seed quantities for threatened species, poor knowledge of the species reproductive biology and the lack of propagation protocols. However, once these challenges are overcome, the establishment of introduced imperiled plant species in restoration projects is similar to the establishment of non-threatened species (e.g. Millet et al. 2013; Schneider et al. 2014; Subiakto et al. 2016). A reference (i.e. conditions that are used for comparison with a contemporary ecosystem to evaluate changes, for design of management actions and for measuring the success of ecological restoration) in a conservation-oriented project should not be a single ecosystem state but a historical range of variability in ecosystem composition, structure, and function (Clewell & Rieger 1997). Searching for and targeting this range of possible alternative ecosystem states as a reference is needed for several reasons. Often, populations of threatened species are found in only a few locations, representing a small fraction of the original abiotic and biotic variability of the habitat. On the other hand, local biotic communities can enter alternative stable states even when they have the same initial species composition and experience identical environmental conditions (Connell & Slatyer 1977; Beisner et al. 2003; Chase 2003; Schroder et al. 2005), because the community assembly is deterministic in the composition of trait-based functional groups, but stochastic in terms of species composition. Thus, functional groups fill the available niches created by particular environmental conditions, while the species compositions within functional groups is determined by the order of species arrival. As a result, under given environmental conditions, the assemblages converge in species traits but diverge in species identities. In working out a reference, it is important to take into account the climatic fluctuations that have occurred in the past, and it is especially important to consider the climate changes that are happening nowadays. This means that restored ecosystems should be re-aligned with current and expected future conditions, rather than a single pre-disturbance state.

In selecting a restoration site, a priority is the least altered although still needing interventions habitats, and those where threatened species grow or grew in the recent past. Strictly protected areas meeting these requirements are the first choice. Lower priority will be habitats that can potentially host imperiled species currently not present there, are located within protected areas, or are important for their connectivity.

Material for planting can come from two species pools. The first comprises species that historically evolved in a region (characteristic diversity species pool), and the second one constitute regional aliens (derived diversity species pool) (Helm et al. 2015). The regional species pool should be the main, and in most cases, the only source of species to be used in restoration. However, in situations when a functionally important species went extinct and needs to be replaced by a functional analog not presented in the regional species pool, or when an endangered species does not have a suitable habitat throughout the region to which it belongs, a candidate species may come from the second group. Many species in the regional species pool that are absent from the restored community can be considered representatives of the “dark diversity” group, the set of species in a region that do not currently inhabit a site due to human-caused alteration of abiotic and biotic conditions, direct exploitation or low colonization ability (Partel et al. 2011).

The choice of planting material sources should consider local adaptation, i.e. a tradeoff in plant performance across environments. Spatially structured intraspecific phenotypic variation can result from either spatially heterogeneous selection causing adaptation of populations to local environmental conditions or limited gene flow. If the observed spatial structure of the phenotypic variation is due to genetic drift, this can be important for working out a sampling design that captures as much of the species variation as possible, although this variation is neutral and unrelated to the performance of the plants across environments. However, if local selection is important, recognition of the spatial distributions of locally adapted phenotypes is of crucial importance for delimiting the geographic zones within which locally collected seeds can be used for planting. For species having no experimentally obtained data on local adaptation, it is safe to assume that plants in different parts of a range are locally adapted if a species is distributed along a steep environmental gradient or in different climatic / edaphic environments, has intraspecific forms or exhibits reproductive isolation.

Considerations based on presumed or detected local adaptation should take into account the possible climate change effects. For many species, climate change can exceed the species innate capacity to adapt. In this situation, not the local provenances, but source material from geographically and ecologically distant populations may have adaptations that more closely match the new environmental settings. Populations from the leading edge (the expanding part of the species range) suit assisted colonization into cooler and wetter conditions because they are descendants of those populations that experienced expansion after the past climate changes (e.g. glacier retreat) (Cwynar & Macdonald 1987; Thomas et al. 2001). In contrast, the trailing edge should be targeted for intensive sampling to preserve ex situ the unique and most threatened by climate change genetic diversity (Hampe & Petit 2005). Germplasm from the trailing edge can be used for assisted colonization within the core of the species range.

Restoration of habitat by planting appropriate species and their provenances requires seed sources large enough to ensure the production of large quantities of seedlings or saplings. Collecting such quantities of seeds in natural populations is either impossible or undesirable due to the small population sizes and low seed productivity of imperiled species, and the negative consequences that seed harvesting can have on local population demography. Plant germplasm maintained in botanical gardens and arboreta can be used for this purpose, but due to space limitations and high cost, their role will be limited. A better way to bridge *ex situ* and *in situ* through making the former a source of material for the latter is creating living collections of the needed capacity outside botanic gardens and arboreta in natural or semi-natural settings. Such *quasi in situ* collections (Volis & Blecher 2010; Volis 2016d) besides preserving species genetic variation, can be a reliable source of seeds for restoration projects. Because plants in these collections originate from several populations and share the same ecoregion, spontaneous or assisted cross-pollination of these plants will result in the production of offspring not suffering from either inbreeding or outbreeding depression (Volis 2016c). Seeds in *quasi in situ* collections can be produced with certainty, at little or no cost, and collected in the quantities required by nurseries producing outplants. These collections can be especially advantageous for species with low or varying greatly among years seed output, or represented by small isolated populations suffering from inbreeding depression. Conservation-oriented restoration is impossible without close coordination of efforts between in situ practitioners providing seed collection permits and logistic help in collection missions, and ex situ facilities creating and maintaining seed and living collections.

Planting and associated interventions (e.g. creation of favorable microsites such as canopy gaps, pits or deadwood), in order to succeed should be applied in an experimental manner rather than as a single «optimal» treatment because optimal levels of required intervention are species specific and rarely known at the beginning of the project. Thus, in order to create suitable conditions for the target species and ensure the transition of an ecosystem towards a reference, it is necessary to test a variety of disturbance types, their levels and management schemes and compare the results. Another reason for adopting experimentation in restoration is climate change which effects on biotic communities is difficult to predict. Among ecosystems transformed by climate change, limited scale translocation trials will identify those suitable for imperiled species. A good experimental approach to planting and management in conservation-oriented restoration is the creation of mosaics of replicated treatments within mosaics of habitats (Howe & Martinez-Garza 2014). Modified in this way, introduction microsites differ in both abiotic conditions and species composition and serve as sources of colonization by rare species for each other.

Restoration must consider the reestablishment of once existed interactions crucial for ecosystem functioning such as food webs, pollination and seed dispersal. The most important mutualistic systems are fleshy-fruiting plants and frugivores (Brodie & Aslan 2012) and co-evolved insect pollinators and flowering plants (Aslan et al. 2012). Support to colonization or combined translocation of these interacting species is most likely to be necessary to restore the lost ecosystem function. Depending on each other coevolved taxa have rarely been considered in species restoration plans, but must be incorporated into restoration planning and implementation to prevent co-extinction. In situations when having important functional role animals (e.g., pollinators or grazers) went extinct, it is necessary to reintroduce them or, when this is not possible because the species went globally extinct or critically declined in number, to use functionally equivalent substitutes (McConkey et al. 2012).

Protecting the habitat is a prerequisite for any conservation-oriented restoration project - it is a guarantee that anthropogenic disturbance will not happen again. However, strictest protection will often not be able to stop further habitat degradation and species disappearance if it is not accompanied by well-organized interventions. These interventions must be allowed by the protection status of the target site. The implementation of conservation-oriented restoration requires redefining the existing categories of protected areas to allow in these areas i) active interventions; and ii) introduction of imperiled species even if there are no records of their past occurrence.

Goals, attributes and targeted ecosystems

If we compare conservation-oriented restoration with having more utilitarian goals traditional restoration and focusing on particular species species-targeted conservation (Fig. 1), we will see that the three approaches differ in their goals, attributes of their targets and types of ecosystems they are applicable to. Despite some overlap, traditional restoration predominantly focuses on novel ecosystems (e.g. those in which the once existing community structure and composition cannot be fully recovered), while species-targeted conservation focuses on historical ecosystems remaining within their natural range of variability, and conservation-oriented restoration focuses on hybrid ones in which anthropogenically caused changes are reversible. The explicit conservation goals of conservation-oriented restoration are to boost the naturally occurring succession, restore some missing compositional or functional elements and bring the ecosystem back to the pre-disturbance state. Therefore, it can be applied to the hybrid but not the novel ecosystem because only the former can be returned to the pre-disturbance state. Even if some species in the restored ecosystem will differ from those that existed before the disturbance, this ecosystem cannot be called novel.

Although in both traditional restoration and conservation-oriented restoration, the choice of areas for restoration is based on a degree of degradation, the priorities are totally different. In traditional restoration, the priority areas for restoration are the most degraded ones. In contrast, in conservation-oriented restoration priority areas for restoration are the least altered habitats which still need interventions to approach a historical reference, but with reasonable chances and affordable investments. In these areas, the removal of direct threats (e.g. logging or grazing by domestic animals) can initiate a spontaneous ecosystem recovery, but usually a successional change will take too long and not necessarily to a desired state without interventions (e.g. thinning or rewilding). Restoration of once-existing community structure and lost functions is often possible only through the introduction of late-successional and functionally important species. Unlike traditional restoration where the criteria for species selection are rapid growth and high survival rate regardless of whether the species are native or exotic, or even invasive, in conservation-oriented restoration the candidate species for introduction are functionally equivalent imperilled species that went locally extinct or declined in abundance due to the disappearance and degradation of their habitats, or direct exploitation (e.g. logging). In selecting a site, beside a conservation value and feasibility of restoring community to a desired state, two other important criteria are the extent of natural vegetation remaining in the landscape and legal protection status. Lack of legal protection or embedment in a much larger hostile anthropogenic landscape will make any interventions just a waste of effort. Restoration of unprotected and easily accessible area will only increase its value for exploitation, which will follow immediately. In traditional restoration. it is less of concern because a goal of the latter is a pre-disturbance ecosystem service (e.g. quality air or non-eroded soil) and not biodiversity *per se*. Agroforestry, selective logging or bushmeat harvest are often compatible with traditional restoration while in a dramatic conflict with conservation-oriented restoration.

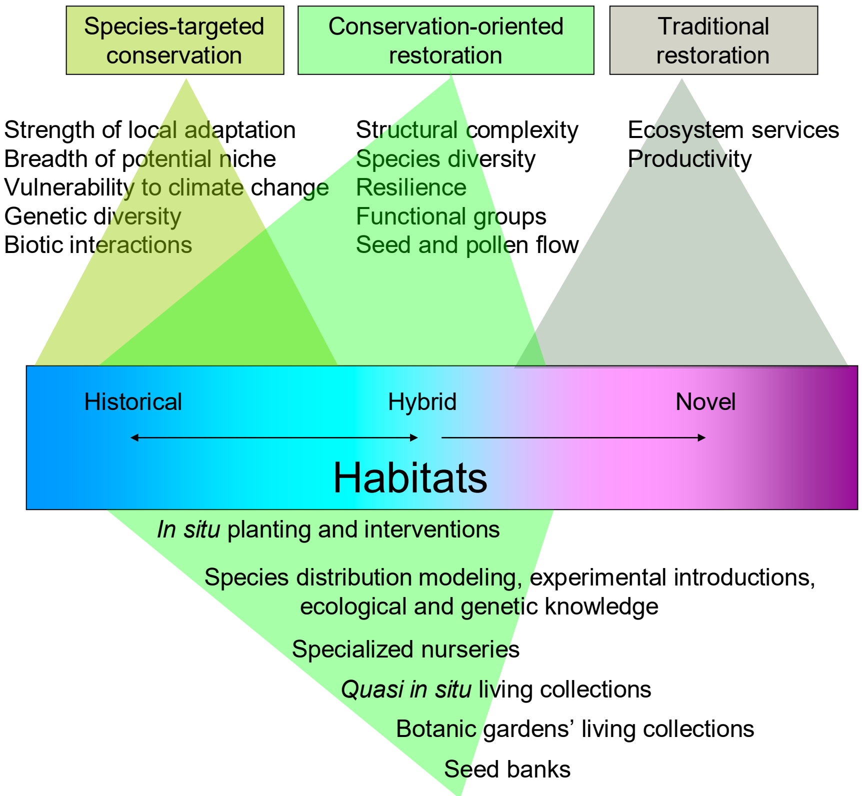

Fig. 1. Three approaches to conservation of species and ecosystems, attributes of their targets on which the approach actions are focused, and the range of ecosystem degradation they can be successfully applied to (terms are *sensu* Hobbs et al. 2013). Vital components of conservation-oriented restoration are listed.

It is important that conservation-oriented restoration seen not as an alternative to either traditional restoration or species-targeted conservation, but as their complement. Because it explicitly focuses on threatened species and targets a suite of imperiled species in a given region rather than one or a few species, it should be more efficient in preventing species mass extinction than both traditional restoration and species-targeted conservation. However, it definitely cannot be applied on a scale at which traditional restoration is practiced. And of course. it does not negate an important role of species-targeted conservation that must continue in well-preserved and relatively undisturbed areas.

Application to Central Asia

There are many indications that current conservation practices, generally obsolete and inefficient in the new realities of the Anthropocene, as described above, are particularly inadequate in Central Asia due to the many specific realities of this region. Below, I will focus on these realities that make traditional conservation approaches particularly problematic when applied to this region. Then I will give my opinion on how the concept of conservation-oriented restoration can be applied in Central Asia as a possible solution to the regional biodiversity crisis.

Threats to biodiversity and their impact

Five Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) occupy a vast territory of about 4 million square km of diverse landscapes with unique biodiversity (Anonymous 2010). Unfortunately, many plant species are highly endangered, and their number is only growing (Khasanov 2019). In general, the Central Asian region is facing a biodiversity crisis as a result of numerous anthropogenic impacts, the main of which are the direct loss or degradation of natural habitats through conversion or exploitation (Kharin 2011). Overall, 14% of the soils in the CA region are totally degraded as a result of intensive and traditional agricultural practices, including over-grazing and deforestation (Qushimov et al. 2007). Historically, this region, like the rest of the world, has suffered from industrialization, economic development and population growth, but in this region the consequences have been particularly detrimental due to the extent of land conversion / impacts and the fragility and low resilience of many regional ecosystems. Most of the lowland semi-deserts and foothills have been converted to agricultural fields, mainly for the cultivation of cotton and cereals, or intensively grazed pastures. The plowing of steeps not only deprived many animals and birds of their traditional habitat, but also caused widespread desertification or the replacement of original grass communities with ruderal ones. As the conversion of natural grasslands to fields has considerably reduced the area available for livestock grazing, it has led to the concentration of domestic livestock in fragile remaining habitats such as unplowed stony and hilly steppe fragments and around water points, with increasing degradation of the latter. Traditional practices such as seasonal movements of the livestock to distant areas have been replaced by year-round grazing around homesteads, leading to overgrazing and soil erosion and suppression of regeneration is these areas. Degradation of grasslands and the predominance of less palatable or unpalatable species reduced the fresh grass yields, causing further increase in grazing intensity by herders. Poor water management and irrigation practices have led to soil salinization. In woodlands, unregulated logging and firewood collection, as well as land clearing for agriculture, have led to the large-scale forest disappearance or degradation. Riparian tugai forests, desert woodlands and mountain forests all have been severely affected. For example, 90% of fruit and nut forest habitats have been lost in the last 50 years (Conservation International 2008). In Kyrgyzstan, 35% of fir and juniper forests disappeared within a few decades (Anonymous 1998). The collection of threatened plants for sale (e.g., various tulip species) and for household use (e.g., medicinal plants), as well as poaching, has been and continues to be widespread.

Flora endemism and vulnerability

A distinct feature of Central Asian flora is its high level of endemism (Korovin 1962; Kamelin 1973; Tahktajan 1978). According to the latest survey, there are 9,341 taxa representing 161 families and 1,288 genera occurring in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan (Khassanov 2015). Approximately 10% of them are endemic. Especially rich in endemics are the mountains of Central Asia, making them a recognized global biodiversity hotspot (Davis et al. 1995; Myers et al. 2000). For example, the Tian-Shan, one of the most important mountain sub-regions of Central Asia, has 871 species and subspecies of vascular plants endemic to this area, of which 225, 205, 69 and 16 species are national endemics of Kyrgyzstan, Kazakhstan, Uzbekistan and Tajikistan, respectively (Tojibaev et al. 2020).

The high level of endemism of Central Asian flora is the result of geological processes taking place in Eurasia during the last approximately 50 million years, which created the current topographic landscape and climatic conditions. Major components of Central Asian flora evolved mostly in the Neogene, after topographic changes (the disappearance of the eastern part of the Tethys Sea and Alpinian orogeny) and the transition from a humid Paleogene climate to an arid one after the uplift of the Tibetan plateau, which created a barrier for humid monsoons, with the formation of deserts, semi-deserts and steppes (Miao et al. 2012; Caves et al. 2016). At the same time, this barrier caused the climate cooling, which in mountain areas depressed the tree line, compressed altitudinal zonation, and created strong environmental heterogeneity. Floristic changes followed these orogenic and climatic changes with a transition from thermophilic Paleogene flora to xerophytic and from temperate to alpine flora by the mid- to late Neogene (Barbolini et al. 2020; Spicer et al. 2020). However, the islands of the Tethys Sea that became mountains and hills after elevation, could preserve relics of the Paleogene flora, and, indeed, we see in the current Central Asian flora relict taxa of Eocene subtropical vegetation and Oligocene mesophitic forests. These relics are often associated with ancient soil outcrops such as Tertiary variegated gypsum soil surrounded by Quaternary alluvial and deluvial sands and loess (e.g. rich in endemic species genus *Otostegia* Benth.) (Kudryashev 1939).

The survival of relict taxa in Central Asia at the generic level was accompanied by intensive speciation and adaptive radiation within genera due to rapid environmental changes and heterogeneity over short distances in mountain areas. This is especially true for many Neogene genera (e.g. *Astragalus*, *Silene*, *Salvia*, *Allium*, *Eremurus*, *Cousinia*) having numerous species localized to very specific habitats and having tiny ranges of only a few square kilometers (Popov 1927; Kamelin 1973). Many species can be found only within a very narrow altitudinal range, at specific slope exposition, in a contact zone of two edaphic types, the most humid or protected from the wind microhabitats etc (Popov 1927; Kamelin 1973). Thus, a specific evolutionary history and high regional climatic, topographic and edaphic heterogeneity are responsible for high regional species richness and a large number of endemics.

Restricted ranges and narrow habitat specialization characteristic of most of Central Asia endemics make these species especially vulnerable to human impacts. Many red-listed Central Asian species are known from only a few or a single location. For example, in Uzbekistan, in the latest edition of the country Red Book (Khasanov 2019) 46 plant species have the CR (critically endangered) status. Of these, 11 have less than 5 occurrence records, and 16 are known from a single location. In Tajikistan, the numbers are even more striking: out of 271 species having CR status, 235 are known from a single location (Nowak et al. 2020). As the anthropogenic impact on the last remaining natural habitats is only increasing, the extinction of these species is only a matter of time.

Conservation of regional biodiversity

An important component of nature conservation in any country is the creation of national lists of endangered species - the major legislative instruments to protect wild plants and animals. The Red Data Books and Red Lists are among the most widely used tools to draw attention to species of conservation concern. Such lists are intended not only to raise awareness but also be linked to actions at national and/or international level. For example, in Australia, 17 out of 18 plant species for which national recovery plans were developed and implemented are in the highest risk category (Possingham et al. 2002). Unfortunately, in Central Asia, Red Lists of plants, unlike animals, are rarely used for planning and implementing recovery plans, because this kind of conservation activity practically does not exist for plans in the region, with only a few timid steps in this direction (Eastwood et al. 2009; Orozumbekov et al. 2015). General recommendations that use the words «improve», «pay attention» and «study further» are common, but I failed to find a single publication reporting a concrete plan for any Central Asian threatened plant species. Thus, being overly important in terms of legislation (e.g. as necessary information for the Convention on International Trade in Endangered Species or for regulation of exploitation as a natural resource) and having a certain impact on governmental economical and social decisions, Red Lists role in direct conservation regional planning (e.g. programs of reintroduction, habitat restoration or creation of *ex situ* collections) is close to zero.

Ex situ conservation (e.g. preserving a species outside its natural settings) is a cost-effective conservation approach providing a species during its storage/cultivation immunity to habitat destruction, grazing and predation. The Global

Strategy for Plant Conservation sets a requirement of preserving at least 75% of threatened plant species in *ex situ* collections, preferably in the country of origin. Especially effective in this respect seed banks because seeds can be collected in relatively large numbers with minimal impact on a natural population, and stored for long periods of time at relatively low cost of maintenance (Guerrant et al. 2014). An important advantage of seed banks over living collections is that for the same amount of genetic diversity they require much smaller space. For example, a typical cold room in Kew's Millennium Seed Bank stores 1 billion seeds representing 20,000 seed collections in just 30 m^3 (Smith 2014). These advantages are well recognized internationally, and, for example, the Western Australian Threatened Flora Seed Center has 332 Critically Endangered collections in storage (Cochrane et al. 2007). In North America, around 21% of 9496 extinct in wild, endangered, or vulnerable plant species native to North America (the United States, Mexico, and Canada) are maintained in seed bank collections in these countries (Kramer et al. 2011). In Europe, 63% of European threatened species are conserved in seed banks (Rivière et al. 2018). In Central Asia, the only seed bank of wild plants is in the Institute of Botany and Phytointroduction in Almaty. According to https://informburo.kz/stati/kak-rabotaet-botanicheskiy-sad-almaty.html, this seed bank has 548 species in its collection, but there is no information on how many of these species are red-listed. It is possible that some threatened species (such as wild crop relatives) are present in seed banks outside Central Asia. However, absence of seed banks in four out of five Central Asian countries is puzzling because seed banks do not require expensive equipment or special maintenance, and the international standard conditions for long-term seed storage (temperature -18°C and a seed moisture content 3–7%, (FAO/IPGRI 1994) can be easily provided in every Central Asian country.

Botanical living collections is another important *ex situ* conservation approach. The Convention on Biological Diversity (https://www.cbd.int/) recognizes the value of *ex situ* conservation in botanic gardens as a support to the «recovery and rehabilitation of threatened species and for their reintroduction into their natural habitats» (Wyse Jackson 1997). The IUCN Species Survival Commission policy on *ex situ* conservation states that «for a growing number of taxa *ex situ* management may play a critical role in preventing extinction as habitats continue to decline or alter and become increasingly unsuitable» (IUCN/SSC 2014). Many botanical gardens work closely with conservation agencies, maintaining threatened species in their living collections and providing seeds and plantlets for various reintroduction and restoration programs (Guerrant & Raven 2003; Wendelberger et al. 2008; Noël et al. 2011; Fotinos et al. 2015; Shaw et al. 2015; Fenu et al. 2016; Menges et al. 2016; Zimmer et al. 2016). Every Central Asian country has at least one botanical garden. However, the gardens' collections of threatened species, if exist, are small, maintained primarily for research or education, and have never provided material for *in situ* conservation programs. In other words, there has never been a direct link between *ex situ* and *in situ* conservation in Central Asia.

Legislative land protection, the most important component of nature conservation, received close government attention during the Soviet era, and a system of 30 nature reserves was created to preserve the major Central Asian ecosystems and regional species diversity. These areas were well protected with a strict prohibition of not only any utilization of the reserve natural resources but even entry being permitted to the reserve personal and researchers only. This well-organized and properly functioning protected area system has suffered huge losses in terms of budget, staff qualifications and motivation in the 30 years after the collapse of the Soviet Union. Besides, the governmental policy of the new independent states has become much more liberal towards visitors. As a result, in many PAs the cases of poaching, illegal cutting of timber, incidents of man-made fires and heavy grazing by domestic livestock are sad reality. For example, in Badhyz Nature Reserve (Turkmenistan), which major goal since establishment in 1941 was to protect kulan

(*Equus hemionus* Pallas), the population of this species accounted about 5000 individuals at the beginning of the 90th (Gorelov 1999). In the next two decades poaching has made this species functionally extinct in Turkmenistan, with no confirmed observations since 2015 (Kaczensky 2019).

Currently, the number of strictly protected territories and the area they cover in Central Asia is very small considering its ecological diversity, endemism and vast territory. From the existing or in a process of legislation approximately 300 PAs (categories I-VI), only 41 (Anonymous 2011) or 36 (WDPA 2020) represent categories Ia and Ib, and these areas cover only 1.2% of the Central Asian territory (WDPA 2020). Over the past 20 years, there has been a trend towards an increase in the number of protected areas, but very few of the new established areas were the strictly protected nature reserves. The goal of the majority of the new PAs was preservation of some scenic views or natural features rather than safeguarding ecosystems, flora and fauna; in these areas visitation and recreation are encouraged, and continuous human interaction with nature allowed by law. This pursue of tourism as an economic growth priority, or at least as something more important for a government than nature conservation, is not something specific to Central Asia. A similar situation exists in China (Volis 2018). In China, although many local governments proclaim protecting nature as an important goal of their region development, actions on behalf of this goal are not in favor of supporting active conservation. Instead the funds flow to build high-profile tourist attractions and supporting them infrastructure. We may expect that, like in China, the newly established Nature Parks will become crowded with visitors, packed with hotels and shops, and intersected with roads. Probably this is important for increasing a choice of recreational activities available for the country population, but these developments hardly will help to preserve biodiversity in the area.

Another problem, beside low cover of the regional territory by the strictly protected NRs, is the actual level of protection these reserves provide. This level can be surmised from the scarce available literature. Orozumbekov et al. (2015) assessed status of 10 threatened fruit and nut tree species of Kyrgyzstan. A field survey was carried out across the entire range of walnut-fruit forests in this country, supported by a socio-economic survey. Sample plots were established in 10 forest locations, one of which was the Sary-Chilek Biosphere Reserve. Signs of human disturbances (tracks, burning, presence of browsing livestock, browsing on seedlings, saplings and tree twigs, tree cutting) were common throughout the reserve territory, and 100% of interviewed local villagers responded that they allow their grazing animals to enter the forest. The extent of damage did not differ from that of other surveyed unprotected areas. In Tajikistan, a forest survey and semi-structured interviews were conducted in Dashtijum Nature Reserve to study forest composition, tree population demography and assess the use of forest resources by local villagers (Pilkington et al. 2020). There were high levels of livestock grazing within the reserve, only a few plots had seedlings and saplings, and most households admitted to grazing livestock illegally in the forest. The authors attributed illegal grazing to a disregard for grazing laws, which they believe is systemic throughout the community, resulting from family ties between those protecting the forest and those grazing the livestock. We can only hope that the situation will improve and that patrolling protected areas will one day be at least as good as it was under Soviet rule. However, the damage made to many existing Central Asian protected areas over the past 30 years is so severe that their ecosystems may not return to their pre-disturbance state through natural re-vegetation, even if illegal activities are stopped.

The combination of high regional endemism and biodiversity, small number and size of populations of threatened species, strong anthropogenic pressure and a small number of existing protected areas have created in Central Asia a situation when only a minor fraction of endangered plant species have their populations in NRs and NPs. For example, Lazkov et al. (2002) noticed that only a negligible number of rare plant species of Kyrgyzstan are protected in the country's NRs. Volis and Tojibaev (2021) found in their study of critical habitat of 50 most endangered plant species of Uzbekistan, that about half of these species not only do not have any records of occurrence within the existing protected areas, but even their predicted as suitable habitat (which covers substantially larger territory than the known occurrences) is outside any NR / NP. Moreover, for many endangered species listed as protected in NRs / NPs, the majority of their populations are in unprotected environment. These populations are very small, declining and are in a degraded environment that has no conservation value. Protecting these remaining populations via establishing Plant Micro-Reserves (Laguna 2001), a solution that has proven effective in some Mediterranean countries (Laguna et al. 2004; Kadis et al. 2013; Laguna et al. 2016), will not work in Central Asia due to cultural differences and much stronger anthropogenic pressure. In Central Asia, preserving plant species is possible only in relatively large protected areas that can be regularly inspected by rangers. Although inspection of these areas by rangers currently is not very effective, and violation of bans is common, the situation can be improved with better funding, enforced motivation of rangers and education of the local communities. Much more problematic, even under much improved funding, is establishing new protected areas in areas important for biodiversity conservation, a procedure that is not only very time-consuming and bureaucratically complicated, but is always in conflict with regional economic development and therefore harshly opposed by local administration.

Proposed solution

Summarizing the role of existing conservation approaches in the preservation of Central Asian flora, we have to state that in this region plant Red Lists play very little, if any, role in conservation planning, *ex situ* conservation virtually does not exist, and *in situ* conservation has serious problems in terms of how well the ranges of threatened species are covered by protected areas and how efficiently these areas are safeguarded. What can we do to make all these approaches work and work properly in Central Asia? I propose to use the concept of conservation-oriented restoration as a methodological ground for working out a solution.

As I tried to show above, plant protection in Central Asia faces a challenge when many habitats that are home for a large number of imperilled species (e.g. steppes, semi-deserts, low mountain areas) are underrepresented in protected areas, but establishing a network of new reserves and parks supplemental to the existing ones that would cover adequately these habitats is unrealistic. The solution is, while struggling for creation of new protected areas, to use the very few existing in these habitats protected areas as «refuges», making them the major focus of *in situ* conservation. Focusing on these areas will make possible stricter protection against poaching, collecting and grazing. The latter, in turn, will greatly increase the chances of successful introduction to these areas of a large number of endangered species which environmental requirements match the local conditions. The procedure for the latter is shown in Fig. 2 using as an example 12 critically endangered plant species of Uzbekistan. It is important to note that while most endangered species hardly played an important functional role in the ecosystems from which they disappeared or where they became rare, many of them do belong to the category of functionally important and even keystone species.

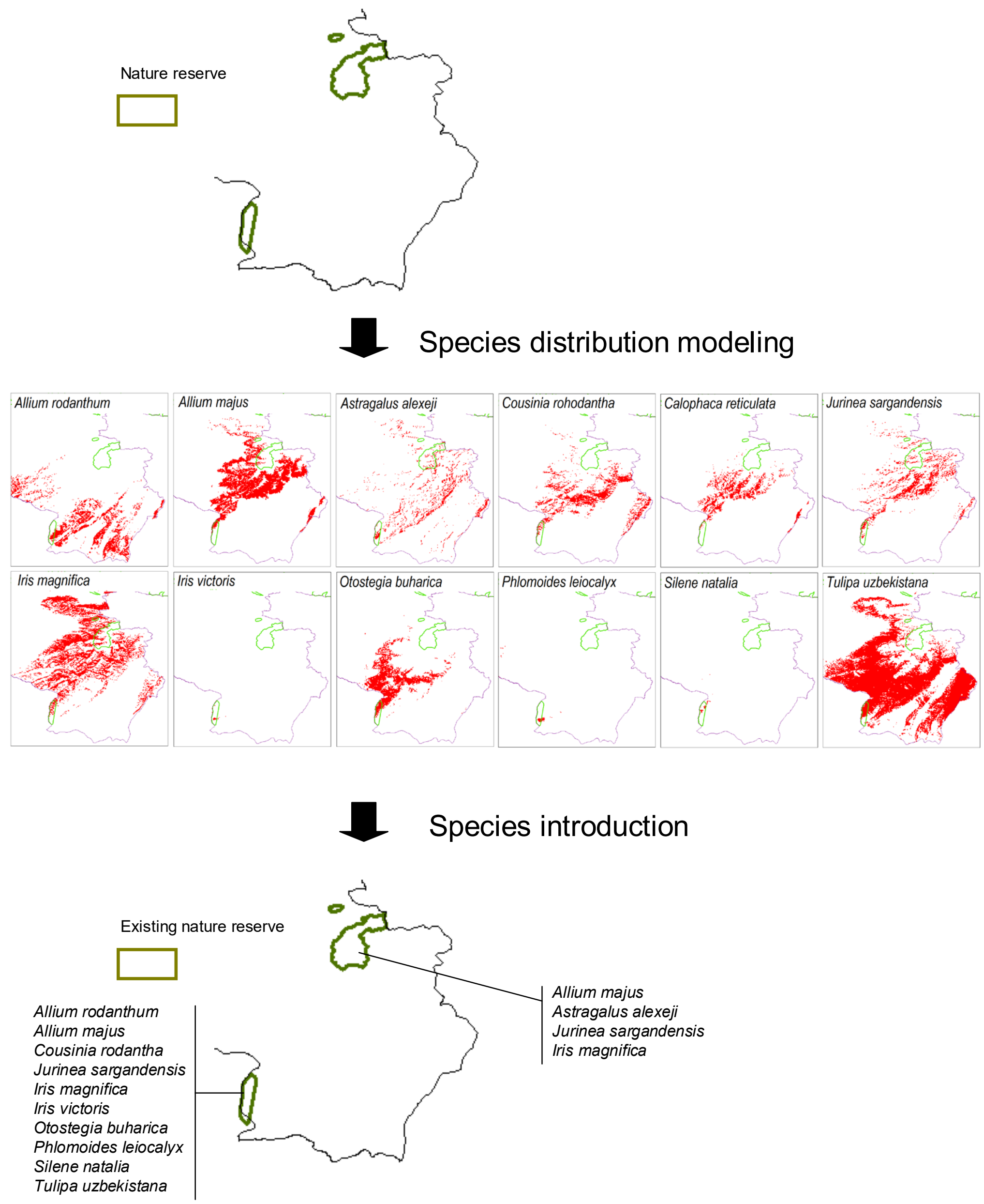

Fig. 2. Creation of new populations of endangered plant species in the existing nature reserves based on results of SDM. At first, species distribution modeling is used to produce for 12 critically endangered in Uzbekistan plant species their habitat suitability maps. Based on these maps, the species are assigned to the lists of species to be introduced into Gissar and Surkhan nature reserves.

For example, listed in the Red Book of Uzbekistan (Khasanov 2019) woody species *Platanus orientalis* L., *Punica granatum* L., *Ficus carica* L., *Diospyros lotus* L. in the past were common species as they still are elsewhere. These species can be used for reforestation of river banks and forest clearings that resulted from illegal cutting or fires to restore once existing vegetation communities.

Due to the huge number of plant species that are threatened, both species prioritization and simultaneous work with many species are necessary. The first targets must be red-listed species having the highest categories CR and EN. Many CR species are known only from herbarium specimens and may actually be extinct. Therefore, it is necessary to conduct a complex, ecoregion-based inventory study.

During this field survey focusing on the known species locations, many CR species no longer present there can be assigned to a group of presumably extinct species. Since the resources that can be allocated to conservation are always limited, it is important not to waste them. Species still having natural populations can be targeted for the next steps. They must be organized into lists according to their ecoregion and habitat / vegetation community, and dealt with as groups of species rather than as separate species. The highest level in subdivision of Central Asian territory should be 24 terrestrial ecoregions from the «Global 200» list of Olson & Dinerstein (1998), which are represented in Central Asian countries (Table 1). A finer subdivision should be based on climatic, topographic and edaphic differences, but not on political criteria (i.e. country borders).

For the practical realization of the idea of introducing endangered species into protected areas whose local environment matches these species requirements, several technical issues must be solved. It is known and was already mentioned above that obtaining large seed quantities of threatened species is a difficult task, since the populations of such species usually are few and small, and seed production is limited or completely absent. This especially applies to Central Asia. For example, in the only remaining population of the red-listed in Kazakhstan *Corylus avellana* L., only 30% of the examined adult trees were producing fruits, and majority of these fruits were damaged by pests and diseases (Kushnarenko et al. 2020). Likewise, individuals of the critically endangered in Uzbekistan *Otostegia bucharica* B.Fedtsch. occasionally bear fruits, but all the seeds examined were damaged by insects (Tojibaev, unpublished data). This makes necessary the establishing a well-organized and properly funded seed collection program. For species with problematic seed production, vegetative propagation should be tried. Previously, propagale collection missions were occasionally organized in Central Asian countries for selected threatened species, usually wild progenitors or relatives of crops. The collected seeds were then stored in seed banks or used for creation of horti- or agricultural living collections. The intended use of these collections never included introduction *in situ*. For example, several collecting trips were organized in Central Asia by the U.S. Department of Agriculture and Cornell University in 1989 and 1993 to collect seeds of wild *Malus sieversii* M.Roem. In 1992, an *ex situ* plot was established in US to examine the collected accessions for desirable horticultural traits and resistance to diseases.

A much-needed program of seed collecting in Central Asian countries must have an explicit objective of a) storage in seed banks; and b) use for the creation of *quasi in situ* collections. The concept of these collections is briefly described above and detailed elsewhere (Volis & Blecher 2010; Volis 2016d). Not only seeds can be collected, but also bulbs, rhizomes or stem cuttings. Since protection is vital for these collections as much as for *in situ* populations, they should be established in protected areas as well. Either buffer or core zones of a protected territory can be used depending on the suitability of conditions and strength of protection. Properly organized *quasi in situ* collections can guarantee production of healthy, showing good performance offspring with certainty, at no or very low cost and in large quantities. It is important that the planning and implementation of conservation actions is done at the regional rather than national level. Wilson et al. (2021), studying 10 Central Asian tulip species, came to a conclusion that a regional approach is crucial for tulip conservation efforts, and most likely for Central Asian plant conservation in general. It is impossible to disagree with this conclusion, because in this region the ranges of many endangered species are not confined to one country, but usually span the borders of several countries. One recent study performed on an endangered Central Asian species can highlight many points presented above. *Malus niedzwetzkyana* Dieck, the presumed ancestor (along with *M. siversii*) of most domesticated apples and once a key component of the walnut–fruit forests of Central Asia, is nowadays restricted to a few small, isolated populations.

Table 1. The terrestrial ecoregions from the «Global 200» list ((Olson & Dinerstein 1998)) represented in Central Asian countries

Major habitat type	Ecoregion	Central Asian country
Deserts and xeric shrublands	Paropamisus xeric woodlands	TJ
	Kopet Dag semi-desert	TU
	Kazakh semi-desert	KZ
	Junggar Basin semi-desert	KZ
	Central Asian southern desert	UZ, TU, KZ
	Central Asian riparian woodlands	UZ, TU, KZ
	Central Asian northern desert	UZ, KG, KZ
	Caspian lowland desert	KZ, TU
	Badghyz and Karabil semi-desert	UZ, TU, TJ
Montane grasslands and shrublands	Tian Shan montane steppe and meadows	KG
	Pamir alpine desert and tundra	TJ, KG
	Kopet Dag woodlands and forest steppe	TU
	Altai alpine meadow and tundra	KZ
Temperate grasslands, savannas, and shrublands	Tian Shan foothill arid steppe	KZ, KG
	Pontic–Caspian steppe	KZ
	Kazakh Uplands	KZ
	Kazakh Steppe	KZ
	Kazakh forest steppe	KZ
	Gissaro–Alai open woodlands	UZ, KG, TJ, KZ
	Emin Valley	KZ
	Altai steppe and semi-desert	KZ
	Alai–Western Tian Shan steppe	UZ, TJ, KZ, TU
Temperate coniferous forest	Tian Shan montane conifer forests	KZ, KG
	Altai montane forest and forest steppe	KZ

Abbreviation: KZ – Kazakhstan, KG – Kyrgyzstan, TJ – Tajikistan, TU – Turkmenistan, UZ – Uzbekistan

The four locations with the largest populations of this species, all located in the Jalal-Abad region of Kyrgyzstan, were the subject of a study by Wilson et al. (2019). At these sites, Wilson and colleagues analyzed the population structure of *M. niedzwetzkyana*, focusing on the species regeneration capacity. In addition, they conducted species distribution modeling to identify climatically suitable areas for *M. niedzwetzkyana* throughout Kyrgyzstan. Based on the SDM results, the authors concluded that the potential species range is considerably greater than currently known. As for the four studied populations, only one (located in the protected area) had some regeneration capacity, and even in that population, regeneration was limited due to the small number of reproducing trees. At two sites, the populations showed a reduced regeneration capacity, and at the fourth location, *M. niedzwetzkyana* went extinct. The authors recommended focusing conservation work in the region on two locations with regenerating *M. niedzwetzkyana*, the least degraded environments, and with the support of local community for conservation in these areas. The other two locations showed signs of extensive damage, indicating a failing or absent management system. One of these places had the status of the Reserve but did not correspond to it. The authors noted the lack of prospects for reducing the damage caused by neighboring villages to these two sites due to "insufficient capacity within the socio-ecology of these rural villages to reduce resource use and control livestock". In other words, any investment in the restoration of these two sites would make little sense under continuing logging, firewood collecting and grazing. What we can learn from this study is that all extant populations of *M. niedzwetzkyana* need reinforcement with new planted individuals, and their locations require some restoration work. Some of these populations can be effectively protected but not all. And *M. niedzwetzkyana* can probably survive in other protected areas for which we have no historical records of its occurrence. Recommendations based on this knowledge and utilizing the conservation-oriented restoration concept are as follows: 1) carry out a properly organized seed collection across the current species range; 2) create seed and living collections; 3) raise a large number of seedlings/saplings in specialized nurseries from the collected in natural populations and subsequently from seeds produced in living collections; 4) focus restoration and planting efforts on locations with the most viable populations of *M. niedzwetzkyana* that can be effectively protected; 5) conduct the experimental introduction of this species into other well protected locations identified by SDM as suitable. Ideally, a conservation plan for *M. niedzwetzkyana* should be placed within a more global context of Central Asian walnut–

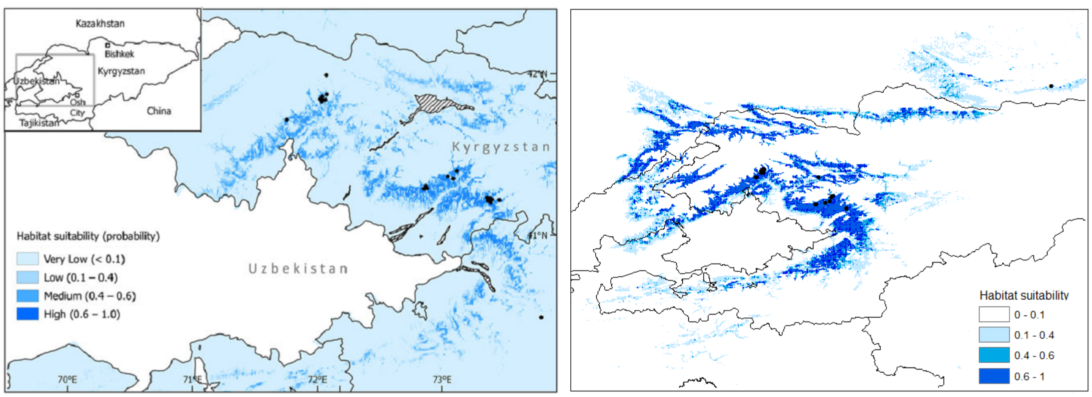

Fig. 3. Predicted suitable habitat for *Malus niedzwetzkyana*. Left: spatial extent of the modeling was limited to the western Kyrgyzstan (from Wilson et al. 2019). Right: spatial extent of the modeling included the adjacent countries. The two modeling studies utilized the same environmental variables. The used occurrence records are shown as dots.

fruit forest restoration, and not be restricted to a single Central Asian country, because, as can be seen in Fig. 3, the predicted as suitable for *M. niedzwetzkyana* habitat extends beyond Kyrgyzstan. A conservation planning for the Gissaro-Alai open woodlands ecoregion (WWF ID: PA0808) should include, as target species, beside *M. niedzwetzkyana*, also globally endangered (as assessed by IUCN) *Amygdalus bucharica* Korsh., *Armeniaca vulgaris* L., *Malus sieversii*, *Pyrus korshinskyi* Litv. and probably rapidly declining *Crataegus pontica* K.Koch, *Pistacia vera* L. and *Sorbus persica* Hedl. Many endangered non-arboreal species that have occurrence records in Tien Shan mountains, should be examined, using expert knowledge and SDM, for their introduction into existing in this region reserves Sary-Chilek (Kyrgyzstan), Gissar, Zaamin and Chatkal (Uzbekistan), Ramit (Tajikistan).

Disclosure statement

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