Seed banking not an option for many threatened plants

The Global Strategy for Plant Conservation requires 75% of threatened plant species conserved ex situ by 2020. Currently, ex situ conservation focuses on conventional seed banking, yet this method is unsuitable for many threatened species. The 75% target is unattainable without urgent investment into alternative techniques.

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Although fundamental for life on Earth, plant diversity is under considerable threat, and is currently being lost at a rate unparalleled in recent geological history[1]. In a bid to halt the continuing loss of global plant diversity, the Conference of Parties to the Convention on Biological Diversity (CBD) adopted the Global Strategy for Plant Conservation (GSPC) in 2002 (updated in 2010). This Strategy contains 16 global targets set for 2020[2]. Target 8 requires that at least 75% of threatened plant species be conserved ex situ, with the aim of at least 20% available to be used for recovery and restoration programmes. In addition, Target 9 calls for the conservation of 70% of the genetic diversity of crops, their wild relatives and other socio-economically valuable plant species.

Ex situ techniques involve the preservation of plants or germplasm away from where they naturally occur, using methods such as: the cultivation of plants in botanic gardens and arboreta[3]; cryopreservation of seeds, embryos or other tissues in liquid nitrogen; and the storage of seeds that are dried and then deep-frozen in seed banks[1]. Of these techniques, the latter, often referred to as 'conventional seed banking', is most widely employed. This is the preferred method because it allows the preservation of high levels of genetic diversity at relatively low cost, in minimal space and for comparatively long periods[4].

There has been a recent groundswell within the scientific literature concerning ex situ methods, and especially seed banking, for the conservation of threatened plants[3–7]; especially given the rise of novel plant pathogens as a threat both to plant populations and in situ conservation efforts[7]. However, it has long been recognised that conventional seed banking is not suitable for all seed plants, with some species having recalcitrant (desiccation-sensitive) seeds unable to survive the drying process and therefore incapable of being frozen. In addition, some orthodox (desiccation-tolerant) species can be dried and frozen, but are too short-lived (<10 years) in storage for seed banking to present a viable option for their conservation[1].

A key knowledge gap, therefore, is in knowing which of the world's most rare, endemic and economically important plant species will not be suitable for ex situ conservation in conventional seed banks. Although the majority of crop species are known to have orthodox seeds, storage behaviour is unknown for most wild species[8]. It is estimated that the incidence of recalcitrant species is around 8% of seed plants globally[9], with a higher prevalence in certain habitats[9,10]. However, seed storage behaviour has only been assessed for a small proportion of these species, and to date there has been no method to predict the storage behaviour of the many untested species.

Recent work[11] has developed a set of models that predict the likely seed-storage behaviour of species for which this trait is currently unknown. These models are informed by existing data on seed and plant traits, the climate of the species' habitat and the seed-storage behaviour of the species' relatives (see ref.[11] for further details of the models and assessment of their success rates). The development of these models now allows us to estimate the proportions of orthodox- and recalcitrant-seeded species of conservation and socio-economic value, and thus evaluate for the first time the extent to which conventional seed banks may be capable of contributing to the GSPC targets. We therefore use these models to ask two questions: are conventional seed banks capable of achieving the threatened plant diversity aims of Target 8; and how much can they contribute towards Target 9 and the conservation of 70% of the genetic diversity of crops, their wild relatives and other socio-economically valuable plant species?

Looking at the likely 'bankable' proportion of species on four species lists — the International Union for Conservation of Nature Red List of Threatened Species (IUCN Red List), the Royal Botanic Gardens Kew's Medicinal Plants database, the Crop Trust's inventory of crop wild relatives (CWRs), and all known tree species as per the GlobalTreeSearch[12] — the highest incidence of recalcitrant species is in the 'critically endangered' category of the IUCN Red List. At least 36% of these Red List species are likely to produce recalcitrant seeds (Fig. 1) and thus cannot be conserved in conventional seed banks. The other threatened categories of species on the IUCN Red List ('endangered', and 'vulnerable'), as well as the global tree species list, also contain high proportions of species that are likely to produce recalcitrant seeds: 35% of species in the 'vulnerable' category, 27% in the 'endangered' category, and 33% of all tree species (Fig. 1). In contrast, the prevalence of recalcitrant species is likely to be comparatively low among the remaining groups of species. This is particularly so for the species classified as being of 'least concern' on the IUCN Red List, CWRs and medicinal plants, where the proportions of probable recalcitrant species are likely approximately equal to the global background incidence of the trait (Fig. 2).

Previous research has suggested that the majority of recalcitrant species constitute canopy trees from the later stages of forest succession in tropical moist forests and mangrove habitats[9,10] — situations where both the highest plant diversity and the highest frequency of threatened species also occur. Examining this, we can see a positive relationship between the proportion of a species list that is likely to produce recalcitrant seeds and the proportion of the list made up by tree species from these tropical habitats (Fig. 2).

Conventional seed banking as an ex situ conservation strategy is well matched to contributing to the delivery of GSPC Target 9, being an appropriate conservation

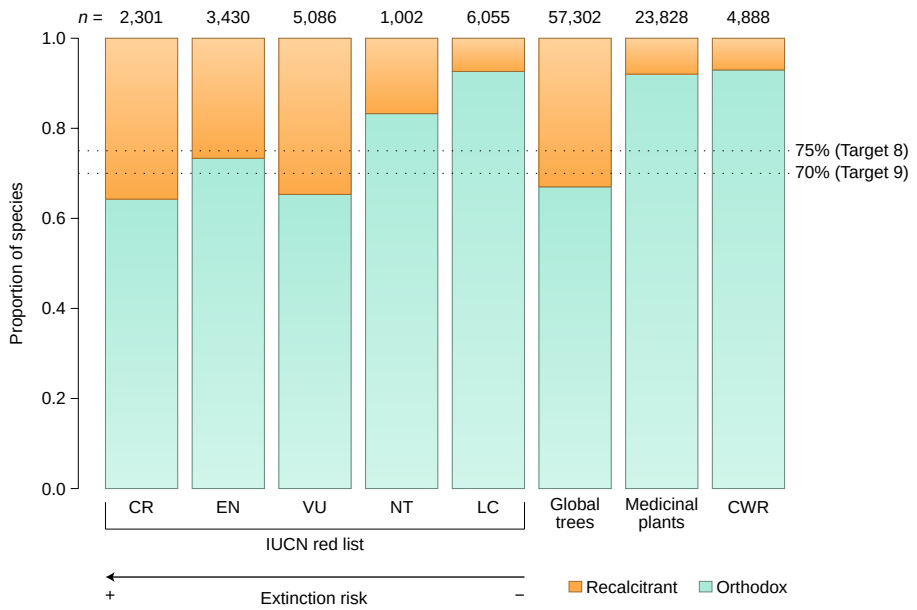

Fig. 1 | The likely proportions of seed storage behaviours across different plant lists. Species lists used are: the IUCN red list; GlobalTreeSearch, a database of all known tree species[12]; the Royal Botanic Gardens Kew's 'Medicinal plants' database; and the Crop Trust's inventory of crop wild relatives (CWR). CR, critically endangered; EN, endangered; VU, vulnerable (the three 'threatened' categories); NT, near threatened; and LC, least concern. Horizontal dotted lines denote the proportions of species that Targets 8 and 9 of the Global Strategy for Plant Conservation aim to conserve. Proportions predicted using models developed by Wyse and Dickie[11]. Target 8 aims for at least 75% of threatened plant species conserved in ex situ collections; Target 9 aims for the conservation of 70% of the genetic diversity of crops, including CWRs and other socio-economically valuable plant species.

technique for approximately 90% of the CWRs and medicinal plants examined here. The suitability of seed banking for the conservation of CWRs is perhaps unsurprising, since this technology was initially developed for the preservation of crops and as a tool for crop breeders[8]. As seed desiccation response is generally conserved at the lower taxonomic levels (that is, species and genera)[9,11], it follows that their close wild relatives should be similarly well-suited. Conversely, it is evident that heavy reliance on conventional seed banks for the ex situ conservation of threatened plant species will make the GSPC Target 8 practically unattainable, as it is likely to only allow effective conservation of around 60% of critically endangered species. This issue is particularly acute for tree species, especially those of tropical moist forests where there are also other difficulties associated with the successful collection of population seed samples. These difficulties include non-seasonal fruiting; seeds and fruit borne high in the canopy; predation by canopy–living animals; and difficulty in defining and accessing the 'population' of mother trees in dense, highly species-rich vegetation, to capture adequate genetic representation. Furthermore, the proportion of 'bankable' species is probably even less, because it is likely that many produce seeds that, even if orthodox, are too short-lived in storage to be practically conserved ex situ in conventional seed banks. The proportion of orthodox species that are short-lived in storage is not yet reliably estimated but one study[13], for example, found 10% of a collection of seeds from threatened plant species showed significant declines in viability after 5–12 years of storage at –20°C. It is therefore clear that simply increasing activity of conventional seed banks to collect and conserve threatened species[6] will not meet Target 8. Rather, a greater investment into alternative ex situ techniques is imperative.

Alternative ex situ techniques currently available for achieving Target 8 are cryopreservation (and associated in vitro methods) and collections of living specimens. However, neither of these represents a 'silver bullet'. Specimen collections, such as in botanic gardens, are frequently limited in the number of individuals conserved and therefore often represent extremely poor genetic variability and a genetic bottleneck[1,4]. Building on approaches developed by the zoological community — such as metapopulation management across networks of institutions, as well as germplasm exchange — may help assuage these shortcomings, but institutions will need to make such efforts a strategic priority[4,14]. In contrast, cryopreservation is a technique that holds great potential to conserve high levels of a species' genetic diversity for long periods, including those with recalcitrant or short-lived orthodox seeds[1]. However, it is time consuming and the techniques to restore species to habitats from cryopreserved material are often far from straightforward. Additionally, while cryopreservation has been found to preserve the viability of some short-lived orthodox species for longer than conventional storage, the lifespans of such seeds may still be impractically low[15]. Thus, whilst there have been calls (for example, by Li and Pritchard[1]) for the 2010 update of the GSPC to outline clear aims for cryopreservation under Target 8, this has yet to occur. We are, consequently, still in a position where a substantial research effort is required to take full advantage of this technology as an ex situ conservation tool. Developing cryopreservation techniques as a routine method for ex situ conservation of both recalcitrant and short-lived orthodox species by 2020 is, therefore, now unrealistic, especially given the need for significantly increased under-pinning research in this area and its inevitable lead-time. However, we suggest that intensifying research efforts into cryopreservation as a conservation tool in post 2020 targets is vital for increasing the ex situ conservation opportunities for threatened species. Furthermore, it is very likely that research under-pinning cryopreservation will also enable further optimisation of conventional seed banking[16].

The seed storage behaviour predictions discussed here help indicate which species are most likely to be successfully conserved ex situ in seed banks, and thus where the strengths of seed banks may lie. For conventional wild-species seed banks to 'play to their strengths', we suggest that they should focus their efforts on areas or groups of species with a low frequency of tree species characteristic of tropical moist forest or mangrove habitats, and redouble efforts to collect and preserve threatened temperate species, medicinal plants and CWRs, all of which are of high value to society for use and for biodiversity conservation. Conversely, ex situ efforts focusing on threatened tropical moist forest and mangrove tree species require either 'pushing the boundaries' of conventional seed banking, or concerted research efforts to improve the practicality of other ex situ techniques, such as cryopreservation methods. We recommend the latter, as it is in alternative techniques that the greatest gains are likely to be made in our abilities to safeguard such species outside their

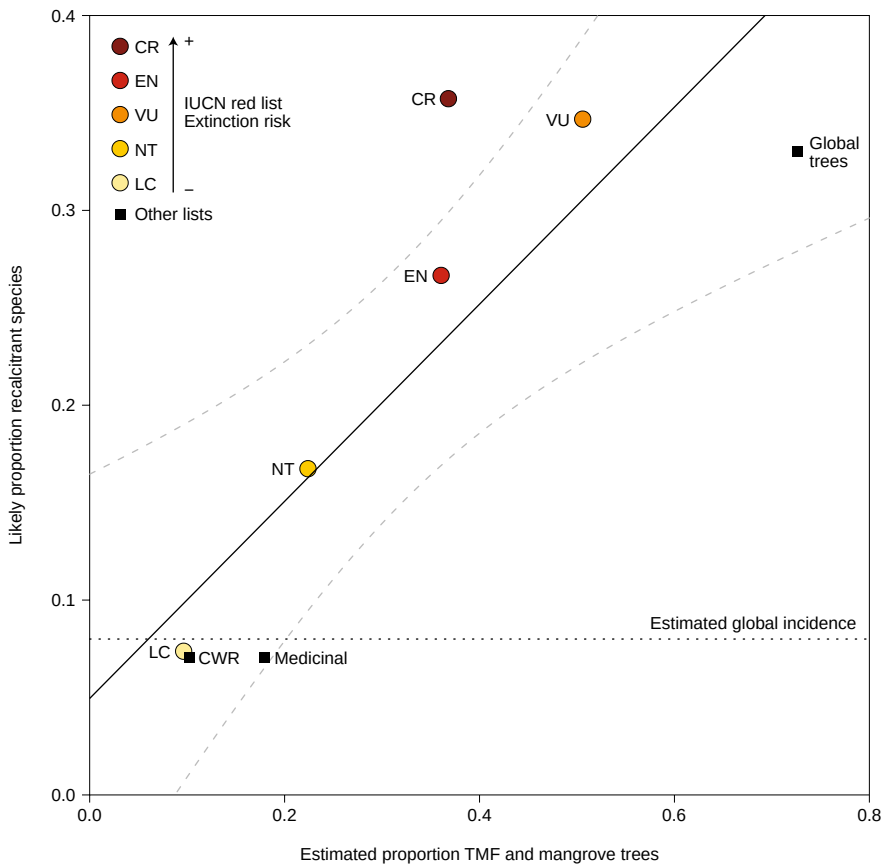

Fig. 2 | The likely proportions of recalcitrant species on different plant lists in relation to the estimated proportion of the list made up of trees from tropical moist forest and mangrove habitats. Solid black line is a linear model fitted for these two variables ($r^2 = 0.73$, $P = 0.007$); dashed grey lines represent the upper and lower 95% confidence bounds. Horizontal dotted line is the estimated global incidence of recalcitrant seed plants[9], storage behaviour was predicted using models developed by Wyse and Dickie[11]. Estimated proportion of tropical moist forest (TMF) and mangrove tree species calculated using data from GlobalTreeSearch, a database of all known tree species[12], the Global Biodiversity Information Facility (GBIF; www.gbif.org) and the Terrestrial Ecoregions of the World[17]. Species lists used are: the IUCN red list; GlobalTreeSearch, a database of all known tree species[12]; the Royal Botanic Gardens Kew's 'Medicinal plants' database; and the Crop Trust's inventory of CWRs. CR, critically endangered; EN, endangered; VU, vulnerable (the three 'threatened' categories); NT, near threatened; and LC, least concern.

habitats. Finally, we question whether it may even be somewhat naïve and dangerous to assume that ex situ conservation is a valid means of safeguarding a high proportion of threatened tropical moist forest trees from extinction. In situ conservation may be the only feasible tool in the conservation toolbox for many such plants. ❐

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Competing interests

The authors declare no competing interests.