# CONSERVATION OF ENDEMIC AND THREATENED FLOWERING PLANTS: CHALLENGES AND PRIORITIES FOR INDIA

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In the light of the anthropogenic-induced sixth mass extinction crisis that is pushing a large number of species to threatened category, conservation of biological diversity has become a global challenge in the coming decades. Establishing protected areas has been the main conservation approach; however, many threatened species require human intervention for effective recovery and conservation. Although human-induced environmental changes act as proximate drivers for species extinction, the ultimate cause is the inability of species to recruit adequate number of new individuals to sustain populations. Identification of recruitment constraint(s) is the primary requirement for their effective conservation. In the light of uncertainties of conserving a majority of endemic and endangered species of flowering plants before they become extinct, many Western countries have initiated their *ex situ* conservation in seed banks, similar to seeds of crop species, as an insurance measure. India is a megadiversity country with a large number of endemic and threatened species. Although a number of protected areas have been established around the country, neither they are effectively managed nor the recovery of species to be conserved are monitored until they become self-sustainable. We do not have the base-line data on recruitment constraints of most of our species to be conserved, and our conservation efforts have largely remained arbitrary and unfocussed; there are very few success stories. For effective conservation, there is a need for initiating long-term, multidisciplinary, integrated approach involving not only scientists but also local communities, government and non-government organizations and general public. As it is unlikely to conserve most of our endemic and threatened species within a reasonable time frame, there is an urgent need to start preserving their germplasm in seed banks as a viable and cost-effective conservation approach.

**Keywords:** Conservation, flowering plants, recruitment constraints, seed banks, threatened species

The vast biodiversity made up of a large number of species of plants, animals and microbes present on our Planet is the result of evolutionary processes taking place since life originated about 4 billion years ago. The current working estimate of the total number of species present varies between 8.7 and 12 million (Hammond 1995, Mora *et al.* 2011, Raven 2020), although only over 1.2 million of them have so far been documented. Humanity depends, partially or fully, on other species and ecosystem services for most of its essential needs – food, fibers, shelter, medicines, clean air and water, and natural beauty. Our survival and welfare, therefore, depends on sustenance of biodiversity and ecosystem services (Sekercioglu 2010, Negrutiu *et al.* 2020, Raven 2020, Vimala *et al.* 2021). Increase in human population combined with human greed for luxurious living, particularly after the industrial revolution, has affected the environment to such an extent that sustenance of biodiversity and ecosystems is seriously threatened and has initiated the 'sixth mass extinction crisis' which is likely to result in the extinction of a large proportion of the existing species (see Dirzo and Raven 2003, Hooper *et al.* 2012, Ehrlich and Ehrlich 2013, Dasgupta and Ehrlich 2019, Pimm 2009, Pimm and Raven, Ceballos *et al.* 2015, 2017; Shivanna 2019, Negrutiu *et al.* 2020, Raven 2020, WWF 2020, Bradshaw *et al.* 2021, Wagner *et al.* 2021). As new species evolve, based on selection pressure acting on heritable variations, some of the species which are unable to adapt to the changed environment become extinct. This is referred to as baseline extinction and is estimated to be 1-2 species per million species per year (E/MSY, Ceballos *et al.* 2015, IUCN 2019). Thus, evolution of a large number of new species and extinction of a few species has been a regular feature of biological diversity of our Planet.

Human impact has increased the rate of species extinction in recent decades by 100s or even 1000s of times more than the baseline

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extinction. Assessment of threatened plant species by different authors/organizations is highly variable. According to Brummett *et al.* (2015) 20% of plant species (that includes all groups) at global level are threatened and most of them are in the tropics. According to the IUCN (2021), out of 134,425 plant species evaluated, 37,400 species, amounting to nearly 28% of the assessed species, are threatened ( see also Lughadha *et al.* 2020). Out of 52,077 species of flowering plants assessed, 20,883 have been evaluated as threatened. State of the World Plants and Fungi (Antonelli *et al.* 2020) estimates that about 39% of vascular plants are threatened (see also Vellend *et al.* 2017, Anonymous 2020). In the absence of any mitigation steps, IUCN predicts that 99.9 percent of critically endangered species and 67 percent of endangered species will be lost within the next 100 years. More importantly a large number of plant and animal species may not be extinct by definition but are "functionally extinct" as their population in the wild is so reduced that the species cannot be a functional part of the ecosystem. According to WWF (2020) estimation, based on monitoring of 21000 populations, an average of 68% in population sizes of mammals, birds, amphibians, reptiles and fishes have declined between 1970 and 2016. As population extinctions are prelude to species extinctions (Ceballos *et al.* 2017) such species with declining populations are bound to become extinct in the near future. The impact of humans on the planet Earth especially on its environment has been so dominant, that geologists now refer the recent geologic period as Anthropocene (see Glossary).

Plant species are considered to be more stable and resistant to extinction, and their background extinction rates were considered to be lower (0.05-0.15 extinctions per million species per year) (see Cronk 2016, Vellend *et al.* 2017) compared to animal species (1-2 E/MSY, Ceballos *et al.* 2017). A point to be noted about the reported recent extinctions of animal and plant species is that many of the species recorded as extinct are being rediscovered. Recently, in a rigorously researched paper, Humphreys *et al.* (2019) from the Royal Botanic Gardens, Kew and the University of Stockholm, have reported 571 species of seed plants that have become extinct since the time of Linnaeus' *Species Plantarum* (1753), after deleting the species which were declared extinct but subsequently rediscovered (see also Ledford 2019). This amounts to 2.3 plant extinctions per year, nearly 500 times more extinctions than the background (pre-Anthropocene) extinctions. Extinctions were found to be twice as high after 1900 compared to the earlier period (1753-1900). They found extinctions to be more common in biodiversity-rich tropical and Mediterranean climates and on islands. Woody species were found to be more prone for extinction compared to herbaceous species and grasses (Humphreys *et al.* 2019).

The drivers of this Anthropocene mass extinction have been habitat loss and their degradation, overexploitation of bioresources, intensification of agriculture, introduction of alien species and climate change (Traveset and Richardson 2006, Le-Feon *et al.* 2010, Ghazoul and Sheil 2010, Bawa *et al.* 2011, Lenzen *et al.* 2012, Vanbergen *et al.* 2013, Tobin 2015, IPBES 2016, 2018, 2019, Shivanna 2019, IPCC 2021). According to many conservation biologists, the ongoing human-induced sixth mass extinction crisis is going to be the worst calamity that is likely to befall on humanity in the coming decades (see Wilson 1984, Raven 2020, WWF 2020). Thus, mitigating and reversing human-induced environmental impacts on biodiversity and ecosystems has become one of the highest priorities for the humanity to safeguard human welfare (Sekercioglu 2010, Ehrlich and Ehrlich 2013, IPCC 2021). Realizing the urgency of restoration of biodiversity and ecosystems, the United Nations General Assembly has declared 2021–2030 the 'Decade of Ecosystem Restoration'.

So far, conservation attempts have

largely been confined to animal species especially charismatic ones such as tigers, elephants, leopards, lions, rhinos, amphibians, birds and mammals. Unfortunately, the threat status of plants has remained poorly appreciated and investigated (see Bolam *et al.* 2020, WWF 2020). Even the distributional data is not available for about half of the plant species (Pelletier *et al.* 2018). Conservation of plants, particularly flowering plants which provide most of the requirements of humans and other animals, and form the basis of civilization, has not received due consideration (Negrutiu *et al.* 2020). Limited conservation efforts made on plant species, particularly in tropical countries where the biodiversity is rich, have not been very successful. This review elaborates the importance of studies on reproductive ecology, particularly on identifying recruitment constraints, which are the ultimate drivers for species extinction, for effective conservation of threatened flowering plants. Apart from *in situ* conservation attempts, the need for *ex situ* conservation of endemic and threatened species in seed banks is emphasized as an insurance policy. Conservation scenario of India is also discussed briefly.

## BASIS OF SUSTAINABILITY OF POPULATIONS AND SPECIES

The sustainability of any population or species in their natural habitat depends essentially on efficient recruitment of new individuals. In a stable population (coming under the least concern category of IUCN) the recruitment of new individuals is equal to or more than the number of deaths. When recruitment becomes a constraint, the number of new additions to the population would be less than the number of deaths. When this continues for generations, the population becomes endangered and eventually becomes extinct leading to the loss in ecosystem integrity and its services. Thus, species extinction begins with the loss in abundance of individuals of its populations. Although human-induced environmental changes mentioned above are the primary drivers for the sixth mass extinction crisis, recruitment constraint is the ultimate driver for population and species vulnerability, and eventual extinction.

**Major constraints for recruitment in flowering plants:** Although a number of plant species reproduce through vegetative propagation, seeds are the major source of recruitment that determines sustainability in a majority of flowering plants. Recruitment of new individuals involves a number of sequential events (Fig. 1). Of these, pollination and seed dispersal are the major and most critical constraints. In a majority of flowering plants, both these events are the result of mutualistic interactions between plants and a range of animal species. Therefore, extinction of pollinators or seed dispersers leads to secondary extinction of plant species dependent on its mutualistic partners (Kearns *et al.* 1998, Brodie *et al.* 2014). There are also constraints at other steps, but they are not as common and critical compared to pollination

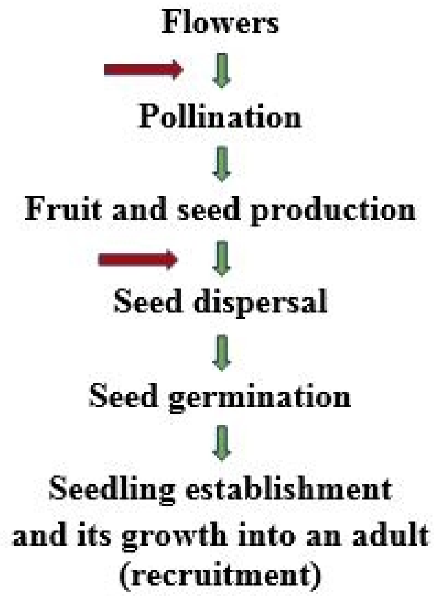


**Figure 1:** Sequential steps (green arrows) and major constraints (red arrows) involved in the recruitment of new individuals.

and seed dispersal.

Pollination, the transfer of pollen grains from the anthers to the stigma, is the first and the most critical step for fertilization and subsequent fruit and seed set. Enormous literature is available on pollination ecology (Pellmyr 2002, Willmer 2011, Patiny 2012, Shivanna 2014). Plants are sedentary and cannot achieve pollination on their own.They have effectively outsourced this function to other agencies – animals, wind and water. Nearly 90% of the flowering plants are pollinated by animals (biotic pollination) and the remaining are pollinated by wind or water (abiotic pollination). Wind-pollination (anemophily) is the major of the two abiotic agents. The most important groups of animal pollinators are the insects, birds and bats. Of these, insects form the most important components; prominent insect pollinators belong to Coleoptera (beetles), Diptera (flies), Hymenoptera (bees, wasps and ants) and Lepidoptera (moths and butterflies). Hymenoptera, especially bees, are the ubiquitous pollinators and form nearly half of the insect pollinators in both natural and agricultural habitats. There are about 20,000 bee species around the world. The Earth watch Institute has declared bee as 'The Most Important Living Being on the Planet', and the United Nations has declared May 20th as the 'World Bee Day' to acknowledge the role of bees in the ecosystem. Next to insects, birds are the most important pollinators in natural habitats (Ford 1985). More than 900 species of birds are reported to pollinate about 500 genera of flowering plants (see Sekercioglu 2011). The most important group of bird pollinators are sunbirds and sugarbirds in the Old World, hummingbirds in the New World, honeyeaters in Australia and honeycreepers in Hawaii. Pollination may take place during the day (diurnal) in which insects and birds are the major pollinators or during the night (nocturnal) in which bats and moths are the major pollinators. Nocturnal pollination is reported in about 30% of angiosperm families (Borges *et al.* 2016). Bat pollination is reported in over 528 species of flowering plants belonging to 67 families (Fleming *et al.* 2009, Kung *et al.* 2011). Moths are also important nocturnal pollinators, although they are much less investigated. A total of 227 moth-pollinated species have been reported (Hahn and Bruhl 2016). Some species are pollinated by both diurnal and nocturnal pollinators (ambophily) (Dafni *et al.* 2012).

Following successful pollination, pollen grains germinate on the stigma and the resulting pollen tubes grow through the tissues of the stigma and style, enter the ovule, and eventually the embryo sac (female gametophyte) where the female gamete is located. Pollen tube discharges the two male gametes in the embryo sac; one of them fuses with the egg to give rise to the zygote and the other fuses with the central cell to give rise to the primary endosperm cell, thus completing double fertilization, the characteristic feature of the flowering plants. The zygote develops into the embryo and the primary endosperm cell into the endosperm, a nutrient tissue for the embryo. The ovule develops into the seed, and the ovary into the fruit, thus completing the events of sexual reproduction. Pollination is, therefore, the primary requirement for fertilization, and fruit and seed development. A large number of papers and reviews are available on the decline of pollinators due to human-induced environmental changes and the resulting pollination constraints both in natural and agricultural habitats (Buchmann and Nabhan 1996, Kearns *et al.* 1988, Kremen and Ricketts 2000, Wilcock and Nieland 2002, Kevan and Viana 2003, Biesmeijer *et al.* 2006, Potts *et al.* 2010, 2016, Anderson *et al.* 2011, Cameron *et al.* 2011, Stout and Morales 2009, Vanbergen *et al.* 2013, Macgregor *et al.* 2015, IPBES 2016, Garcia-Moralis *et al.* 2016, Knop *et al.* 2017, Sanches-Bayo and Wyckhuys 2019, Shivanna *et al.* 2020, Jactel *et al.* 2020), which are not discussed here.

Seed dispersal is equally important for the recruitment of new individuals. Seed dispersal provides three important ecoservices for seedling recruitment (see Howe 1990, Clark and Clark 1984, Turner 2001, Hansen *et al.* 2008); it i) enables seeds and seedlings to escape from high level of competition and predation concentrated below and around the parents, ii) provides increased opportunities for seed germination and seedling establishment away from the parent and iii) facilitates colonization of species at new locations. Animals are the major dispersers of seeds (zoochory). In tropical forests zoochory is the main seed dispersal strategy; about 70% of the flowering plants depend on zoochory for dispersal of their seeds (Howe and Smallwood 1982, Howe 1990, Turner 2001, Norjhauer and Newberg 2010, Tadwalker *et al.* 2012, Sinu *et al.* 2020). In a tropical forests of Congo, Beaune *et al.* (2013) reported zoochory in about 83% among the trees, 98% among the shrubs and 79% among the lianas while autochorous and wind-dispersed species were rare. Amongst animals, birds are the major seed dispersers; in an Atlantic forest of northeast Brazil 47.9 % of the animal-dispersed trees depend on birds for seed dispersal (de Silva and Tabarelli 2000). Apart from birds, several other vertebrates, particularly bats, primates, mammals, rodents and even fishes are the important seed dispersal agents. A total of at least 549 species of 191 genera of flowering plants are dispersed by bats in the Neotropics (Mickleburg *et al.* 1992, Lobova *et al.* 2009). Fruits of some species get dispersed by developing external devises to attach on the body of the animals. Seeds of some species are adapted to abiotic dispersal in which wind or water or gravity facilitates dispersal. Seed dispersers are becoming scarce in natural habitats as they are hunted/poached extensively and their habitats are shrinking through deforestation, fragmentation and invasion by alien species (Ghazoul and Sheil 2010, Sekercioglu 2011, Rosenberg *et al.* 2019). The decline of seed dispersers leading to dispersal constraints in wild habitats are discussed extensively (Bond 1995, Anonymous 2007, Sekercioglu *et al.* 2004, Sekercioglu 2011, McConkey *et al.* 2012, Erikson 2012, Marjakangas *et al.* 2019, Rija *et al.* 2020, Rogers *et al.* 2020). Another major anthropogenic impact on dispersal constraint particularly in developing countries is extensive collection of economically important seeds and/or fruits before they are collected by frugivores, and collection of whole plants or plant parts of medicinal plants (Ghazoul and Sheil 2010, Bawa *et al.* 2011).

## CONSERVATION APPROACHES

Conservation includes protection and restoration of ecosystems, and the recovery of threatened species along with their ecological functions. Conservation of biodiversity has been a global priority for a few decades and a number of treaties have been adapted by a large number of countries. The treaty on the Convention on Biological Diversity (CBD), that came into force in 1993, has three main goals: the conservation of biological diversity, the sustainable use of its components and fair and equitable sharing of benefits arising from bioresources and associated traditional knowledge. In its tenth meeting, the Conference of the Parties (COP-10) to the Convention on Biological Diversity, held in October 2010 in Nagoya, Aichi Prefecture, Japan, adopted a Strategic Plan 2011-2020 referred to as Aichi Biodiversity Targets consisting of 20 targets under five strategic goals A-E. This gave an international framework for biodiversity management. However, according to the UN report (2020), none of the 20 Aichi biodiversity targets were met, although some progress was made on six of them (Sharrock *et al.* 2018, Sharrock 2020).

Another important legislation related to conservation of biodiversity has been the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) which prevents illicit trade of threatened species (see Glossary). According to the Convention on Wetlands of International Importance, signed in 1971 in Ramsar, Iran, referred to as Ramsar Convention, 114 signatory countries are required to designate wetlands to be included in the list and manage them. World Heritage Convention for protection of World Cultural and Natural heritage was adapted in 1972 in Paris; 189 countries are signatories to this convention and the list includes over 1000 sites around the world.

An international initiative for plant conservation was proposed at the International Botanical Congress in 1999 that led to the adoption of the Global Strategy for Plant Conservation (GSPC) by the worlds' governments in 2002 as a programme under the Convention of Biological Diversity (CBD) in its sixth meeting (COP-6). The GSPC included 16 targets under five objectives for plant conservation to be achieved by 2020 (Anonymous 2012, Sharrock 2012). The GSPC targets were updated in 2010 in COP-10 with a set of revised targets for 2020, with a decision that implementation of the GSPC should be pursued as part of the broader framework of the Strategic Plan for Biodiversity 2011-2020. Many GSPC targets were similar to those in the CBD Strategic Plan for biodiversity (2010-2020) (see Anonymous 2012, Sharrock 2012). This enabled collaboration between organizations to initiate target-oriented work on plant conservation and some progress was made towards achieving most of the sixteen targets of the GSPC although it was variable between targets as well as between countries.

***In situ* conservation:** There are thirty six global biodiversity hotspots (see Glossary) covering about 2.4% of Earth's land surface but support > 50% of endemic plant species which are highly threatened (Conservation International Biodiversity hotspots, see also Myers *et al.* 2000, Mittermeier *et al.* 2011). The biodiversity of islands is also rich with a large proportion of endemic elements and suffers greater degree of human-impacted environmental degradation (Sakai *et al.* 2002, Burney and Burney 2007, Morales and Traveset 2009, Keiser-Bunbury *et al.* 2010, Humphreys *et al.* 2019, Gore *et al.* 2022). Realizing the enormity of conservation goals and the difficulty of conserving all threatened species growing around the world, several conservation biologists have emphasized the need to give priority to global hotspots and islands as it would enable conservation of maximum number of species with limited resources (Myers 2000, Mittermeier *et al.* 2011, see also Humphreys *et al.* 2019).

*In situ* conservation (see Glossary) has been the primary approach for conservation. Establishment of protected areas in the form of Biosphere Reserves, Wildlife Sanctuaries, National Parks, etc has been the main approach for in situ conservation of biodiversity. This is probably the only effective method for most of the species, which are dependent on specialized complex community interactions with other species (such as specific pollinators, soil bacteria etc.) for their survival. A large number of protected areas have been established in almost all countries around the world. Under proper management, protected areas would help the recovery of those threatened plant species which are overexploited and do not have any other recruitment constraints. Establishment of protected areas has not always been successful in conservation efforts, particularly in developing countries (Ghazoul and Sheil 2010, Clark *et al.* 2013, Leisher *et al.* 2013, Volis 2019, Heywood 2017, 2019). Apart from practical difficulties of their effective management from anthropogenic disturbances, ongoing climate change-induced impacts have made the original habitats no more suitable for sustenance of many of the threatened species especially of narrow endemics even in the Reserves. The populations of a number of threatened species are drastically reduced with marked loss of genetic variability due to degradation of their habitat or other recruitment constraints; such species may not be able to recover even in the protected areas. Recovery of such species need human intervention; their populations need to be augmented through reinforcement. They may require reintroduction to establish viable populations by translocation of individuals to areas of its natural range from which it is no more present. Intervention may also involve raising populations in partly novel ecosystems in which species compositions differ from historical ranges. Thus, species with loss of genetic variability or decrease in population size beyond sustainability or loss of habitat or presence of strong recruitment constraints requires effective intervention even in protected areas (see Volis 2016, 2019, IUCN/SSC 2013, 2014). Population enhancement and reintroduction of populations in their natural or new habitats may be carried out through seeding or transplantation of seedlings from existing populations or those raised in nurseries or through *in vitro* multiplication. Those species which have recruitment constraints due to one or several limitations require more elaborate efforts to identify the constraints and apply suitable remedial measures.

Any conservation study also involves monitoring of populations over a period of time not only to understand the threat status of the population/species but also to monitor the success of the conservation efforts, which may take many years. Thus, successful recovery of species involves a clear understanding of the nature of recruitment constraints and application of suitable methods to mitigate such constraints until the species reach sustainable level. It requires expertise of researchers from different fields such as ecology, taxonomy, reproductive biology, forestry and the involvement of government and nongovernment organizations and local communities. In the absence of such an approach, all the efforts and resources spent on conservation of species would go waste (Heywood 2019). Finding resources for conservation becomes critical especially in developing and underdeveloped countries with rich biodiversity in which majority of the population suffers from poverty.

***Ex situ* conservation:** *Ex situ* plant conservation (see Glossary) is the conservation of threatened species outside their natural habitat (Shaffer1981, Guerrant *et al.* 2004, Mounce *et al.* 2017). So far *ex situ* conservation has largely been confined to cultivation of threatened species in Botanical Gardens, Arboreta and field gene banks. The number of plants that can be grown *ex situ* is limited but they act as a safety back-up and an insurance against extinction of threatened species in the wild. Standard sampling method to include genetic variability of the species needs to be followed for *ex situ* conservation (Guerrant 2014, Hoban 2019).

***Storage of germplasm in seed banks:*** *Ex situ* conservation of species relevant to agri-horticulture (all cultivated and abandoned varieties, land races and wild relatives of crop and horticultural species) in seed banks, cryo-banks and *in vitro* banks has been a regular practice around the world since many decades. As seed banks permit storage of a large germplasm in a limited space, their preservation in seed banks has been a popular *ex situ* conservation approach and millions of accessions have been stored in seed banks (Thormann *et al.* 2006, Peres 2016, Gore et al. 2022). There are over 1750 seed banks around the world; however, they are exposed to natural and man-made disasters such as earthquakes, floods and wars, and face the risk of losing all their seed samples under such catastrophes. The Svalbard Global Seed Vault (Doomsday Vault) was established in 1984 on a Norwegian Island near the north pole (nonmilitarized and geologically stable location without the risk of flooding and sea level rise). It stores duplicate samples from National Seed Banks as an insurance policy to prevent the loss of seed samples to such disasters. Svalbard Seed Vault has the capacity to store 4.5 million seed samples; as of now it has nearly one million samples. About 70,000 samples are from India. So far most of the existing seed banks concentrate on seeds of agro-biodiversity (Liu *et al.* 2018); there is very little representation of other endemic and threatened species (Godefroid *et al.* 2011).

In recent years *ex situ* conservation in seed banks, pollen banks and in vitro banks has been advocated as a cost efficient approach for endemic and threatened plant species also (Thormann *et al.* 2006, Godefroid *et al.* 2011, Liu *et al.* 2018). The Millennium Seed Bank Partnership developed and managed by the Royal Botanic Gardens, Kew, England, is probably the largest *ex situ* conservation seed bank in the world (Liu *et al.* 2018). Apart from species of agro-biodiversity, it has also maintained huge collections of endangered and endemic plants originating from 189 countries. As of 2018, it has seed collections of plants representing 365 families, 5813 genera, 36,975 species. Of these 78% belong to endemic or endangered species (Liu *et al.* 2018). The main focus of this seed bank has been on plants and regions most at risk from climate change and the ever-increasing impact of human activities. Recently threatened species of Mediterranean islands which are rich in endemic species are also being stored in seed banks under the CARE-MEDIFLORA Project; as of now, seeds of a total of 750 accessions from 429 species have been stored (Fenu *et al.* 2020, Godefroid *et al.* 2011). As conservation of all the threatened species before they become extinct appears to be almost impossible, their *ex situ* preservation in seed banks need to be strengthened.

## CONSERVATION SCENARIO OF INDIA

According to IUCN (2021) 457 plant species of India have been listed as threatened. However, Barik *et al.* (2018a) have listed 2704 seed plant species of India as threatened. Of these, 150 species are considered to be critically endangered (Ravikant *et al.* 2018). India has enacted a number of legislations related to the management of biodiversity. Indian Constitution itself has made specific provision for the protection of the environment – "It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife, and to have compassion for living creatures" (Article 51-A (g). The Biological Diversity Act enacted in 2002 and its Rules formulated in 2004, elaborates the details for conservation of biological diversity, sustainable use of its components and equitable sharing of benefits arising out of biological diversity and associated traditional knowledge. The National Biodiversity Authority was set up in 2003 to implement the provisions of the Biodiversity Act. Its responsibilities involve giving permission to conduct research, commercial activities, biodiversity surveys and utilization. It works in collaboration with State Biodiversity Boards, Biodiversity Councils of Union Territories and Biodiversity Management Committees at Panchayat, Municipal and Corporations. India is also a signatory to CITES and Ramsar Conventions, Nogoya protocol and many other conventions related to biodiversity. The National Biodiversity Authority under section 38 of the Biodiversity Act has notified a list of threatened species of plants and animals from different states in consultation with the Botanical Survey of India, Zoological Survey of India and respective state Forest Departments for their conservation. The State Biodiversity Boards were assigned this responsibility, but practically no efforts seem to have been made by any of the states or forest departments. The State Forest departments seem to be least bothered as they are not specifically assigned this responsibility. On the contrary, there are many complaints by researchers about their inability to get permission from the Forest Departments for assessing these species for effective conservation, particularly in protected areas. The only effort made for their *ex situ* conservation is by the Ministry of Environment, Forests & Climate Change (MoEFCC), Government of India, through 'Assistance to Botanic Garden Scheme' particularly to the identified 'Lead Gardens'.

Even in these lead gardens the efforts are limited to developing nursery methods for their multiplication and establishing a limited number of individuals in their gardens. There is hardly any successful effort to rehabilitate them in their natural habitats.

***In situ* Conservation:** India has established a number of protected areas in the form of National Parks, Wildlife Sanctuaries, Conservation Reserves, Biosphere Reserves, Community reserves and Reserves for tigers and elephants (Kothari *et al.* 1989, Ghosh-Harihar *et al.* 2019, ENVIS Centre on wildlife and protected areas 1997). Protected areas cover about 5% of the total land area and include all ecoregions/biogeographic regions. Several field germplasm banks particularly for medicinal plants (Medicinal Plant Conservation Areas -- MPCAs) and a few other economically important species such as bamboos, rattans, orchids, rhododendrons, wild *Musa*, wild citrus have also been established. Chilika Lake, Loktak Lake, Kolluru Lake and Keoladeo National Park etc are included under 42 declared Ramsar Sites. Great Himalayan National Park, Manas Wildlife Sanctuary, Keoladeo National Park, Nanda Devi and the Valley of Flowers National Parks, Kaziranga National Park and Sundarbans of India are included under the World Heritage Sites. India has also framed rules to protect biological diversity by the potential risks posed by genetically modified organisms. A large number of threatened species have been placed under Appendices and their export market is controlled by CITES rules. A large number of species are also listed in Negative List of export by the Commerce ministry. These conservation measures on paper are quite impressive.

However, the situation at the ground level is rather poor. Protected areas are not being managed effectively due to a number of limitations. Most of the protected areas are inhabited by indigenous people creating additional complications in their management. Lack of involvement and support of the inhabitants living inside and adjacent to the protected areas has been a major limitation for effective management of protected areas (Kothari *et al.*1989). Effective monitoring of endangered species in protected areas is largely confined to animal species (Ghosh-Harihar *et al.* 2019); there is hardly any monitoring on the recovery of endangered plant species. No doubt, protected areas do provide opportunities for a number of endangered plant species also to recover. As pointed out earlier, the recovery would be confined largely to those species which have become endangered due to overexploitation and do not have any other recruitment constraints. Unfortunately exploitation of endangered plants has continued even in the protected areas through unsustainable harvest of economically important products such as fruits and seeds, roots and barks, gums and resins and species of medicinal importance (Murali *et al.* 1996, Ved *et al.* 2003, Ganeshan and Setty 2004, Shahabuddin and Prasad 2004, Bawa *et al.* 2011, Sinu and Shivanna 2016). About 880 species of medicinal plants are traded in the country and 538 of them occur only in the wild; over 66% of them involve harvesting of the whole plant or its roots or bark/stem (Ved *et al.* 2003) affecting the sustainability of the harvested perennial species. Cultivation has long been suggested as a possible mitigation to the unsustainable harvest from wild species, particularly for medicinal plants. This would help in boosting their commercial value without imposing pressure on wild populations. However, this is not an easy task; many species require special ecological niches for establishment and tend to be slow growing. Often, synthesis of their active products is lower or often considered less potent under cultivation. Also, large number of threatened species are located outside the protected areas and they are being lost rapidly (e.g. *Decalepis hamiltonii* called Swallow root). They need individual recovery programmes which would be more difficult if they happen to be the sources of economically important products. Limited availability of many over-harvested species has led to adulteration, especially of medicinal products.

A number of conservation and recovery programmes by the Ministry of Environment, Forests and Climate Change, and the Department of Biotechnology (DBT) are being implemented. In 2012, DBT initiated a mega network programme entitled 'preventing extinction and improving the conservation status of threatened plants through application of biotechnological tools' for successful conservation of about 100 threatened species of India. Under this programme many research projects (2012-2018) covering ten major targets were sanctioned. However, the 10 identified targets are largely of pre-requisites (such as resolving the taxonomic disputes, preparing herbarium records, characterization of populations, distribution maps, reclassification of threat status, reproductive biology, molecular characterization, profiling of bioactive compounds, and standardization of micro- and macro-propagation protocols) for effective conservation rather than the recovery of these species to self-sustainable level. It also included establishing field germplasm banks and reintroduction of species, but they were confined to a few species and there was no provision for continued monitoring. The results of many of these projects were published in several papers in a special section in Current Science (Anonymous 2018). Of the selected species, populations of 75 species were reported to have become stable, and over 100 species have been reported to be reintroduced (Barik *et al.* 2018a, b). However, the details of the species which have been stabilized or the fate of the reintroduced species in terms of their self-sustaining ability are not reported nor proposed for long term monitoring. In 2019, another initiative 'National mission on biodiversity and human well-being' was initiated (see Bawa *et al.* 2020). This has two major components. One is the National initiative for sustained assessment of resource governance; one of its components cover exploration, discovery, and genetic characterization of India's biodiversity. The other component includes six field-based projects on sustainable development goals. We have to see how this ambitious programme on Indian biodiversity progresses at practical level.

It appears that plant conservation attempts in India so far are largely at the preliminary stage starting from systematic identification of critically endangered species to collection of data required for effective conservation. This of course is a requirement but does not indicate effectiveness of conservation efforts. Literature survey reveals that there are only a few critically endangered species that have been successfully recovered (Vasudeva *et al.* 2003,Yadav *et al.* 2009, Chandore 2010, see also Ravikant *et al.* 2018). Ravichandran (unpublished) of MS University, Tirunelveli, Tamil Nadu with limited funding was able to produce a large number of seedlings of an endangered species, *Kingiodendron pinnatum* (Leguminosae) and over 1000 seedlings were planted in their natural habitat during 2009-2012 directly by his group and by the forest Department. Around 90% of the transplanted seedlings got established (personal communication). He has also handed over a number of seedlings of several endangered medicinal plant species to the Forest Department for planting. It is yet to be seen how many of them have established as young reproducing adults to assess the success of his conservation efforts.

As pointed out earlier, there is a need for baseline data on recruitment constraints for effective conservation. Unfortunately, only a limited number of species such as *Syzygium microphyllum* and *Elaeocarpus venustus* (Irwin *et al*. 2003, 2013) have details on their distribution and recruitment constraints. We do not have such data for most of our threatened species. As mentioned earlier, effective conservation is a team work involving expertise from different scientific and social fields, and it is a long-term programme requiring at least 10 years or more, until the species attains self-sustainability without human help. Most of the recovery studies in the country are project-oriented, sanctioned to one or a few individuals of one expertise for a specific period. For example, a number of research projects have been carried out on the use of tissue culture technology to multiply endangered species; but there are hardly any examples of recovery of species by transplanting such plantlets into their natural habitats and monitoring them until sustainability.

***Ex situ* conservation :** *Ex situ* conservation is often the only alternative particularly for those threatened species which are located outside the protected area. Botanical Gardens of our country are playing an important role in *ex situ* conservation in spite of their limited resources. Acharya Jagadish Chandra Bose Indian Botanic Garden, Shibpur, Howrah in West Bengal, the oldest garden in the country established in 1787, has a large collection of endangered plants under cultivation. Apart from a number of rare, endemic and endangered species, it has a large collection of palms representing 115 species (mostly exotic ones inherited from colonial rule) belonging to 53 genera. Similarly Jawahar Lal Nehru Tropical Botanical Garden and Research Institute, Palode in Kerala is cultivating a large number of threatened species particularly of the Western Ghats and Andaman and Nicobar Islands. Presently it holds living collections of about 120 endangered and endemic taxa, especially of medicinal, aromatic and spice plants, in their threatened tree species park. The Bambusetum is holding 69 species (12 hybrids) procured from different regions of the Indian subcontinent and Andaman and Nicobar Islands; it represents the largest bamboo collection in India. The Garden also has a rich collection of orchids (650 species and 200 hybrids). One of the National Gene Banks for select medicinal and aromatic plants is being maintained here. Many University Botanical Gardens such as the Shivaji University, Kolhapur and Mahatma Gandhi Botanical Garden, University of Agricultural Sciences, Bengaluru are also carrying out ex situ conservation of endangered species. Apart from conservation, Botanical Gardens also help in creating public awareness on the importance of plant diversity and the need for their conservation.

***Ex situ* conservation in seed banks:** The possibility of conserving most of the threatened species of the country, particularly those growing outside the protected areas, before they go extinct does not seem to be feasible at least in the near future. As it is being emphasized in Western countries, in India also there is an urgent need to initiate conservation of endemic and threatened species in seed banks. As seed banks permit storage of considerable number of seeds representing adequate genetic diversity of the species from different populations with minimum cost, the objective of saving endemic and endangered species can be realized within a reasonable period. India already has a strong germplasm repository confined to the species of agrobiodiversity in seed banks at the National Bureau of Plant Genetic Resources, New Delhi and also in a few other seed banks such as International Crop Research Institute for Semi-Arid Tropics. For conserving vast number of endemic and endangered species of the country, it may be necessary to establish one seed bank in each biodiversity-rich areas of the country or in a centralised place in high altitude Himalaya where the temperatures are low even during summers so that maintenance costs are less. Jawaharlal Nehru Tropical Botanical Garden and Research Institute, Kerala already has a small seed bank (holds 986 active, 38 base and 4000 reference accessions) of tropical species. The gardens attached to the Botanical Survey of India, the botanical garden of Shivaji University, Kolhapur, Maharashtra also maintains a short term conventional seed bank.

These may be expanded and strengthened.

## CONCLUDING REMARKS

The details discussed in this review amply indicate that the biosphere has never been under such a serious threat; humanity has pushed biodiversity and ecosystem services to their brink. Conservation of biodiversity in general and of plant diversity in particular is going to be the greatest challenge for maintaining the food and nutritional security, health and wellbeing of humanity. The first part of the sixth report of IPCC was released in August 2021 highlighting the unequivocal role of humanity in driving climate change and the threshold warming of 1.5°C (the goal of the Paris agreement to limit the rise of pre-industrial temperature by 2100) would reach in the next 20 years itself (IPCC 2021); it has already reached 1.1°C. Thus all available evidences warn of climate catastrophe which will drastically affect biodiversity and human welfare.

UN Climate Change Conference (COP-26) with a membership of 196 countries was held recently (Glasgow, Scotland, October 31-November 2021). The main aim of the COP-26 was to prepare action plan for keeping the 2015 Paris Agreement's target of global warming at 1.5°C above preindustrial level to avert its worst effects on biodiversity and human welfare. Many countries made commitments to reach net zero emission (see Glossary) by 2050. However, according to Climate Action Tracker, there is considerable gap between commitment and action; the world as of now is heading for 2.4°C of warming. If all promises made by countries at this conference are kept, global warming could be kept to 1.9°C above preindustrial level, which is a significant progress. Another important meeting, the UN Biodiversity Conference (CBD COP-15) is to be held in Kunming, China, in April - May 2022 to review the achievements of the CBD's Strategic Plan for Biodiversity 2011-2020. The decisions taken in this meeting are also going to be very crucial for conservation and sustainable use of biodiversity.

As highlighted in this review, one of the major limitations of conservation of threatened flowering plants is the lack of data on reproductive ecology of most of our endangered species especially of the tropics, where the biodiversity is rich and threats to its sustenance are maximum. Once we know the details of the constraint(s), it would be feasible to come up with rational approach(s) to conserve the species. India's conservation programmes have, in general, been arbitrary and largely ineffective. Institution-based, time-bound, species-specific and targeted team efforts (in collaboration with State Forest Departments) with sufficient funding are needed to yield the desired results. Such ideal approach is hardly visible in Indian plant conservation efforts. Meanwhile additional *ex situ* approach in the form of conservation of germplasm of endangered and endemic species in seed banks should be initiated with vigour as an insurance policy. Conservation of seed plants scenario in India is still a long way to go.

## GLOSSARIES OF TERMS RELEVANT TO CONSERVATION OF BIODIVERSITY

***Anthropocene (the human-epoch)***: Anthropocene is the proposed recent geological period/epoch since the time humans started to have significant impact on the Earth's environment including climate and ecosystem. The term, proposed in 2002, is associated with Paul Crutzen, a Dutch chemist and Nobel laurate (for discovering the effects of ozone). The period of the beginning of Anthropocene, however, is not fixed; it varies from the beginning of agriculture to the industrial revolution (1850).

***Biodiversity Hotspots:*** Biodiversity-rich biogeographical areas with high proportion of endemics (>1500 vascular plants) and are highly threatened (must have 30% or less of its original natural vegetation). There are 36 hotspots around the world; they cover only 2.5% of the earth's surface but support nearly 60% of the world's plant, bird, mammal, reptile, and amphibian species.

***CITES:*** *The Convention on International Trade in Endangered Species* of Wild Fauna and Flora, is a global agreement among governments to regulate international trade in threatened species. It has formed rules for regulation of over 5,000 species of animals and 29,000 species of plants and their products ensuring their survival in the wild for the livelihood of local people. The species covered in CITES are listed under three Appendices, according to the degree of protection they need. Appendix I lists species that are most endangered and can be traded only when both exporting and importing countries give special permits and consent to the trade. Appendix II lists species that are not necessarily threatened with extinction at present but may become so in the coming years. They require only export permit for trade. Appendix III lists species that are protected in at least one country, which has asked other CITES Parties for assistance in controlling the trade (see CITES list of species protected by Appendices – Wikipedia).

***Ecoservices:*** Goods and services humanity derives from biophysical environment for their sustenance and well-being. Some of the major ecoservices include production of food, fuel, fibre, medicines, recreational benefits, regulation of the quality of water, soil, air, climate and diseases, decomposition of waste and nutrient recycling (Reid *et al.* 2005, Sekercioglu 2010).

***Ex situ conservation:*** Conservation of threatened plants and animals outside their natural habitat such as zoos, wildlife safari parks, aquariums, botanical gardens, nurseries, and gene-, pollen-, seed-, seedling- and tissue culture-banks. It does not allow natural evolutionary processes to proceed and is considered only as a supplement to *in situ* conservation. (IUCN/SSC 2014).

***In situ conservation:*** Conservation of ecosystems and natural habitats, and maintenance and recovery of viable populations of species in their natural surroundings. This permits natural evolutionary processes to continue.

***IPBES:*** *The Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services,* established in 2012, is an independent intergovernmental body to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development. It prepares assessment reports on specific themes such as biodiversity and ecosystem services, pollinators, pollination and food production at regional and global levels and ensures effective communications and outreach.

***IPCC:*** The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options. Thus the IPCC determines the state of knowledge on climate change through its regular assessments. The Fifth Assessment Report of the IPCC, released in November 2014, highlighted likely temperature rise by the end of the century to be 4.8° which paved the way for negotiations on reducing carbon emissions at the UN Climate Change Conference in Paris during late 2015. The first part of the sixth report of IPCC was released in August 2021 (IPCC 2021).

***IUCN:*** The International Union for Conservation of Nature and Natural Resources has been preparing the *Red List of Threatened Species* by evaluating their risk status since 1964. It divides species into nine categories: not evaluated, data deficient, least concern, near threatened, vulnerable, endangered, critically endangered, extinct in the wild and extinct. Vulnerable, endangered and critically endangered categories are considered threatened. IUCN Red List has become the world's most comprehensive information source on the global extinction risk status of animal, plant and fungus species (Rodrigues *et al.* 2006).

Recognizing the need to evaluate species recovery and conservation impact, the IUCN called for the development of a Green List of Species in 2012 (subsequently changed to IUCN Green Status of Species). This is a complement to the Red List of threatened species and gives information about the recovery level of endangered species and thus assesses the impact of conservation action (see Akçakaya *et al*. 2018). In the Green Status Assessment, a species may move to a lower category of extinction risk due to effective conservation measure or may remain in a high threat category despite conservation efforts indicating that the species would have gone extinct without conservation efforts. Recently the assessment results of the Green Status of 181 species by about 200 researchers working under the auspices of IUCN was published (Grace *et al.* 2021).

***Megadiversity countries:*** A country having at least 5000 of the world's plant species as endemics and having marine ecosystems within its borders. The World Conservation International has identified a total of 17 megadiversity countries: Australia, Brazil, Columbia, China, Democratic Republic of Congo, Ecuador, India, Indonesia, Madagascar, Malaysia, Mexico, Papua New Guinea, Peru, Philippines, South Africa, United States, Venezuela.

***Net zero emission:*** A condition in which emissions of global warming green-house gases due to human activities to the atmosphere will be no more than the amount removed from the atmosphere. Some of the major approaches to reduce emissions include replacing coal and fossil fuel based transportation and industries with renewable energy, and managing agriculture and forestry so that they can absorb more $CO_2$. Another approach is to extract $CO_2$ directly from the atmosphere through carbon capture, its usage and storage for which we still do not have economically viable technologies.

***Species recovery:*** Species recovery is the process whereby native species or populations that have become endangered as a result of habitat loss, decrease in population size or loss of genetic variability, are recovered within their indigenous range to a state where they are able to maintain themselves without further human intervention.

***Species reintroduction:*** Species reintroduction is the deliberate introduction of individuals of a species to parts of its natural range from which it has been lost.

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