Recovery of critically endangered plant species in India: need for a comprehensive approach

G. Ravikanth[1,*], M. R. Jagadish[1], R. Vasudeva[2], R. Uma Shaanker[1,3] and N. A. Aravind[1]

[1]Ashoka Trust for Research in Ecology and the Environment, Royal Enclave, Srirampura, Jakkur Post, Bengaluru 560 064, India
[2]College of Forestry, University of Agricultural Sciences, Sirsi 581 401, India
[3]School of Ecology and Conservation, and Department of Crop Physiology, University of Agricultural Sciences, GKVK Campus, Bengaluru 560 065, India

There has been a growing concern about the increasing number of species that are globally threatened. Developmental projects, and increased dependence on forests both for sustenance and livelihood have rendered many species threatened. In the Indian context, more than 150 species are critically endangered and require immediate intervention to sustain their populations. A number of plant species are destructively extracted solely from the forests. Apart from anthropogenic threats, several species are threatened due to invasive species and climate change. In the light of increasing and continued threats, species recovery is the only viable option for restoring many of them from extinction. Here, we review the existing recovery programmes in the country and suggest a comprehensive approach in the conservation and recovery of many of the critically endangered species. We highlight issues that need to be addressed and discuss strategies for recovering the critically endangered species in the country.

Keywords: Endangered plants, ecological interactions, genetic enrichment, niche modelling, species recovery.

Introduction

IN India, as in many other tropical regions, intense developmental activities over the last few decades have left behind forests that are highly fragmented and non-contiguous. It is estimated that in India about 1052 species are Red-listed, which also includes several hundreds of medicinal plants[1]. Among these, eight species are already extinct, and 75 animal and 77 plant species are critically endangered (Figure 1)[1]. In the Western Ghats alone, more than 100 tree species of high economic importance are threatened and critically endangered. For many of these critically endangered species, the major threat is their extremely small population sizes, far below the size that can sustain them (due to inbreeding and loss of genetic variability)[2]. Thus, unless urgent conservation action is taken up in terms of recovering these species, many of them may be completely lost. A species is critically endangered when its population size reaches a critical lower limit and unless measures are taken to restore the species, it would become extinct (Figure 2). Recovery is the process by which the decline of a threatened species is arrested or reversed and threats removed so that its survival in the wild can be ensured. The ultimate goal is the recovery of threatened species and the ecosystems on which they depend.

Several countries worldwide have initiated national plans to address the resurrection of rare, endangered and threatened (RET) species. Species recovery programmes have been systematically carried out in countries like the United States, Canada, Great Britain and Australia. In most of these countries, special legislation like the Endangered Species Act, 1973, United States of America (ESA) has been implemented to carry out species recovery programmes. The ESA, which was put into force in 1973, has provisions for listing the species as endangered, developing recovery plans for each species and designating critical habitats. Thus, in the US, 1158 species have special recovery programmes[3]. In the past few years, populations of 47 species have been stabilized through various recovery processes and are now de-listed from the recovery programme (https://ecos.fws.gov/ecp0/reports/delisting-report). The bald eagle, for example, had reduced to just 450 individuals in 1967 and was declared as endangered (www.baldeagleinfo.com). However, captive breeding of individuals and subsequent release into the wild resulted in the population bouncing back to about 4500 individuals. Subsequently, the bald eagle has been delisted from the endangered list in 2007 (www.baldeagleinfo.com). Many other critically endangered species in the US such as California condor, black-footed ferret, peregrine falcon, grey whale, whooping crane, red wolf, etc. have also been saved from extinction. Through recovery programmes there has been either an increase in the population size (green pitcher plant), habitat restoration (Aleutian Canadian goose), captive breeding (black footed ferret, bald eagle, etc.) or population stabilization (fringed orchid)[3]. In this article, we discuss the status of the threatened species in India and potential issues in

*For correspondence. (e-mail: gravikanth@gamil.com)

recovering them, and suggest possible steps in carrying out species recovery in the country.

Species recovery in India

In India, like in many other tropical countries, a number of species are under the threatened category. The country's 1.34 billion people, about 18% of the world's population, exert tremendous pressure on the forest areas for agriculture, commercial crop plantations and other developmental activities. Many of the economically important plants are severely threatened due to excessive harvesting. Among the 1052 species in the threatened category, 36% of plants are Red-listed[1]. Many economically important plants in India are often considered as semi-public goods and unregulated harvest from the wild goes unabated. It is estimated that in the Western Ghats alone, many species of high economic importance may be threatened and critically endangered. Many of the species have population sizes far more precarious than those reported for some of the well-known animals such as the great panda, cheetah, or the grey wolf. For instance, *Semecarpus kathalekanensis*, a dioecious canopy tree, is restricted to merely four freshwater swamps in the Western Ghats with a total population of only 42 breeding individuals[4]. *Syzygium travancoricum*, an economically important tree species is reported to exist with a population size of only 15–20 individuals[4]. Similarly, only 14 individuals of another endangered species *Dipterocarpus bourdillonii* were found to occur in three patches in Kodagu district, Karnataka[5].

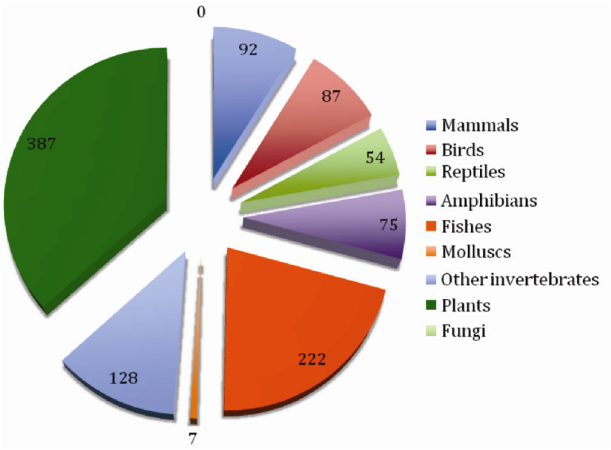

Figure 1. Number of species in the threatened category in India[1].

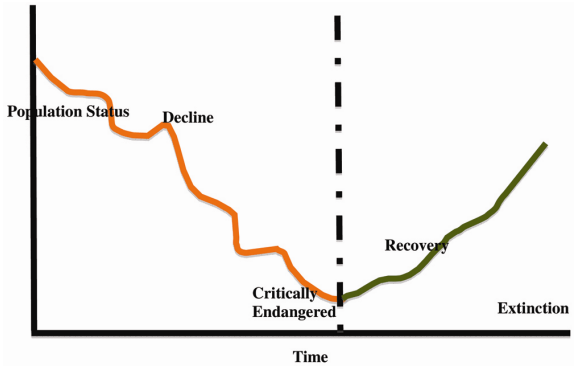

Figure 2. Schematic diagram representing the population status of endangered species before and after recovery.

The state of medicinal plants in India is precarious. About 880 medicinal plants are traded in the country[6]. The analyses of these 880 species with respect to their parts in trade indicate that 66% of them involve harvesting of roots, bark, wood stem or the whole plant. Harvesting of such parts, in respect to perennial shrubs and trees, has implications on the survival of these species. Further, of these 880 species, 538 (61%) occur only in the wild[6]. In recent years, due to the liberalization policies of the government, the export of both Ayurvedic and Unani commodities has increased both in quantity and value terms. In 2016, India exported herbal products to the tune of 20,000 crores[7]. This has resulted in increased extraction of these commodities from the wild. In fact, analysis of the RET status of medicinal plants indicates that around 100 species (58 of which are globally threatened) of medicinal plants in the Western Ghats are highly threatened due to excessive harvesting.

Excessive harvesting and large-scale developmental activities have resulted in fragmentation and reduced population size for a number of species. Such small population size can lead to loss of genetic variability resulting in inbreeding depression, loss of alleles and overall genetic impoverishment[2]. As trees require decades for population re-growth, their present abundance cannot be considered healthy if their regeneration is lacking or habitat is shrinking or destructive over-harvest is on the rise. Fragmentation of populations has resulted in increased inbreeding due to limited pollen and seed dispersal flow, and this could impact regeneration of the species[8]. For instance, in *Dysoxylum malabaricum*, an endangered species in the Western Ghats, mating between related individuals due to inbreeding has led to reduced regeneration[9].

Thus, unless urgent steps are taken to restore the population of some of these species, they may be irreversibly lost. However, because species recovery programmes are often expensive and time-consuming, clear rationale needs to be developed for carrying out species recovery programmes. Though several efforts are underway worldwide to conserve critically endangered species, the efforts in India are far too few. In the absence of any well-defined programme, research on the recovery of RET species has suffered from lack of focus and has often tended to be ad hoc. Many of the species recovery programmes in India have traditionally been animal-centric, being carried out for tiger (Project Tiger), gharial, elephant (Project elephant), Gir lions, etc. There have been few cases of species recovery programmes for plant systems. For example, *Paphiopedilum druryi*, a slipper

Figure 3. *Semecarpus kathalekanenis*, *Hubbardia heptoneuron* and *Ceropegia fantastica* restored from the brink of extinction in the last decade.

orchid was multiplied through tissue culture and reintroduced to type localities in Agasthiamalai hill ranges of south Western Ghats[10].

In recent years, the Department of Biotechnology, Government of India has initiated a series of programmes to recover half a dozen plant species in the Western Ghats in the first phase and over 100 plant species for the entire country in the second phase. In this programme, a number of critically endangered species are being restored. In the Western Ghats, Vasudeva *et al.*[11] have attempted to reintroduce *S. kathalekanensis*, a critically endangered species into a new habitat. Similarly, Yadav *et al.*[12] have been able to successfully reintroduce and restore *Hubbardia heptaneuron* Bor, a monospecific, critically endangered and endemic genus on the verge of extinction to its natural habitats in the Western Ghats. Two hundred and fifty tissue-cultured individuals of *Ceropegia fantastica*, a critically endangered and endemic species were successfully reintroduced in 18 native locations in the Western Ghats[13] under this programme (Figure 3). Similar attempts have been made in the second phase to recover a number of critically endangered species in the entire country.

What are the species that need recovery?

An important first step in addressing the recovery of the critically endangered species has often been to recognize which of them need to be recovered, as the list seems to be enormous. Considering the time and resources, one needs to make a judicious decision of identifying the species that need to be recovered.

For many of the critically endangered species, critical information is lacking on the type and extent of threat and to what extent habitat alteration influences their decline. However, for the conservation and recovery of RET species, collating data on the population size and identifying specific threats and developing mitigating strategies could be attempted. Specifically, species recovery programmes could be targetted at (a) species that are globally threatened (priority to species with small population size, showing decreasing natural population, with intrinsic reproductive problems and high economic value/highly harvested); (b) precarious habitats (such as *Myristica* swamps, riverine species); (c) species which have reproductive constraints and population decline, and (d) species that are highly traded (such as medicinal plants) (Figure 4).

In case of plant species for example, out of the 387 Red-listed plants of India[1], 77 species are assigned as critically endangered species, 6 are extinct and two species are extinct in the wild. These 77 species could be taken up for recovery on a priority basis, following which the next 172 species, which are characterized as endangered, could be considered. In other words, a systematic species recovery needs to be carried out to restore the populations of these species.

Approaches to the species recovery programme

A variety of methods can be used to recover critically endangered species, such as protective measures to prevent extinction or further decline, consultation to avoid adverse impacts, habitat acquisition and restoration, and other on-the-ground activities for managing and monitoring endangered and threatened species. Recovery of the critically endangered species could be done at the landscape level, species level or at the population level.

I. Landscape/habitat/community level

Considering that habitat loss and over-harvesting have been the primary cause of species endangerment, a central component of species recovery has been to establish a network of conservation areas and reserves that represent all the pertinent terrestrial and riparian natural communities.

The existing national parks, biosphere reserves, and wildlife sanctuaries address these issues. Protected areas seem to provide the last refugia for many species threatened with extinction and have been effective in conserving forest habitats[14].

In India, there are about 103 national parks and 531 wildlife sanctuaries covering 4.8% of land area (https://data.gov.in/catalog/number-and-area-national-parks-and-wildlife-sanctuaries-india). The country also has 18 biosphere reserves, besides a number of tiger and elephant reserves and 25 Ramsar wetland sites (http://www.moef.nic.in/division/introduction-19). However, critics claim that the protected areas cannot serve as effective means of conservation, because often these forests are vulnerable to anthropogenic pressures or have been subjected to intensive harvest pressures. The World Bank/World Wildlife Fund (WWF) Alliance has shown that less than one quarter of declared national parks, wildlife refuges and other protected areas in 10 key forested countries is well managed, and many have no management at all. In other words, only 1% of the protected land area is secured from serious threats such as human settlement, agriculture, logging, hunting, mining, pollution, war and tourism, among other pressures. In India, 65% of these protected areas is inhabited by the indigenous communities[15]. However, officially designated conservation areas have been effective in reducing forest clearance and, to a lesser degree, effective at mitigating logging, hunting, fire and grazing.

Establishing smaller specialty reserves is also necessary for the conservation of specific taxa. Moreover, recovery of certain species with highly restricted geographic ranges or specialized habitat requirements needs special management. For example, in South India, the Foundation for Revitalization of Local Health Traditions (FRLHT), Bengaluru has specifically identified *in situ* conservation areas for the conservation of endangered medicinal plant species (medicinal plant conservation areas; MPCAs). The Aghanashini Lion-tailed Macaque Conservation Reserve, Gibbon Sanctuary, Sessa Orchid Sanctuary, etc. have been established to preserve specific taxa. However, till date no specific protected area has been established in India to protect a single endangered plant species, except for the species groups such as the Varsey *Rhododendron* Sanctuary in Sikkim or the Sessa Orchid Sanctuary in Arunachal Pradesh.

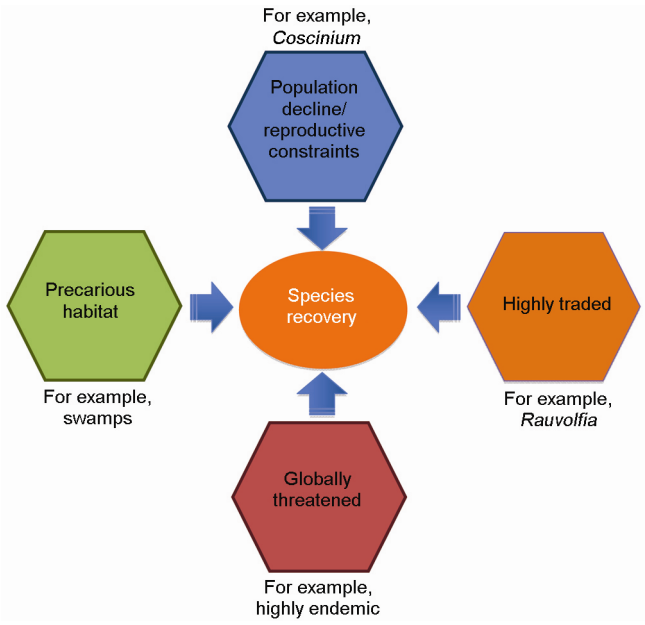

Figure 4. Criteria for prioritizing plant species for recovery.

II. Species level

The community-level approach facilitates recovery but does not negate the need to consider the requirements of each species. However, individual recovery plans with greater emphasis on species which are at the brink of extinction need focused attention. The individual recovery criteria for the critically endangered species need plans to track their progress towards recovery. Species restoration plans need to be established to a point where they no longer require protection and their population is stabilized. At the species level, recovery can be by individual species, reintroduction of the species, carrying out genetic enrichment, or by rehabilitating species into newer habitats. This process of recovery involves arresting the decline of the species by removing all the external threats, so that they can bounce back to their original status. For example, by banning the harvest of an endangered species such as *Santalum album*, an attempt was made to restore the population to genetically viable size. Similarly, many animal species such as the tiger and elephant have been recovered and their population stabilized through species-specific programmes such as 'Project Tiger' and 'Project Elephant'.

(a) *Species reintroduction:* A further possible step in the recovery of an endangered species is to introduce/reintroduce propagules into sites where the species is likely to survive, and/or to replenish existing populations. Such recovery plans for endangered plants often call for the creation of new, self-sustaining populations within their historic range and characteristic habitat[4]. Reintroduction can also be done into an area where species can potentially survive. Nowadays, several tools exist which can identify potential sites for species reintroduction based on the ecological niche of the species. For example, using niche-modelling tools, Shivaprakash *et al.*[16] have identified the potential niche of *Myristica malabarica* in southern India; Thriveni *et al.*[17] for *Coscinium fenestratum*, and Adhikari *et al.*[18] for *Ilex khasiana*. Similar attempts have been made to predict the potential areas where Myristicaceae and *Piper nigrum* species are

likely to survive using future climate data[19,20]. Thus, species reintroduction would act as a functional bridge between *ex situ* and *in situ* conservation methods[21].

For reintroduction programmes, necessary information on the potential habitat required for the survival of the species has to be identified. Using species distribution/ ecological niche models one could arrive at the potential sites where a species is likely to survive in future[19,20]. Based on these, one could carry out the species reintroduction programmes. Reintroduction should be a supplement to habitat management and not a substitute. The final goal is not the success of an individual plant, but the establishment of a viable reproducing population where genetic variation is maintained[22]. Sites for reintroduction can be placed in at least three categories, each having special considerations.

(a) Reintroduction of a species within historical range: Reintroduction in sites where the species is known to have existed, but is now extinct. In this case, specific information about the habitat characteristics of the source population must be matched as close as possible to provide the best chance for survival.

(b) Enrichment planting: This involves introducing propagules or plants into existing wild populations which have reduced to very few numbers.

(c) Introduction of a species to a site outside the known historical range: This involves reintroducing in a site outside of the known historical range of the species, as that is the only place safe from the threats that brought the species to extinction.

Potential problems in reintroduction

(i) *Founding population size:* For reintroduction programmes, it is necessary that there are sufficient individuals in the founding population. The population genetic theory predicts that the presence of a small number of individuals sustained over many generations in a partially or completely isolated population will lead to depletion of genetic diversity. Thus, optimum founding population must be taken into account for any recovery programme.

(ii) *Ecological interactions:* For any species, which has very close symbiotic associations (for example, fig wasp), maintenance of ecological interactions is a big challenge. When reintroducing a species, it is necessary to obtain information on the pollinators and seed dispersal agents. For example, wind-pollinated species need to be planted close enough to ensure successful cross-pollination, and species which require a bird or an insect pollinator need to be planted in an area where an appropriate pollinator is known to exist. In a situation, where a reintroduced population needs to be kept as distinct from a wild population, the site must be far enough not to allow cross-pollination. Similarly, for reintroduction of dioecious species, ensuring the sex ratio or sufficient number of individuals to increase the effective population size must be considered.

(b) *Genetic enrichment:* Conceptually, the genetic enrichment refers to an *in situ* site that serves as a repository of genes of as many diverse populations of a species as possible to represent the widest possible spectrum of genetic variability. The genetic enrichment can be carried out by identifying suitable genetic banks which function as *in situ* 'sinks' into which gene pools from various 'source' sites are introduced and maintained[22]. In this way, genetic enrichment could be regarded as a modification of the existing protocols of *in situ* conservation with provision for gene flow into it. By virtue of such gene introductions, genetic enrichment facilitate the maintenance of a 'global' allelic set of the species. Further, because of continuous interaction between and among the different allelic sets maintained, the genetic diversity would be allowed to 'evolve' as it would in any other natural habitat.

Thus genetic enrichment incorporates the virtues of both *in situ* conservation sites and field gene banks in conserving the genetic resources of the natural population. They are of particular relevance in the conservation of genetic resources of long-lived forest tree species which are highly threatened, where the existing methods of *ex situ* gardens and *in situ* sites might be of limited use. In fact in these populations, where *in situ* conservation programmes will be vulnerable for loss of diversity through drift and other processes, forest gene banks could help avert the loss.

(c) *Rehabilitation:* In instances where the habitat has been completely destroyed (for the construction of dams, mining or other developmental activities), rehabilitation of the species of that region could be attempted. Rehabilitation of a species in areas suitable for its optimum survival and growth from areas where the habitat is completely altered/destroyed is often necessary so that the species can recover and continue to survive.

III. Populations

In most economically important species, it is common to encounter different populations having unique merits and potential performance. In these cases, species recovery programmes could be attempted at the population level. In cases where unique populations or unique clones/ varieties of species are identified, attempts to recover these should be made with an ultimate aim of maintaining genetic purity of the clones/varieties. For example, Thindlu sandal could be a unique clone rich in santalol, which could be conserved[23]. Similarly, there have been numerable clones identified in teak, each with a characteristic trait.

Figure 5. Extrinsic and intrinsic factors that lead to the endangered status of plants.

Monitoring of the recovery programme

One of the major steps in attempting to recover a species would be to collect information on the extent of reduction in the population size and identify specific threats, either intrinsic (biology – altered sex ratio, low viability, poor regeneration, etc.) or extrinsic (habitat loss, over-harvesting, etc.) on a periodical basis (Figure 5). Success of these recovery programmes will depend upon close monitoring of the population change. Long-term monitoring will keep us informed of the imminent changes as to which species would require further recovery. Coordination with the agency or individual responsible for monitoring the existing populations may be necessary to see that a reintroduced population gets on a regular monitoring schedule. Monitoring will ensure that for any unforeseen threats, corrective measures can be taken up. The goal of a successful reintroduction is the establishment of a viable population that maintains the genetic variability of the species and produces successful offspring. Recruitment in the wild is necessary for the reintroduction to be deemed successful. Reintroduction must be accomplished by establishing long-term monitoring plots where density, reproductive status, management needs, resource relationships and conservation opportunities of both common and at-risk species could be closely monitored.

Species recovery: a comprehensive approach

A species is considered 'recovered' when the factors that initially led to its listing are remedied and protection is no longer needed. For many species, concerted efforts are required on the part of both Forest Department (state governments) as well as private parties (forest fringe communities and other stakeholders) to enact laws and regulations, and to reach agreements to protect the threatened species. Only when adequate legal mechanisms are implemented to manage a listed species whose populations have recovered can the species be truly said to no longer require protection and thus be considered for delisting. Formulation of a national agenda involving the protection and recovery of a species could help in systematic recovery of endangered species.

For a successful recovery programme, a number of factors need to be considered (Figure 6). A comprehensive approach to recovery would involve documentation as exhaustively and as scientifically as is possible, the threatened status of plant species, surveying all known

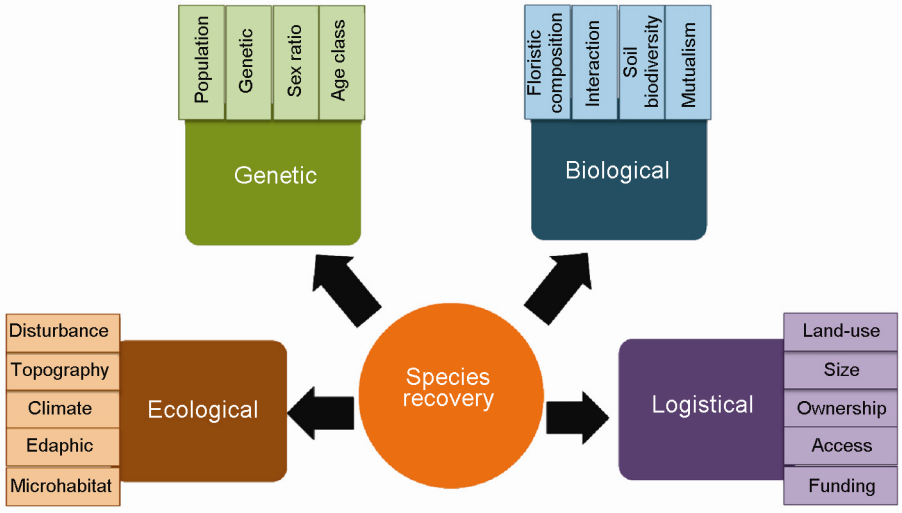

Figure 6. Factors to be considered in the species recovery programme.

populations of the species and mapping their locations, identification of the extrinsic and intrinsic factors driving species to threatened status (identification of extent and type of threat), assessing the genetic variability of the species and identification of genetic hotspots ecological niche of the species to locate the possible places for reintroduction.

Based on these factors, appropriate strategies for the restoration and recovery of the endangered species need to be formulated and specific management protocols (for economically important species) need to be developed for utilization of these threatened species. Long-term monitoring programmes also need to be developed to periodically assess the population changes of the species to potentially delist them from the Red-list.

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