



# What Are the Grand Challenges for Plant Conservation in the 21st Century?

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**Keywords:** citizen science, complexity, databases, extreme events, interdisciplinarity, modeling, palaeoecology, resilience

## OPEN ACCESS

### Edited and reviewed by:

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### Specialty section:

This article was submitted to  
Plant Conservation,  
a section of the journal  
Frontiers in Conservation Science

**Received:** 31 August 2020

**Accepted:** 08 October 2020

**Published:** 13 November 2020

### Citation:

Gillson L, Seymour CL, Slingsby JA  
and Inouye DW (2020) What Are the  
Grand Challenges for Plant  
Conservation in the 21st Century?  
*Front. Conserv. Sci.* 1:600943.  
doi: 10.3389/fcosc.2020.600943

## INTRODUCTION

Conserving plants in these turbulent and rapidly changing times is challenging, but nevertheless essential to the well-being of humans and all organisms on our planet. Plants supply our food, fiber, and medicines, regulate our climate, clean water and protect our soils, provide flood protection, underpin many cultures, and provide landscapes that restore and connect us to nature. Yet they face multiple interacting stressors and require urgent attention and decisive action that is effective, inclusive, and just.

## FOUNDATIONAL DATA ON PLANT DISTRIBUTION AND ABUNDANCE

The effective conservation of plants is underpinned by **fundamental information on plant diversity, distribution and abundance**, and how this is changing over time. Some species become extinct before they are even described by science, especially in tropical areas, where more financial, human and infrastructure resources are urgently needed (Vorontsova et al., 2020). At least 571 plant species have gone extinct since the 1750s (Humphreys et al., 2019), and 40% of current plant species are at risk of extinction (Antonelli et al., 2020). Genetic diversity and ecological and evolutionary processes are just as important as species in conserving plant diversity, providing bases for plants and their communities to adapt to global environmental change and local pressures such as habitat fragmentation (Coates et al., 2018, Quiroga et al., 2019). Data on distribution, changes in abundance and genetic diversity can inform the prioritization of conservation funding and effort, and research aimed at advancing conservation and management of plants and the processes that maintain healthy ecosystems.

Accurate inventories of genetic diversity, populations, species, and ecosystems, are essential both in understanding the biogeographic determinants of plant distribution and abundance, and in assessing changes over time. The likely trajectories of decline and effectiveness of conservation interventions can only be assessed if there is foundational data collection that can then be monitored over time. These surveys can use the energy and expertise of **citizen scientists**, who participate in capturing information including plant and animal distributions, range extensions or contractions, phenology of migrations, and plant flowering, and the presence or absence of

pollinators (McKinley et al., 2017). Most of the information recorded for the Global Biodiversity Information Facility (GBIF) and the USA National Phenology Network, for instance, comes from citizen scientists (Chandler et al., 2017, Taylor et al., 2019). Interfaces such as iNaturalist provide user-friendly and accessible means of connecting citizen scientists and co-ordinating data. That said, **greater investment in teaching of natural history** is needed to grow our foundational knowledge and understanding of species and ecosystems (Greene, 2005). Data on distribution and abundance are required to inform *in-situ* conservation efforts such as species-focused conservation interventions and protected area planning and prioritization, as well as *inter-situ* conservation and assisted migration (Richardson et al., 2009). The resources of *ex-situ* conservation such as seed banks, arboreta and botanic gardens could complement *in-situ* conservation and play a vital role in restoration projects and conservation of genetic diversity (Mounce et al., 2017, Abeli et al., 2020).

## CURATION AND MODELING OF DATA

Biodiversity data need to be managed in forms that are **accessible and useful to practitioners** (Ball-Damerow et al., 2019), requiring collaborative efforts that integrate and co-ordinate while remaining flexible enough to accommodate the dynamics of changing knowledge and available information (Costello et al., 2018).

As spatial data and computational tools improve, more **accurate monitoring of vegetation change and modeling of the drivers of plant distribution and abundance** at spatial and temporal scales fine enough to be relevant for conservation action are becoming possible. There are many new algorithms for continuous satellite-based monitoring of vegetation in near-real time (Zhu, 2017), and recent advances that help account for high dynamism in disturbance-prone ecosystems (Slingsby et al., 2020b). Both correlative and mechanistic approaches to modeling the distribution of species and ecosystems are advancing rapidly, and are invaluable in conservation planning and prioritization. Species Distribution Models (SDMs) can now incorporate a range of biotic and abiotic variables alongside the climate parameters, including soil type, disturbance regime, local adaptation, phenotypic plasticity and competition (Gavish et al., 2017, Benito Garzón et al., 2019, Magadzire et al., 2019). Similarly, Dynamic Global Vegetation Models (DGVMS), are increasing in sophistication and can include disturbance factors (e.g., fire) and are better able to predict responses in grass- or shrub-dominated systems (Hantson et al., 2016, Ruffault and Mouillot, 2017). Combined modeling offers the benefits and simplicity of correlative approaches with the biological realism of mechanistic and trait-based approaches, enabling demographic process, competition, dispersal and land-use change, for example, to be considered alongside climatic and other environmental parameters (Foden et al., 2019). The recent push for more emphasis on iterative near-term ecological forecasting is also testing our understanding of and ability to model ecological processes, and will hopefully accelerate our

learning and model development (Dietze et al., 2018). These exciting developments are technically demanding and data-hungry, presenting both challenges and opportunities for the coming decades.

## UNDERSTANDING LANDSCAPE HISTORY

Knowledge of the **history of landscapes and processes** that generate the biodiversity patterns we see today is crucial to ensuring we understand the ecological character and effects of long-term human influence (Gillson, 2015). **Data require context and interpretation** to guide conservation and restoration efforts effectively. For example, global analyses highlight vast areas that could support trees for climate mitigation (Bastin et al., 2019), with potential benefits for biodiversity restoration in deforested landscapes, but the maps include large areas of disturbance-maintained grasslands, shrublands, and savannas, where tree-planting would have severe detrimental effects on biodiversity and human livelihoods (Bond et al., 2019).

**Interdisciplinary studies** that include long-term data from palaeoecology and other disciplines can help to identify the range of variability prior to extensive human impact, aiding understanding of ecological character and helping to define limits of acceptable change/thresholds of potential concern (Gell, 2010, Wu, 2011). Furthermore, integration of **customary management and local ecological knowledge** into conservation practice can help maintain heterogeneous landscapes that benefit both people and biodiversity (Lindholm and Ekblom, 2019). This approach is especially powerful when combined with a willingness to **adapt social-ecological systems to novel and changing conditions**. Interdisciplinary teams can work together with communities to build nuanced understanding of landscape change and apply this knowledge in shaping conservation that is locally appropriate (Balvanera et al., 2017, Bennett et al., 2017).

## GRAPPLING WITH THE COMPLEXITY OF MULTIPLE INTERACTING DRIVERS

Models provide valuable tools for testing hypotheses and exploring future scenarios. Nevertheless, they do not capture the **complexity of all interacting factors** that determine population viability and ecosystem health. There are synergistic effects between habitat degradation, over-exploitation, disturbance, and climate change that can lead to unexpected and non-linear effects when environmental and biotic factors coincide. In western North America, for example, the warming climate has seen die-back of coniferous forests as a result of tree-killing beetles now able to over-winter more successfully and breed more rapidly (Lovejoy, 2019), and of aspen trees from increasingly frequent drought, which makes trees more susceptible to herbivory and disease (Anderegg et al., 2013).

Plants are also affected by **changes in the major disturbance regimes and their drivers**, such as alteration of fire regimes (Slingsby et al., 2020a), the loss of megafauna, or trophic

cascades through the loss of apex predators and other keystone species from terrestrial and aquatic environments. This can affect processes at the level of biome or even Earth system, with potentially serious impacts on ecosystem structure and function, ecosystem services, and biogeochemical cycles (Bowman et al., 2009, Norris et al., 2020). Loss of carnivores, for example, can propagate through multiple trophic levels, ultimately affecting plant assemblages; such cascading effects have been observed in terrestrial, freshwater, and marine ecosystems (Estes et al., 2011, Galetti and Dirzo, 2013). **Rewilding** of landscapes provides exciting opportunities to re-integrate plant and animal conservation, restore trophic interactions as well as to revive landscapes that inspire a fascination and care of nature, though of course requiring caution when functional equivalents are used to replace extinct species (Lundgren et al., 2018; Wolf and Ripple, 2018; Perino et al., 2019; Svenning et al., 2019).

## DEALING WITH EXTREMES—THE NEW NORMAL

As the devastating recent fires in Australia and California illustrate, the combination of changing climate, and the legacy of past and present fire management and suppression have led to fires that exceed the historical range of variability, in extent, intensity and duration. For example, Australia, although used to fire, experienced the most intense and widespread fires yet seen in the 2019–2020 austral summer, certainly the largest in Eastern Australia since European occupation (Wintle et al., 2020). The fires were so ferocious that they burnt through areas that ordinarily would serve as fire-free refuges. Almost half of the most impacted plant species lost over 80% of their range, and rehabilitation may be next to impossible given that the areas burnt are so large and that the distances that recolonizing mutualists will need to cover may be too great (Wintle et al., 2020). The relief effort for fire control was understandably focused on human safety, with only few pre-emptive responses aimed at reducing loss of biodiversity, although one example was saving the critically endangered Wollemi pine (*Wollemia nobilis*) (Wintle et al., 2020). A more future-focused effort to fire management could focus on restoring heterogeneity and building resilience (Gillson et al., 2019).

Temporary policies that are triggered during **states of emergency** can over-ride longer-term goals that safeguard the environment and conservation (Seymour et al., 2020). Therefore, as we acknowledge the likelihood that extreme events will become both more frequent and more severe, the time is right to take actions that **bolster green infrastructure** and integrate biodiversity conservation into climate change adaptation and disaster management, as well as to train a cohort of policy makers who can think strategically and plan for long-term resilience using sound underlying ecological principles (Ha, 2019).

## BALANCING BIODIVERSITY CONSERVATION WITH OTHER PRESSING NEEDS

As we grapple with **multiple interacting drivers of biodiversity loss**, the planet has other urgent concerns that compete for capacity and resources. For example, the recent drive to plant trees and increase carbon storage and contribute to climate regulation can come at a cost when non-native species replace native vegetation, compromising biodiversity and other ecosystem services. In Madagascar, for example, many afforestation projects use *Eucalyptus* spp. to provide wood for construction and fuel; these alien species, which evolved in very different systems, alter soil properties and water quality and alter fire regimes (Rakotondrasoa et al., 2012, Kull et al., 2019). **Improving carbon storage while maintaining ecosystem integrity** requires accurate understanding of carbon storage potential of native ecosystems and a thorough understanding of landscape history (Veldman et al., 2019).

With our minds understandably preoccupied with the current COVID-19 pandemic, there is no better time to consider the **links between human health and ecosystem health**. The transmission of zoonotic diseases to humans underlines the interconnectedness of living things and could inspire us to grapple with the complexity and uncertainty involved in doing conservation effectively, and building social ecological systems that are both resilient and adaptable. **Land degradation is extensive** in many countries, brought about by heavy grazing, invasion by non-native plants, and unsustainable agricultural and forestry practices. Habitat degradation and fragmentation shrink the resilience of ecosystems, reducing population sizes, and restricting gene flow. But there are other far-reaching consequences, including erosion, and damage to water quality and quantity and freshwater and often, marine ecosystems. Furthermore, many emerging infectious diseases arise from human encroachment into wildlife habitats. Human activities, particularly agricultural expansion and intensification and bushmeat harvesting make the transmission of diseases from animal populations to humans more likely (Allen et al., 2017, Rohr et al., 2019). Furthermore, the use of Genetically Modified (GM) crops with inbuilt herbicide tolerance (Woodbury et al., 2017), leads to increased herbicide use and associated loss of weeds that support pollinator species (Benbrook, 2012). **Wildlife-friendly, locally appropriate means of securing food and diversifying livelihoods** are needed, that support human and ecological health at the same time as conserving the genetic heritage that is in danger of being lost due to agricultural intensification and homogenization (Isbell et al., 2017).

In the past, fortress approaches to conservation have led to loss of livelihoods and cultural connections to landscapes, fuelling tension between conservation and development aims. However, more-inclusive approaches to conservation integrate customary protection of biodiversity like sacred groves into the protected area network, as occurred in Madagascar (Virah-Sawmy et al., 2014). Integrating poverty alleviation and food security with climate action and biodiversity conservation highlights the need

for intersectional thinking, as articulated in the Sustainable Development Goals (United Nations, 2015).

## FOSTERING CONNECTIONS AMONG PLANTS, PEOPLE, AND PLACE

Creative solutions are needed that integrate ecological and societal benefits. For example, controlling non-native invasive species can be costly and time-consuming, but in South Africa, the “Working for Water” programme, aimed at clearing such plant species, provides social upliftment as well as environmental benefits. Clearing these species benefits biodiversity and ecosystem services, improving water quality and quantity and helping in fire management and regulation. It also provides much-needed training and employment opportunities and spin-off opportunities that make use of the wood (van Wilgen and Wannenburg, 2016).

Projects that have both social and ecological benefits are especially advantageous when they are **co-created with stakeholder communities and are rooted in local ecological knowledge**. An example of this is the West Arnhem Land Fire Abatement (WALFA) program in northern Australia, which reintroduces traditional management of fire with benefits for carbon storage and biodiversity, providing cultural, natural resource, and biodiversity benefits at local levels, while addressing climate-change issues at the global level (Russell-Smith et al., 2013). Such initiatives help build resilience that will be crucial to adapting to the increasingly drier and fire-prone environments in the coming decades (Bowman and Murphy, 2011).

Cultural landscapes such as those in West Arnhem Land depend on human intervention for their maintenance and loss of management can lead to homogenisation of landscapes and associated loss of biodiversity (Gil-Romera et al., 2010; Lindholm and Ekblom, 2019). Yet, younger generations often do not want to participate in traditional agriculture and land management, instead preferring to seek employment in urban and coastal areas, leading to rural depopulation and loss of local ecological knowledge, as has happened in parts of Europe (Dax and Fischer, 2018). As more people dwell in urban areas, there are fewer opportunities to engage with nature. This extinction of experience can erode concern for nature (Seymour et al., 2020). To remedy this will require genuine efforts to **reconnect people with the landscapes and ecosystems** that they depend on, while recognizing our 21st Century context and the aspirations of young people and rural communities (Fischer et al., 2012). Stewardship and certification schemes, and access to global markets for high-value artisan products, can provide means of diversifying livelihoods and engaging with customary management that is locally appropriate and culturally rooted (Chapin et al., 2010, Lindholm and Ekblom, 2019). Furthermore, there are exciting opportunities for citizen science that enable individuals to contribute to our

knowledge of species’ distributions and abundance (McKinley et al., 2017).

## CONCLUDING REMARKS

As the current COVID-19 pandemic has shown, in times of emergency we turn to our neighbors, communities and local environment to meet material, social and emotional needs. At the same time, the unpredictability of our increasingly volatile Earth systems requires us to be adaptable and think at global scales. Policy frameworks, platforms and assessments such as the Sustainable Development Goals, Convention on Biodiversity and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Brondizio et al., 2019, Secretariat of the Convention on Biological Diversity, 2020; Sharrock, 2020) need to be translated into national and local interventions that are place-based, locally rooted and culturally appropriate. Our approach to plant conservation must remain responsive, flexible, and alert to new directions and opportunities, including the possibility that novel emerging ecosystems, better adapted to our no-analog future, might provide unexpected benefits. Action needs to take place at all scales from local to global, underpinned by a willingness to overhaul radically our approach to consumption and production, and incorporating interdisciplinary research, and co-learning and transparent communication between scientists and practitioners (Norris et al., 2020). Perhaps above all, as we grapple with issues at the intersection of social and environmental justice, we must seek to be equitable and inclusive. Citizen science and knowledge co-production achieve another vital goal, of helping to educate and enthuse. In the words of Baba Dioum, “In the end we will conserve only what we love, we will love only what we understand” (Dioum, 1968).

## AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

## FUNDING

LG was funded by the National Research Foundation, African Origins Platform, SASSCAL (Grant numbers 118538, 117666, and 118589) and the Vice Chancellor’s Future Leaders Fund. JS was supported by the National Research Foundation of South Africa, Grant no. 118593. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

## ACKNOWLEDGMENTS

We thank the reviewer for helpful comments.

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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