

## OPINION

# People and plants: The unbreakable bond

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**Societal Impact Statement**

Plants are crucial for human survival, providing nutrition, warmth, clothing, and shelter, as well as the air that we breathe. Plants also enhance our environment by making it more beautiful and thereby enriching our lives and increasing our wellbeing. We need to study plants more and better understand their biodiversity so that we can conserve and safeguard their future to create an ecological civilization. Plant scientists must work together with other members of human societies to ensure the survival of these crucial organisms upon which we are reliant.

**Summary**

We are losing biodiversity at an unprecedented rate, which will have unknown but potentially devastating consequences for the Earth's planetary systems. Before we can conserve biodiversity, however, we must understand it, both as a concept and by performing an assessment of the diversity of life on our planet. Here, I highlight and explore the relationships between people and plants. Plants perform a diverse array of ecosystem processes, which provide us with a huge number of ecosystem services. We have domesticated a relatively tiny number of plant species to better optimize some of the products they provide us, including food, fiber, and fuel, but our relationships even with these few species are complex. Using the Solanaceae as an example, I explore the cultural, societal, economic, and nutritional aspects of our relationships with crop plants, as well as our use and knowledge of the genetic diversity stored in their wild relatives. Conserving plant biodiversity is vital for ourselves and for the rest of the biosphere, but plant scientists cannot achieve this alone. Highlighting the importance of biodiversity is key to attract public support and collaboration, enabling us to better map diversity and understand the impacts of our local behaviors on a global scale.

**KEYWORDS**

citizen science, diversity loss, ecosystem services, Solanaceae, species richness

## 1 | INTRODUCTION

The opening ceremony of the International Botanical Congress in Shenzhen, China (July 2017) highlighted the importance of plants, both for us as a species, as well as for the planet. This article will focus on the relationships that we humans have with plants. In an article, also

in this issue of *Plants, People, Planet*, Peter Raven (2018) describes the role that we must take to save our Green Earth. Our world is, as far as we know, the only habitable planet in the solar system. Protecting the Earth's ability to sustain human life as well as the diversity of the rest of life means protecting the dynamic systems that comprise our planet. It is something that we must do; there is nowhere else to go.

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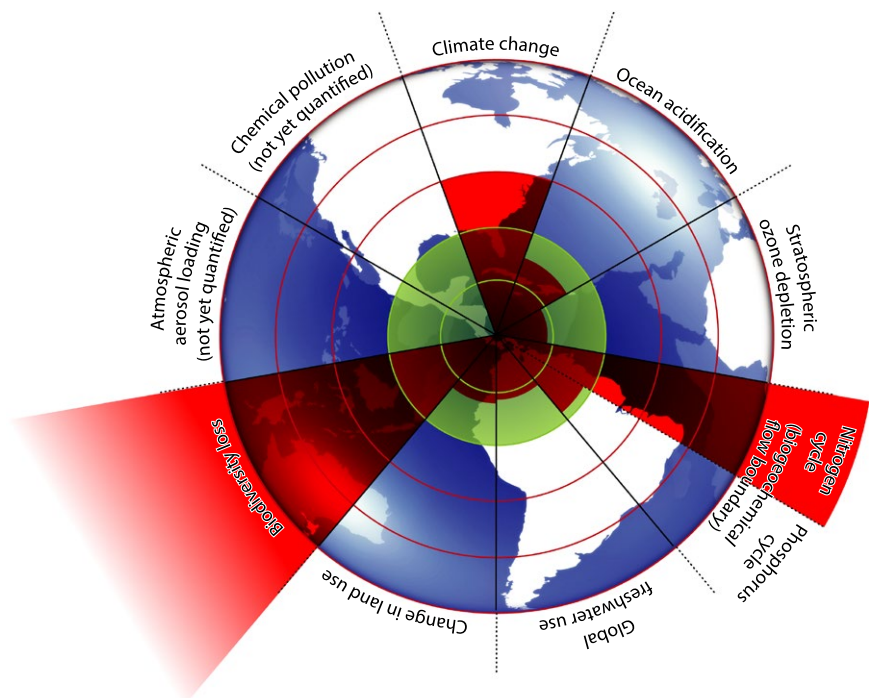
Plants form the basis of terrestrial ecosystems, acting as the framework that supports the diversity of life. Biodiversity itself is a very difficult concept. A number of years ago, I conducted a very informal, very unscientific study at the Natural History Museum in London, United Kingdom (UK), asking people what they thought biodiversity is. Rather alarmingly, many people thought that biodiversity was a soap powder for washing their clothes, which poses a problem for trying to engage people with it and the need to conserve it. When we talk about biodiversity, and about plants as components of biodiversity, we should bear in mind the Convention on Biological Diversity (<https://www.cbd.int>), signed and ratified by most countries on Earth. The three main pillars of the Convention are the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from the utilization of genetic resources. Only one of these pillars relates to the conservation of biological diversity; the other two focus on the use of the planet's biodiversity, and so are really about us, the human species.

## 2 | WHAT IS BIODIVERSITY?

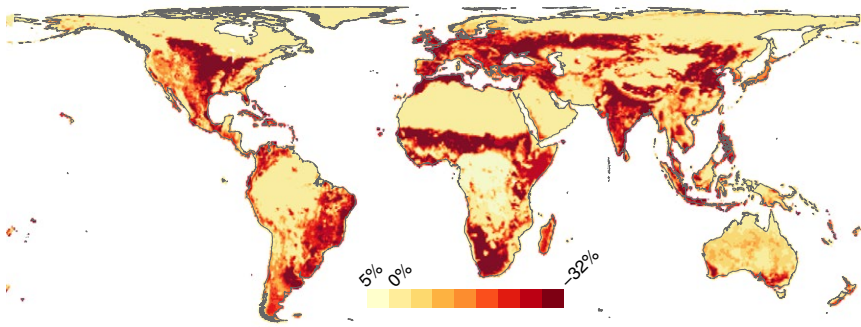
The Convention on Biological Diversity defines biodiversity as “the variability of living organisms from all sources, including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes biodiversity within species, between species and of ecosystems” (<https://www.cbd.int/>). The concept of biodiversity is therefore very difficult for people to come to grips with because it is extremely broad; it is everything living we can see, as well as everything living we cannot see. Biodiversity incorporates the interactions between the many different organisms in nature, and is found in all landscapes, from lush forests to arid deserts to our city streets; it is in our botanic gardens and in the weeds along railway lines.

We know that biodiversity is being destroyed at a very rapid rate. Some of the reasons for this are highlighted by Raven elsewhere in this issue (Raven, 2018). In 2009, Rockström et al. devised the concept of the “safe operating space for humanity” (Rockström et al., 2009). Using a modeling approach, the authors considered the extent to which the planet's systems were affected by humanity, and whether we had gone beyond safe planetary boundaries (Figure 1). One area in which we have far exceeded the safe operating space is the rate of biodiversity loss; we have no idea how the loss of so many species will affect the planet as a whole. There is a lot of uncertainty surrounding the idea of the safe operating spaces, but it is a concept that focuses our minds on where we need action, both directly and in finding out more—the data gaps.

In 2016, a team of researchers led by Andy Purvis of the Natural History Museum in London, UK, examined the intactness of the biodiversity of terrestrial biomes (Newbold et al., 2016). Like Rockström et al., Newbold and colleagues used a modeling approach, and concluded that many of the ecosystems on Earth are outside of the safe limits, in terms of both species richness and abundance. While we often think of forests when we consider biodiversity loss, the grasslands represented the most damaged regions on Earth and were found to be at most risk (Newbold et al., 2016). This not only includes grasslands all over the planet, comprising those at high elevation, such as grasslands in China and Peru, but also the great grasslands (prairies) of the central part of the U.S.A. and the savannas of eastern Africa. As part of the same project, Newbold and colleagues considered the global change in local species richness in the 500 years leading up to the year 2000, again using a modeling approach (Newbold et al., 2015). Higher levels of biodiversity loss were found in more densely inhabited areas, with much of the loss of terrestrial biodiversity being driven by human beings and our impact on the environment. It seems that wherever we are, biodiversity is not (Figure 2).



**FIGURE 1** Planetary boundaries. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change, and the nitrogen cycle) have already been exceeded. Reproduced with permission from Rockström et al. (2009)



**FIGURE 2** Net change in local species richness caused by land use and related pressures between 1500 and 2000, given as a percentage. Reproduced with permission from Newbold et al. (2015)

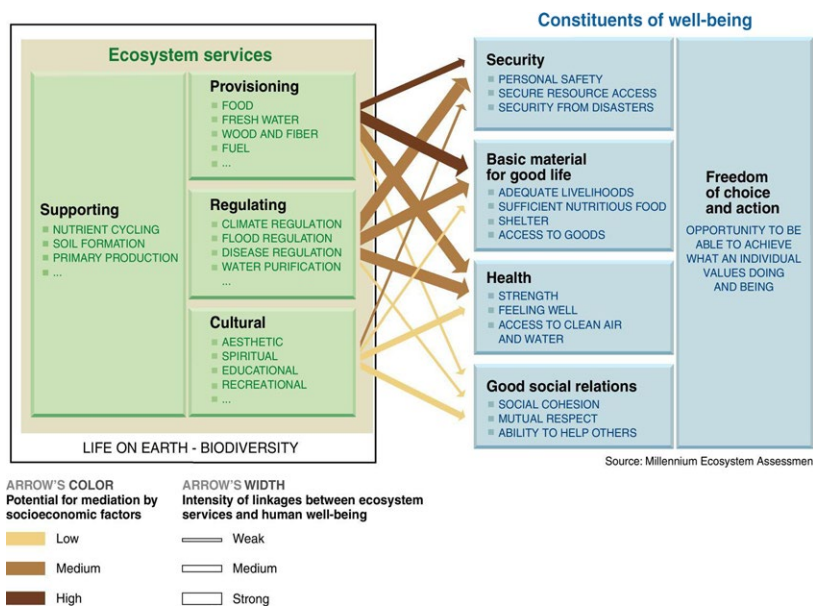
In 2005, the Millennium Ecosystem Assessment was published, which was an attempt to take stock of the Earth and think about its condition as we transitioned to a new millennium. Figure 3 highlights the framework on which the Millennium Ecosystem Assessment was established. It represented a new way of thinking about biodiversity and the services that biodiversity provides to us, from which the concept of “ecosystem services” was derived. Ecosystem services are the benefits we obtain from the diversity of life on Earth, including food, water, wood, fiber, climate regulation, and aesthetic value. These elements directly contribute to the constituents of human wellbeing, affecting livelihoods, health, access to clean air and water, and, very importantly, our very freedom and choice of action. In this diagram, biodiversity underpins ecosystem services, but the explicit connection between the biodiversity of life on Earth and the constituents of human wellbeing is hard to make—biodiversity is, in a way, a “black box” (Figure 3).

### 3 | CONNECTING BIODIVERSITY AND ECOSYSTEM SERVICES

Georgina Mace of University College London developed with colleagues a way of depicting and teasing out the explicit connections

between ecosystem services and biodiversity (Mace, Norris, & Fitter, 2012). Ecosystem processes can be considered the elements that connect biodiversity to ecosystem services; for example, the genetic diversity that goes into agricultural production, or the species diversity that results in a very rich and aesthetically beautiful habitat. Likewise, functional diversity can lead to better decomposition, which can help with climate regulation. These processes occurring in natural environments can therefore help us form and demonstrate the connection between ecosystem services and biodiversity.

When we consider how crop genetic diversity leads to resilience and adaptability, which in turn results in more and/or better food and human nutrition, our thoughts move from biodiversity to ecosystem services. Food is something we can all connect with. Plants are the basis of all our food; we either eat them ourselves or they are eaten by the animals we eat. An incredible variety of foods are available (e.g., Figure 4 shows a market in India with several types of eggplant, or aubergine [*Solanum melongena*], on display). Our society has become more homogeneous, with greater connectivity between nations and cultures; similarly, our food has become much more homogeneous too. In a short period of time, we moved from only having access to certain types of food in season at certain times of year to having an incredible richness available year-round from all over the world (Khoury et al., 2014).



**FIGURE 3** Links between ecosystem services and human well-being. This illustration highlights the importance of such links, as well as indicating the level at which it is feasible for socioeconomic factors to affect them. Reproduced from Millennium Ecosystem Assessment (2005), image prepared by Philippe Rekacewicz and Emmanuelle Bournay of UNEP/Grid-Arendal



**FIGURE 4** A market in the Andaman Islands, India, with local varieties of eggplants and many diverse vegetables for sale

#### 4 | HARNESSING PLANT DIVERSITY

There is more variety in the food available to individuals and nations than ever before; but although our individual diets are richer and more diverse, the food we eat is becoming more and more the same (Khoury et al., 2014). A person in London in the 1700s ate very different foods to a person in Shenzhen, but today, we are all eating many of the same things. This paradox poses a risk to food security, as we are all relying on the same types of food despite the huge variation in the environments on Earth. Despite the incredible diversity of the angiosperms (flowering plants), the majority of the human caloric intake comes from just four species: rice (*Oryza sativa*), maize (*Zea mays*), wheat (*Triticum aestivum*), and potato (*Solanum tuberosum*) (Gruber, 2017). We need to utilize more of this diversity to sustainably support a global population that will soon reach 11 billion. We have only domesticated a very small number of plants throughout history, including many annual species but fewer trees or biennial species (Meyer, DuVal, & Jensen, 2012). These relatively few domesticated plants are used very intensively worldwide, and local variety, even within them, is often at risk.

#### 5 | SOLANACEAE AND SOCIETY

Our use of members of the diverse Solanaceae (nightshade) family illustrates how our relationships with plants vary depending upon our interactions with them. When nightshade species were introduced to Europe from the New World in the 16th century they were seen as very dangerous and regarded with great suspicion, in part because native European plants in this family include deadly nightshade (*Atropa belladonna*), a potent poison thought to once have been used in witchcraft, and mandrake (*Mandragora officinalis*). Mandrakes have roots that, when pulled from the ground, were believed to emit a scream that would kill those who heard it—so the images of the pupils at Hogwarts donning earmuffs before their



**FIGURE 5** A fanciful drawing of the mandrake from Joseph Banks' 16th century hand-colored copy of Dioscorides' *De Materia Medica*. Image reproduced with the permission of the Trustees of the Natural History Museum, London

herbology lesson in repotting mandrakes is rooted in the literature of medieval herbals. In addition to featuring in folktales and literature, human interactions with mandrakes can be seen throughout history; for example, an image of the mandrake can be found in Joseph Banks' 16th century hand-colored copy of Dioscorides' *De Materia Medica*, Figure 5).

We eat many species of the Solanaceae. The most economically important genus in the family, *Solanum*, is hugely diverse and species rich, and one of a small number of angiosperm genera that comprises over 1,000 species (Frodin, 2004). One of the big four calorie providers and thus an important food crop worldwide is the potato, *S. tuberosum*, native to the Andes in South America. The significance of potatoes is demonstrated by the fact that they were the only native food item not to be banned by the Spanish conquistadores when they first reached South America (Earle, 2012). Food is an important part of culture, and throughout history, one of the ways in which a new culture is imposed upon native cultures is to forbid the consumption of local, traditional foods. This was true in Peru when the Europeans first arrived; however, the one food that could not be banned, because it was the complete staple for the entire civilization, was the potato. Potatoes are still grown in the mountains of Peru, but since the 1500s they have been transported around the world and now form one of the main carbohydrate sources for all humans.

## 5.1 | The Galápagos tomato and crop wild relatives

The Galápagos archipelago is a small group of islands off the coast of Ecuador, famed for its extraordinary endemic plants and animals. These islands also resonate in the imagination of biologists because Charles Darwin stopped there during his voyage on the *Beagle*, a visit that began to sow the seeds of his ideas about evolution by natural selection (Darwin, 1859). Much of the improvement we can make to the crops on which we rely depends on the genetic diversity present in their wild relative species, and species of endemic wild tomato in the Galápagos are potent illustrations of the utility and importance of crop wild relatives for crop improvement. Some populations of the Galápagos tomato species *Solanum cheesmaniae* have a distinctive trait, they lack the joint in the pedicel that causes it to break and leave behind the calyx on the fruit; this is caused by a mutation in the *jointless 2* gene (Rick, 1956). Plant breeders introduced this *jointless* mutation into cultivated tomatoes (*Solanum lycopersicum*), meaning the fruit falls with no calyx parts attached, facilitating mechanical harvesting and revolutionizing the tomato industry. Both *S. cheesmaniae* and its close relative *S. galapagense*, also endemic to the Galápagos, have potential for improving stress tolerance in the crop, as they are both salt and aridity tolerant (Pailles et al., 2017; Rush & Epstein, 1976).

Wild relatives can benefit us in obvious ways, such as supplying the genetic diversity that can help crops to survive in adverse environments, but also in more subtle ways; for example, by enabling use of traditional plant breeding methods to improve nutrition in a targeted manner (Gruber, 2017). In an attempt to tackle problems of over-irrigation and increasing soil salinity in many dry parts of the world, plant breeders have turned to wild relatives to identify genes that could be bred into crops to facilitate their growth in saline soils. This could be achieved in tomato using the genetic diversity of the Galápagos tomato, which grows in coastal regions and is tolerant of salinity (Pailles et al., 2017). To improve nutrition, scientists at Oregon State University crossed a Chilean species of tomato (*S. chilense*) with *S. cheesmaniae* to develop the Indigo Rose tomato variety, which is purple and has high levels of antioxidant anthocyanins in the skin and outer flesh. Other breeders crossed *S. habrochaites* to cultivated tomatoes, harnessing the wild relative's *Beta* gene to produce vastly increased levels of beta-carotene, the precursor of vitamin A, and therefore more nutritious fruits.

## 5.2 | Eggplants

Eggplants (or aubergines; *Solanum melongena*) are an important vegetable crop throughout the world (Figure 6). While there is great debate about whether eggplants were first domesticated in India or China, many of its wild relatives come from Africa, which is where we must focus our attention when conserving genetic diversity (Vorontsova, Stern, Bohs, & Knapp, 2013). Research into species identities in the eggplant clade and their phylogenetic relationships has yielded interesting results; *S. melongena*'s wild progenitor is native to China and India, but all other close eggplant wild relatives come from Africa.



**FIGURE 6** Variation in fruit shape and color in cultivars of the common eggplant, *Solanum melongena*, and the scarlet eggplant, *Solanum aethiopicum* (red fruit). Plants cultivated at INRA Avignon, France

In order to use wild relatives for future plant breeding, their germplasm must be collected for conservation. In order to use wild species in eggplant breeding they must be held in genebanks, but how many of these species are available to plant breeders? In 2016, Syfert and colleagues considered the evolutionary tree, genepool, and collections of eggplant relatives stored in germplasm banks, comparing them with the distribution of the wild species from which material is obtained by breeders to improve crops (Syfert et al., 2016). The unfortunate result was that vanishingly few wild eggplant relatives are stored in genebanks, so there is next to nothing for future eggplant breeders to work with. More alarmingly, the eggplant relatives in the wild are not located in protected areas, and are therefore at risk of being lost, impacting both plant breeders and biodiversity forever. Undertaking this type of research requires work in understanding the diversity stored in collections and in the field, and both are important for ensuring that plant breeders can obtain the material they need.

## 5.3 | Black nightshades

Species of black nightshades are commonly cultivated for their leaves in both China and Africa. These crops are not only high in vitamins and minerals, but are also extremely important for local societies. In Africa, women are the principal cultivators of these crops, and are empowered by income derived from the sale and marketing of these relatively minor crops of nightshades, which are most definitely not minor in terms of human nutrition and in social and economic factors. *S. scabrum* is grown across Africa for its leaves which are used as a sort of spinach, but other varieties are also grown for their fruits, which are dark purple, of similar size to cherries and contain very high levels of anthocyanins and antioxidants (hence its English common name, “garden huckleberry”). Another species, this one with orange fruits (*S. villosum*) is also

culturally significant; children in particular eat the fruits, and probably by selecting the plants with the most fruits for further cultivation, are thus involved in the improvement of this crop species. We tend to think that plant breeding and plant improvement are conducted by scientists in laboratories, but as this example illustrates, this type of work can be undertaken by anyone.

## 6 | CULTIVATING COLLABORATION

Understanding plant biodiversity can involve tracing the movement of a plant clade from one continent to another, or following genes from a wild to a cultivated species, or examining germplasm to see what must be saved for future plant breeding. We have a complex relationship with plants, which differs for different species; therefore, the issue of conserving biodiversity is complex. The Millennium Ecosystem Assessment (2005) states that “a major obstacle to knowing (and therefore valuing), preserving, sustainably using, and sharing benefits equitably from the biodiversity of a region is the human and institutional capacity to research a country’s biota.” The human capacity of a country to study and better understand biodiversity is essential for its conservation. It is not enough just to conserve species, we must also conserve and nurture people to further our knowledge of this diversity.

Caring for biodiversity requires people to work together in many activities, including collecting plants, recording where they grow, and determining how they function in their environment. It also requires people to visit unexplored places to discover plant species before they are lost. Although anecdotally scientists often lament that fewer taxonomists are studying plants than ever before, Joppa, Roberts, and Pimm (2011) found that the number of taxonomists, as measured by the listed names of people describing plants, has in fact increased since the 18th century. Despite this, we are still describing the same number of species each year (around 2,000 per year) as we have for the last three decades. So what is happening? If there are more people describing plants, but we are still describing the same number then it follows that taxonomists are doing more than describing species! Taxonomists today do many things—description, discovery of relationships, and more derived and applied research. All these things are important for understanding the world around us, and the job of a taxonomist is more diverse now than it was two centuries ago. But how can we really do more with less?

Plant scientists are not the only people who can generate knowledge about plant diversity; it can, and perhaps should, be generated by everyone. The key element is the sharing of this knowledge between scientific and local communities, between generations, and between different types of people. Sharing knowledge is essential for conserving plant diversity in the future; we cannot care about something until we know it is there. If we do not know about a beautiful orchid species, we will not actively conserve it.

Knowledge from the scientific community is important, but citizen science can also contribute vital information to support plant conservation. This can be illustrated by a project at the Natural

History Museum, London, entitled Orchid Observers (<https://www.nhm.ac.uk/take-part/citizen-science/orchid-observers.html>). The UK is a small country, but contains a huge number of people who love biodiversity, especially orchid biodiversity. This project involved the public directly in research investigating whether climate change is affecting the flowering time of orchid species in the UK. Over the course of one summer, they received almost 2,000 contributions with 51,000 observations of orchid blooming times. Volunteers were also encouraged to examine herbarium specimens to discover orchid blooming dates in the past. Participants in this project were based across the whole of the UK, from Shetland in the very north to the Isles of Scilly in the very southwest. The power of citizen science is hugely underestimated; the observations and the science performed in this project were of very high quality. At its core, this project was about knowledge-sharing across communities. Science is often perceived as a very closed community, composed of experts who guard knowledge. However, a lot of people are interested in science and have keen observational skills, which means we have a large pool of people from all walks of life who can all work together to generate knowledge.

We can observe firsthand how our activities affect our local environment, but people who live in close proximity to particular plant species are not the only ones who should care about them. In our globalized and connected world, our behavior can impact biodiversity a long way away. Practices we have in our daily lives can have impacts we do not see; for example, the precious metals (e.g., platinum and palladium) and rare-earth elements (e.g., yttrium, lanthanum, terbium, neodymium, gadolinium, and praseodymium) in our mobile phones are a nonrenewable resource mined mainly in Africa, a practice that can of course have a huge impact on the local biodiversity. Recent concern over plastic pollution in our oceans is another case in point—plastics from food packaging have been found in the remotest parts of the oceans (Borrelle et al., 2017; Taylor, Gwinnett, Robinson, & Woodall, 2016), and they certainly were not generated there! The effects of our behavior on a day-to-day basis may not be felt in our own backyard, but they may result in the destruction of biodiversity elsewhere. The term “think global, act local” is well known, but I also feel we need to “act global and think local.”

## 7 | CONCLUSIONS

To conclude, I would just like to revisit Rockström and colleagues’ compelling image of the safe operating limits for our planet (Figure 1; Rockström et al., 2009). Some of the Earth’s systems are beyond these safe operating limits, including climate change (see also Raven, 2018, in this issue) and levels of nitrogen and phosphorus pollution, largely the result of overuse of agricultural fertilizers. Biodiversity loss is the factor most beyond the planetary boundaries, however, which is frightening because the effects of this are so uncertain. We have to make a decision; if we want to build an ecological civilization in which plants and other species

can live in harmony with people, we need to think about how we can help other species to exist on this planet.

Much of our food is grown in highly controlled environments. Elite crop cultivars are grown in monocultures; however, such genotypes have very narrow genetic diversity and may be less resilient to the types of environmental changes we know are coming. We need to be able to overcome those challenges using genetic diversity harnessed from crop wild relatives. Conserving the genetic diversity of all plants is important, however, because all species are the results of millions of years of adaptation. Evolution by natural selection has come up with solutions to the problems we are facing (although perhaps not on the scale or at the rate of change we are seeing now), so we lose this diversity at our own peril.

We scientists are good at moving the focus of our attention from the global scale to landscapes to individual plants, even down to the genomic scale. The genome sequencing revolution means we can mine the genetic information of as many species as we like, but what we have not done is taken this genetic material back to the plant, back to the landscape and back to the globe. Moving from small to large scale is a huge challenge, but one that must be faced for science and for society. We must also remember that the best scientific results are achieved with the help of society.

We need plants because they comprise the fabric of the Earth's ecosystems. All the food we eat not only comes from plants in one way or another, but we also need plants for their pure aesthetic value. Can you imagine a world without flowers? In order to create an ecological civilization with plants and people living in harmony, we have to create an Earth that is resilient and able to overcome change. I have heard it said that we need plants but they do not need us. Our planet has coped with huge amounts of change in its four-billion-year history, but for the Earth to continue to adapt and be resilient in the face of future change, plants need us as much as we need them.

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