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Research paper

Maintaining biodiversity will define our long-term success

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ABSTRACT

Human beings are not only a part of our planet's ecosystems, but also, they are massively overusing them. This makes ecosystem protection, including biodiversity preservation, vital for humanity's future. The speed and scale of the threat are unprecedented in human history. The long arch of evolution has been confronted with such a high level of human impact, that we are now facing the sixth mass extinction event, 66 million years after the last one. This threat heightens the imperative for bold human intervention. Our paper identifies three strategies for such an intervention. First, and possibly most challenging, human demand needs to be curbed so it fits within the bounds of what Earth's ecosystems can renew. Without meeting this quantitative goal, biodiversity preservation efforts will not be able to get scaled. Second, in the transition time, we must focus on those locations and areas where most biodiversity is concentrated. Such a focus on ‘hotspots’ will help safeguard the largest portion of biodiversity with least effort. Third, to direct biodiversity preservation strategies, we need to much better document the existence and distribution of biodiversity around the globe. New information technologies could help with this critical effort. In conclusion, biodiversity preservation is no longer just a concern for specialized biologist but is becoming a societal necessity if humanity wants to have a stable future.

1. Introduction

Human beings are a part of the global ecosystem. Our ancestors evolved within it and we continue to depend on it for our survival. We therefore must be concerned with the functioning of that ecosystem and with the future of species, its functional units. With overall human demand having become so massive compared with the ability of ecosystems to provide for it, ecosystem protection, including biodiversity preservation, has become a defining strategy for enabling a thriving future for humanity.

The biosphere and its many local ecosystems depend for their healthy functioning on interactions involving millions of species; these relationships and the sustainability of the ecosystems they make possible have evolved and changed continuously over the whole history of life on Earth. For any particular ecosystem, we do not how many species can be subtracted before the system collapses. The continued functioning of an ecosystem, however, clearly depends on maintenance of its structure.[1]

Plants play an important role in most terrestrial ecosystems, in that they maintain the composition and quality of the atmosphere and of soils. Plants also regulate the flow of water and the extent of erosion worldwide, and profoundly affect local climates. Without plants and a few other groups of photosynthetic organisms, most other life could not survive. In addition, and with very few exceptions, photosynthesis is at the bottom of every food chain. Individually also, plants are very important to human beings. Along with all land-based animals and other organisms, we depend on them directly or indirectly for all of our food. We have many other uses for them, as medicine and for many kinds of building materials, biofuels, chemicals, and other products. Moreover, many plants are extraordinarily beautiful, inspiring us each day we live.

Because we function as a part of ecosystems and therefore depend on them, we must find ways to slow the catastrophic loss of species that is causing increasing damage to all of them (Ceballos et

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[1] In this paper, we have drawn heavily and in part directly on the material provided by Raven (2020A, B), reviews that have helped lead us to the conclusions presented here.

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al., 2015, 2017, 2020). Unless we do so, we are betraying the generations that will come after us and will impoverish their lives to an unimaginable degree.

2. The history and nature of life on earth

To help understand the role of biodiversity and our place as part of it, we need to review how life evolved to where it is now. Our planet is approximately 4.5 billion years old, with various different kinds of single-celled organisms appearing within the first billion years of its history. The critically important process of photosynthesis evolved first in the ancestors of the "blue-green algae," or cyanobacteria, about 3 billion years ago. Abundant in all of the oceans, cyanobacteria have generated oxygen for billions of years, eventually driving the proportion of oxygen in the atmosphere to about one fifth. The first terrestrial organisms appeared on land more than 430 million years ago, with vertebrate animals, plants, arthropods, and fungi making the transition separately and more than once in each group. No longer shielded by water from mutagenic solar radiation, these pioneers depended on the sun-blocking properties of oxygen to enable them to exist on land.

Once established on land, organisms began to differentiate rapidly. Because of this proliferation, a substantial majority of the existing species is terrestrial. Since early times, plants have formed the backbone of ecosystems on land, backbone within which many other forms of life evolved; these eventually included humans. Tetrapod animals had differentiated by the Carboniferous Period, some 335 million years ago, with mammals, turtles, crocodiles, and ultimately birds following; all of these evolutionary lines, along with the older amphibians, were in existence by 150 million years ago. Two of the groups of organisms most prominent in today's world, flowering plants and placental mammals, first appear in the fossil record in the early Cretaceous Period, about 130 million years ago.

During the history of life on Earth, four major extinction events occurred before flowering plants and placental mammals had appeared. Each of these events caused the loss of over half the species that existed when they began. The most recent of them took place about 66 million years ago, at the Cretaceous–Paleogene boundary. All remaining dinosaurs became extinct at that time, together with more than 75% of all other existing species. In time, the disappearance of so many species led to the opening of new, diverse habitats that were key to the course of subsequent evolution within many groups. In these new habitats, terrestrial vertebrates, insects, and plants evolved, eventually building the unprecedented number of species living today.

As reviewed by Raven (2020B), the Cenozoic Era has been a period of drying and, in general, cooling. Grasslands, as well as ecosystems dominated by hard-leaved, evergreen trees and shrubs, appeared and began expanding about 45–30 million years ago. The strong differentiation between frigid polar climates and warm tropical ones strengthened over the course of the past 15 million years, eventually forming the divisions that are so evident today. Communities and ecosystems assumed their characteristic appearances as vascular plants and other kinds of organisms radiated progressively into each of them.

To assess patterns of geographical distribution and overall rates of evolution and extinction properly, we must first determine with relative accuracy the numbers of species in at least a few groups of organisms. Among those that are relatively well known are terrestrial vertebrates, with at least 35,000 species; butterflies, with some 25,000; and vascular plants, with perhaps 450,000 (about 380,000 of them named; Joppa et al., 2010, 2011). In contrast, our knowledge of species numbers for groups such mites (45,000 named species); nematodes (15,000 named species); and fungi (120,000 named species) is clearly inadequate. Together, these three groups may well include at least five million species! Eukaryotic organisms alone may feature at least 20 million species living today, a staggering number relative to fewer than 2 million species of eukaryotes, which have been assigned scientific names, suggesting that the great majority of those species, particularly in the tropics, will remain unknown as we drive them to extinction. For prokaryotic organisms (bacteria and Archaea), we have no realistic idea how many species may exist. In any case, we have recognized and assigned scientific names.

3. The emergence of human beings and their impact

Since human beings, members of our species, are the overwhelming force driving biological extinction today, let us consider our evolutionary journey to where we are today. African apes and the human evolutionary line (hominids) diverged from a common ancestor some 6–8 million years ago. Within that line, our species, Homo sapiens, originated in Africa at least 200,000 years ago, reaching Eurasia at least 60,000 years ago in Africa, reaching Eurasia at least 60,000 years ago. Once there, they spread rapidly throughout Eurasia and to Australia, ultimately reaching the Americas no less than 15,000 years ago. Most of their migration took place during the recent glacial maximum, a cool period that lasted from 110,000 to 10,000 years ago. Some 11,000 years ago, humans who were living as hunter-gatherers developed crop agriculture and began domesticating grazing mammals and birds, a practice probably originating initially in Western Asia. As the process of domestication got underway, there were only about 1 million humans on Earth, though this number immediately began growing steadily, especially around the villages, towns, and cities made possible by agriculture. People living in these early settlements no longer needed to move continuously in search of food, but could stay in one location year-round.

With a total of some 200 million people 2000 years ago and 500 million at the start of the European Renaissance (1500 AD), the human population first reached the level of one billion in Napoleonic times (1804). From that point onward, our numbers, spurred by the Industrial Revolution and the emerging use of fossil fuels, grew rapidly to nearly 7.8 billion today. Given current trends in fertility and longevity, the UN projects that this number will increase by an additional 2.2 billion people during the next 30 years (http://www.prb.org/).

The versatile and powerful fossil fuels, coupled with the inventiveness of the Industrial Revolution and the development of globally-traded currencies that hugely facilitated loans and new investments, massively eased the constraints imposed by our earlier direct dependence on biological resources. Fossil fuel used for fertilizers and for powering tractors and pumps allowed us to produce far more food and animal feed than agriculture was able to grow previously. As an energy source, fossil fuel also enables storing, processing, and shipping food and animal feed around the world, thus overcoming local food production limitations. It also eases the access to remote forests that we have since exploited. It makes possible the manufacture of substitutes for biological fibers of biological origin, with 70% fibers are now produced synthetically (Anzilotti, 2018). Additionally, without burning wood, and makes possible the transport of people around the world without having to feed horses and donkeys.

This fossil fuel use has amplified people's material demand on nature to an extent where our impact on all global ecosystems has become overwhelmingly negative. Agriculture occupies at least 40% of the Earth's land surface, with humans affecting virtually every square centimeter of the planet. Global warming, driven in large part by human activities, has led to a 1 °C increase in world temperatures over the past century; they are now higher than they have been for millions of years. Even if we stayed at current levels, greenhouse gas concentrations in the atmosphere, having reached 500 ppm CO_2 equivalent in 2019 (Butler and Montzka 2019), would almost certainly lead to an eventual increase of 2 °C, with an increase of 1.5 °C projected by 2030. Scientists anticipate that the effects of such an increase would be disastrous, given the threat to agricultural and marine productivity, weather calamities, sea-level rise, marine productivity, sea level rise, and freshwater availability, to name just a few. Despite the enormous threats we face, our efforts to form a global alliance to hold back climate change have not nearly been effective enough. The productivity of plants, which amount to more than four-fifths of the total living biomass on Earth and playing a huge role in absorbing carbon and thus being critical for slowing the rate of warming (Bar-On, Phillips, & Milo, 2018), could be seriously compromised by the expected climate change.

We can measure the scale of human presence in the biosphere by estimating how much people demand relative to what the planet's ecosystems can renew (Wackernagel et al., 2019). Even if the ultimate goal is quality (such as preserving biodiversity), such a quantitative metric is essential as it highlights the quantitative imbalance between human demand and ecosystem regeneration. As long as the quantitative bottom-line condition of demanding less than what can be sustainably renewed is not met, quality cannot be scaled. For instance, assume that a forested area is harvested at double the rate at which it can be sustainably renewed. Of course it is possible to preserve and protect a portion of that area. But if the human demand on this area stays the same, the overuse will be concentrated on the remaining portion of that forest, threatening its integrity. In other words, forest protection can only be scaled across the entire forest area, if the basic quantitative condition of harvesting that forest below sustainable renewal rates is met.

This quantitative argument concerning biological resource security also holds for sustaining economic success (including poverty eradication), certainly at the global level. And on average, it is also true at the local level, as for every resource import by one entity, one other entity on the planet has to provide it as export. Focusing on biological resource security builds on the recognition that the most limiting, material resources are our planet's biological assets, i.e., its biological capacity to renew living matter. Even for fossil fuel which is more limited by the biosphere's ability to absorb the excess CO_2 than by the stocks left underground. In ecological sciences, such balances are often approximated using NPP (or net primary productivity) assessments. While conceptually powerful, they are limited in producing sharp numbers contrasting human demand with biological regeneration as demonstrated by Rojstaczer et al. (2001). Ecological Footprint accounts use an agricultural quantification approach, where harvest of specific agricultural products (such as potatoes) is compared with the regeneration or yield of these products (potato fields). This becomes a sharper comparisons which does not depend on estimating the ancillary biomass involved in such production. This agriculturally inspired lens is the essence of Ecological Footprint accounting which contrasts biological regeneration (called "biocapacity") with human appropriation (called "ecological footprints").

Human demands on nature that compete for biocapacity include sequestration capacity for CO_2 from fossil fuel burning, demand for food and fiber, energy production (from hydropower to biomass), space for roads and shelters, use of freshwater, if it diverts water from other ecosystem uses, etc.

Both biocapacity and ecological footprint can be tracked and compared against each other, based on two simple principles: (1) one can add up all the competing demands on productive surfaces, i.e., the surfaces that contain the planet's biocapacity; (2) by scaling these areas proportional to their biological productivity, they become commensurable. The measurement unit used in this metric are "global hectares" which are biologically productive hectare with world average productivity. More details about the principles and mechanics of this accounting system are documented extensively in the literature. A simple discussion of its underlying accounting principles and guidance for basic result interpretations are provided by Wackernagel et al. (2019).

Ecological footprint and biocapacity estimates by Global Footprint Network, based on UN statistics and shown in Fig. 1, reveal that human demand in 1961 corresponded to about 73% of what Earth could renew at the time. This demand – essentially on plants' ability to renew - has risen to 175% in 2019, according to those estimates (Lin et al., 2018; Global Footprint Network, 2019; https://data.footprintnetwork.org/). One simple way to express this is that from January 1 to July 29, 2019, humanity had demanded as much from the Earth's ecosystems as these ecosystems could regenerate in the entire year (http://www.footprintnetwork.org//http://www.overshootday.org/). The balance, inevitably, stemmed from resource depletion. Fig. 2 shows the same trends on a per-person basis. People consume nature's productivity highly unequally, with national per person averages in the U.S., Gulf countries, and Western Europe being the highest. In contrast to these areas, the averages within countries that lack ecological resources and purchasing power reflect very low demands, indicating extreme deprivation and difficult material prospects for their residents (Wackernagel et al., 2019).

As explained in more detail elsewhere (Lin et al., 2018; Wackernagel et al., 2019), these assessments are limited by the quality and availability of UN data sets. Because of this limitation, and the bias built into the accounts not to exaggerate the deficit, the accounts produce most likely underestimates of human demand (as not all demands are well enough documented) and overestimates of the biocapacity (as soil erosion, groundwater depletion and declining forest productivities due to pests and increased forest fires are not systematically documented in the UN data sets) (Wackernagel et al., 2019).

Still, existing assessments show that both globally and within countries, stark inequalities also prevail for individuals. The distribution of income and financial assets is even more unequal than that of resource demand. The British charity Oxfam estimates that the financially richest eight people among us possess as much wealth the 3.6 billion poorest of us (Hardoon, 2017). Half the people on Earth lack sufficient quantities of at least one essential nutrient and over 700 million have to get by on US $2 per day or less, according to the World Bank (https://www.worldbank.org/en/topic/poverty/overview). Some 795 million of us do not receive enough food to lead a normal active life (www.wfp.org/hunger/stats), and half of us lack adequate supplies of at least one essential mineral.

4. Rates of extinction

As the present century unfolds, human populations are continuing to grow explosively, our agricultural activities are being expanded, climate change is intensifying, and our demand for ever-higher levels of consumption appears to be unrelenting. In the face of these trends, we seem destined to lose many natural habitats and millions of species during the remainder of the 21st century. Where are we now, and what rates of extinction can we expect in the future? Over the past 66 million years we have lost about 0.1

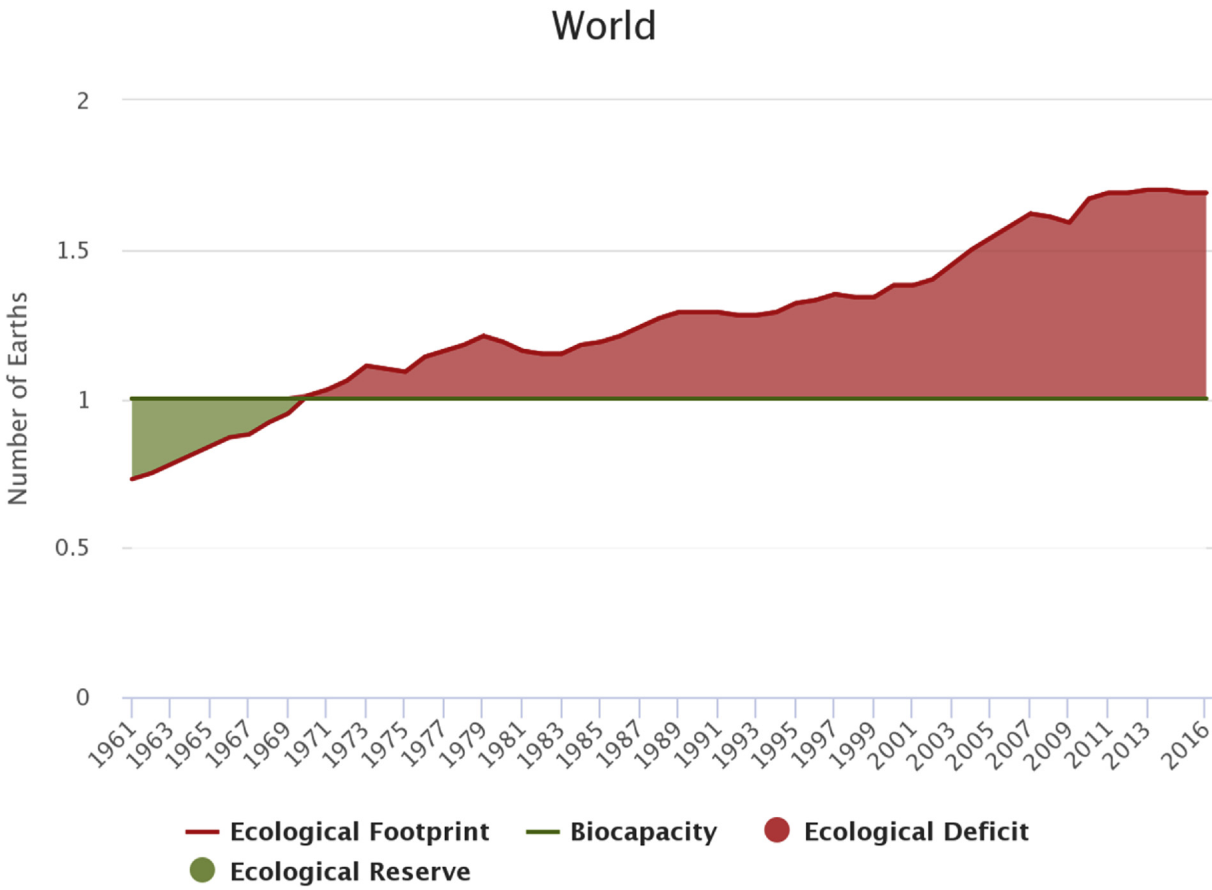

Fig. 1. The change in human demand against our planet's regeneration (shown as the green, horizontal "one-Earth" line). Note that to preserve biodiversity, human demand needs eventually to reach less than one Earth to secure some of the regenerative capacity for other species (data source: data.footprintnetwork.org).

species per million per year in those hard-bodied groups that we can sample adequately in the fossil record (essentially terrestrial vertebrates and mollusks). By comparison, we estimate that current extinction rates have already reached about 1000 times the historical ones (Pimm et al., 2014; De Vos et al., 2014). Taking the evaluations of individual species by conservation groups such as the IUCN into account, perhaps a fifth of all existing species might disappear within the next few decades, with perhaps twice that proportion or even more by the end of the century (Pimm et al., 2014; Kew, 2016; Pimm and Raven, 2017; Raven, 2020A). Beyond the direct loss of species, the rates of population extinction overall are alarming. For example, Ceballos et al. (2015) have shown that some 60% of the populations of Mexican terrestrial vertebrates have disappeared since 1950. Looking at the losses another way, the average size of vertebrate populations might have declined by about 60 percent from 1970 to 2014, according to the Living Planet Index (Grooten and Almond, 2018). These latter estimates indicate that extinction is proceeding far more rapidly than most of us assume. For the biologically richest habitats, the tropics, the situation is especially harsh.

Climate change is a major driver of extinction that can only grow in importance (Lovejoy and Hannah, 2019). The numerous endemic species found along the southern edges of the southern continents in habitats that are changing rapidly will have no place to go when the climate has warmed as we might expect given current trends (Merow et al., 2018). For similar reasons, the species that occur in tropical cloud forests (Janzen and Hallwachs, 2019; Helmer et al., 2019) or at higher elevations in mountains anywhere are in special danger of extinction during the remainder of this century.

5. Suggested focus areas for conservation efforts

We live in a time when about one-fifth of all species are at risk of extinction over the next several decades, with perhaps twice that proportion at risk by the end of the century. In the face of these alarming statistics, there seems to be no possibility of naming and classifying the at least 15 million undiscovered species of eukaryotic organisms while they are still with us. A race to name all the species that exist while so many of them are slipping through our fingers so rapidly would seem to have relatively little potential for augmenting our understanding (Raven, 1980; Raven and Wilson, 1992). Even if we were to name hundreds of thousands or millions of additional species, we would know almost nothing about most of them – a name, a few of their features, a place where they lived once and might persist. In the face of this challenge, it seems clear that we must concentrate our efforts along several innovative axes to obtain informative and lasting results while we still can.

First, we need to recognize that quality cannot be scaled, if basic quantitative conditions are not met. More specifically, it is not possible to conduct biodiversity conservation successfully across the world as long as overall human demand continues to exceed what ecosystems can renew. This is because of the fact that without human demand reduction, all efforts to protect biodiversity and reduce human pressure in certain ecosystems will simply move demand elsewhere, with no net gain. As mentioned, a conservative estimate of humanity's current demand stands at 175% of what Earth can renew as of 2019 (put otherwise, humanity's activities currently use the regenerative capacity of 1.75 Earths). Note also that this gap represents an average, and that many portions of

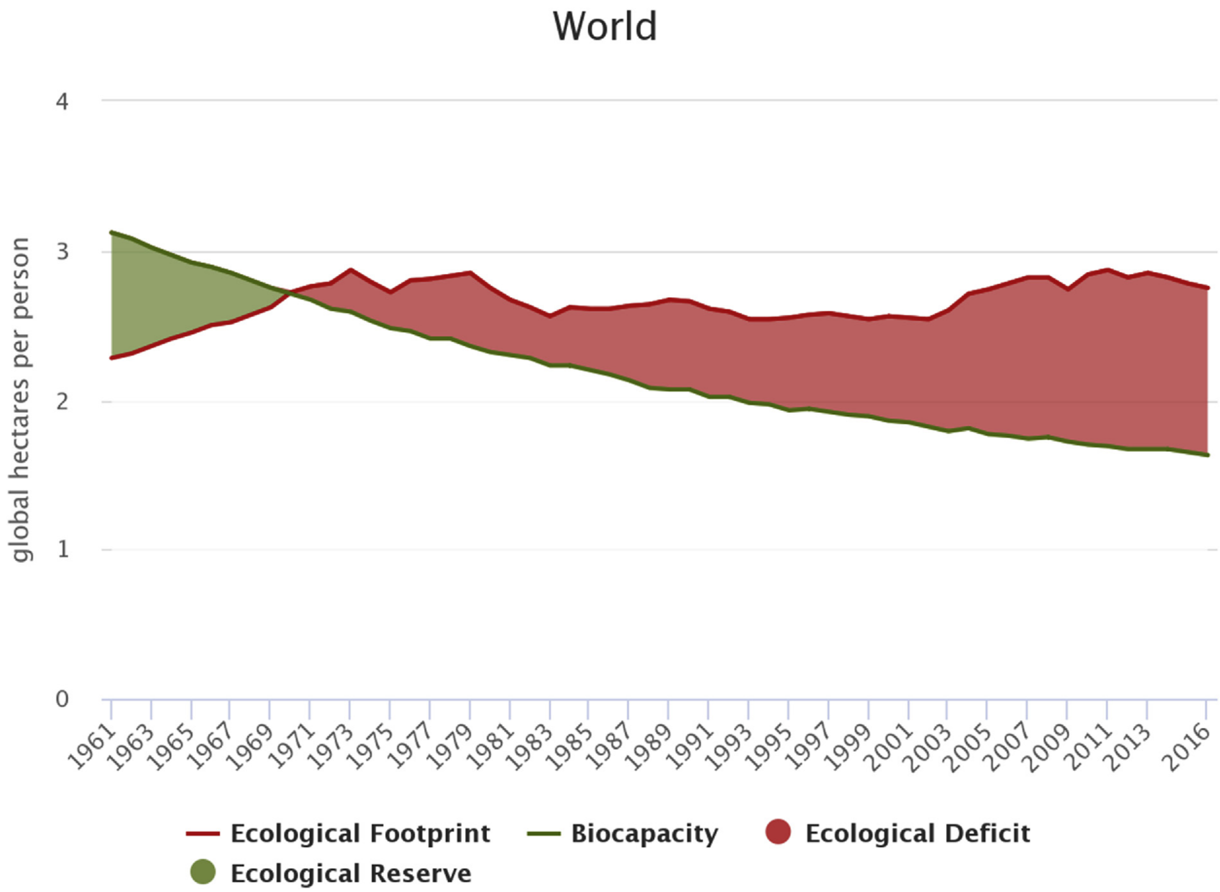

Fig. 2. It is the same graph as Fig. 1, but expressed per person. It shows human demand on nature (humanity's Ecological Footprint per resident) compared to how much Earth's ecosystems can renew (the planet's biocapacity per person) for the last six decades. The results here are expressed not in "number of Earths" as in Fig. 1, but in global hectares, or biologically productive hectares with world average productivity. Explanations on the unit of measurement and the underlying logic is summarized in section 2 of Wackernagel et al.'s open access paper (2019). The graph indicates that the growing human population has led to less biocapacity per person, while demand per Earth resident has stayed relatively similar. Consumption of products may have gone up, but with increases in efficiency the resulting demand on nature per person has not (data source: data.footprintnetwork.org).

humanity still need additional materials and resources to thrive. Also, meaningful biodiversity preservation and climate stabilization may require using far less than the entire regenerative budget of Earth. Lastly, the current gap also does not reveal that humanity's numbers are still on an upward trajectory.

Solving this quantitative challenge will ultimately define humanity's long-term prosperity, the maintenance of biodiversity, and the stabilization of the global climate. Obviously, innovation and foresight can help if they enable a significant and rapid redesign of our economies so that they can operate within the existing biophysical constraints. The alternative to such massive adjustment efforts will be involuntary adjustments accompanied by a huge potential for human suffering and a massive loss of biodiversity. Designed or imposed adjustments are by no means trivial. But the former is far preferable to the latter. The authors have identified some of the basic pathways that would make deliberate adjustments possible (Wackernagel et al., 2019). Humanity's overall demand can be decreased by focusing on four dominant areas: 1) the way we design and operate cities (highly compact, integrated cities with efficient building stocks), 2) the way we power our economies (focus on renewables, while regulating their competition with biologically productive areas), 3) the way we feed ourselves (effective food systems, while avoiding food waste and lowering contribution of animal products), and 4) how many we are (encouraging far smaller families and ultimately lowering our population to within sustainable bounds). Perhaps the most important insight from this study might be that it is in each country's self-interest to manage from a vantage point of resource security, thereby avoiding unnecessary resource dependence, as the world is ever more exposed to the calamities of prolonged ecological overshoot.

Second, this massive quantitative adjustment will take time, even if we carefully choose deliberate and concerted pathways. In the meantime, the question is where to put the conservation efforts to save as much biodiversity as possible in the face of all the challenging additional problems that we face. One of the strategies will be to identify those areas for which our efforts are likely to yield the greatest results. This is where the "Hotspots" concept emerges as a key strategy. Probably a majority of endangered species live in "Hotspots," defined by Myers et al. (2000) as areas that have been at least 70% disturbed by human activities and with at least 2500 endemic vascular plant species, along with many endemics from other groups of organisms. These relationships make it a high priority to explore the biota of Hotspots for as many groups of organisms as possible. Concentrating on conserving Hotspots would make possible to secure the highest attainable levels of species survival, with less effort than with any other strategy. Like any effective conservation effort, however, implementing such a strategy would demand a level of understanding and cooperation between nations that we have not even begun to approach. Without this cooperation, extinction will remain rampant in lower-income countries, where most species are concentrated. Higher income countries may be able to succeed with conservation efforts in their own territory, but their massive demand on other countries through their supply chains will continue to drive enormous impact on biodiversity elsewhere.

Third, it is desirable for selected groups of organisms to get a relatively complete picture of the numbers of species and distribution patterns while we can still do so. These groups mainly consist of those which are the best known, vascular plants, terrestrial vertebrates, butterflies, and a few others. Deeper knowledge fo these specific groups allows for estimates to be made of similar parameters for other groups of organisms that humans will never see. It is therefore worthwhile to keep driving to obtain as complete a picture as possible of their characteristics, evolutionary relationships, and distribution patterns. Since habitats all over the world are disappearing, but at very different rates, and since our knowledge of the species differs widely from place to place, it is logical for specialists to establish priorities for exploration as soon as possible. Having done so, we could seek special funding to realize these priorities. Meanwhile, we should continue to encourage researchers with different plans to deal with other groups in other places. Any accumulation of knowledge in an age of catastrophic extinction is clearly a good thing, but by focusing our efforts, we shall be able to achieve the most informative results.

Using vascular plants as a guide to what we know, Roy Gereau (pers. comm.) has estimated that continental Africa (including Madagascar) is home to about 63,500 species of vascular plants. In Latin America (Mexico south through South America), in an area only about two-thirds the size of Africa + Madagascar, there are some 120,000 known species of vascular plants, with the number being increased much more rapidly than in Africa (Raven, 2020B). Madagascar, which has consistently had more equable climates than most of continental Africa, also has for its area a much richer and more balanced flora than the continent (Raven and Axelrod, 1974). Tropical Asia, an area half the size of Latin America, is home to about 50,000 known species, but the number is increasing rapidly as we continue to report additional discoveries. Consequently, of these three tropical areas, we know the most about Africa and much less about the others. Raven has determined that distribution patterns in butterflies and in the different groups of terrestrial vertebrates resemble those in vascular plants, and is preparing to publish these comparisons. Such comparisons show promise to leading us directly to the richest and biologically least known areas.

Barcoding as many species as possible affords yet another way to examine patterns of distribution and abundance and provides a scaffolding to which we can add additional information that we accumulate. As always, it is of key importance to decide what sampling strategies will yield the most useful results via barcoding, since a very large number of the species for which we are obtaining barcodes will be gone within a few decades, leaving nothing behind but the analysis of a limited portion of their molecular sequences. As it steadily becomes simpler and less extensive to obtain larger, or even complete, nucleic acid sequences, we should certainly do so, attempting to focus in ways that will help us save species or understand phylogenies the most effectively.

For those groups of organisms that remain the least known, we obviously must implement the precisely developed sampling schemes to accomplish as much while we can. These schemes might, for example, involve sampling all the species of a particular group present in samples taken at, say, 100 km intervals over as wide an area as possible. Such sampling would provide a vastly improved understanding of the geographical patterns displayed by the species of such groups. The results certainly would be much more informative than those gained by simply traveling around and sampling as many species of, for example, mites, as possible. It is disturbing to think that by our grandchildren's generation a major fraction of the species existing now will be gone. For many groups of eukaryotes, we do not even know yet which areas and habitats are the richest in species.

Another strategy would be to focus in depth on a limited number of specific localities, recording as many of the kinds of organisms present as possible and gaining an understanding of the interactions between them in the local ecosystems. By adopting this strategy, we could attain both a relatively deep knowledge of ecosystem function as well as of the representation of individual groups of organisms involved (Raven, 1980). Results of that sort will clearly help to illuminate the whole picture of life on Earth; certainly, we could not gain such results as effectively or soon by the common practice of taking random samples and hoping they will eventually make possible the deep analyses that we so clearly need.

In addition, there is the topic of specimens. We have hundreds of millions of them in our biological collections, but do not often recognize that they will soon be the only material representations of their species remaining on Earth. This suggests that we need to preserve the specimens as well as we can when they are collected, and work to determine the very best conditions for their very long-term preservation once we have them in our cases. It would clearly be worthwhile to put aside samples other than the specimens themselves for molecular analysis, and to obtain as much supplementary material as possible when they are collected. We must take these steps in view of the responsibility we have to future generations. More species exist today than there will be again for many millions of years into the future.

6. Options for slowing down the loss of species

Implementing strategies for finding and if possible, conserving as many species as possible is of critical importance for the future well-being of life on Earth, and therefore for making possible the effective continuation of human civilization. It is impossible to assume the continued healthy functioning of many ecosystems if the destruction we are causing continues unabated. It is necessary to reduce human demand massively, which is only likely to happen only when sufficient economic decision-makers recognize that operating within the planetary boundaries is necessary for their own success. Unfortunately, this is not yet the dominant perspective among economic decision-makers. In fact, many of the mainstream documents dealing with this area of thinking fail to recognize this need. They may recognize the environmental challenge, but fail to make the link between it and their own ability to operate, as in the example of the World Economic Forum's competitiveness report (World Economic Forum, 2019). Obviously, this aspect requires massive attention.

However, this paper primarily addresses biologists, and for them it is important to be aware of what they can do in their professional lives. As has been pointed out (Pimm et al., 2014), the species most likely to become extinct are by definition the rare ones, and most undescribed species are relatively rare. Many species must have disappeared since the time we started to practice agriculture in particular areas. For example, one can only imagine how many species must have vanished as a result of the spread of agriculture in regions such as the intensively cultivated Mediterranean of western Eurasia and North Africa. At the same time, invasive species of animals and plants, pests and pathogens, are spreading around the world in ever-increasing numbers, out-competing or killing native species. On top of this, we are not yet controlling global climate change, despite the fact that it threatens to affect the productivity, even the habitability, of major sections of the Earth, and certainly will do so if individual and national narrow self-interest continues to prevail over our common interest.

Concentrating much of our conservation efforts on Hotspots would increase its efficiency and the number of species that we would be able to save. At the same time, preserving large stretches of forests and other relatively undisturbed habitats is also necessary. For example, an estimated two-thirds of all species occur in the tropics, some in hot spots and some not. We have destroyed about a quarter of tropical lowland forests in the 27 years since the 1993 ratification of the Convention on Biological Diversity (CBD) — hardly a mark of conservation success. These forests are biologically the most poorly known regions on Earth, and are the home of at least two thirds of the world's species. Raven and others provided some details about individual countries in thier collection of essays, “Voices from the Tropics” (Sodhi, Gibson, & Raven, eds., 2013), showing that a majority of the forests of some of the richest and most poorly known areas, such as New Guinea, are likely to be gone by mid-century or soon after. As if this news was not bad enough, the destruction of these forests will increase the rate of climate change, and this in turn is likely to further increase the rate of ecosystem destruction. Relationships of this kind present us with a real sense of urgency, since there is only so much we can learn during the time we have remaining, and suggests that those in a position to do something about the matter ought to develop some joint goals and pursue them vigorously. Unfortunately, there will be no second chances.

When it comes to preserving tropical forests, the large differences in wealth and the unsustainable patterns of consumption and production prevalent in most countries means that, without change, saving much of these biologically rich forests will be exceedingly difficult. Let us highlight a few country cases representing the spectrum of possibilities of resource abundance and income around the world.

An increasing number of the countries where tropical forests are under threat have already fallen or are falling into what we have defined as an “Ecological Poverty Trap” (Wackernagel et al., 2019). At such a point, the countries' residents are already consuming very little, face a declining biocapacity per person, and generate incomes too low to import resources. The trends for Kenya, shown in Fig. 3, are a striking example. The country is challenged by a growing biocapacity deficit, at a time of declining per person resource use. In addition, Kenyan average income is very low, compared to world average, making it difficult access sufficient resources from elsewhere. In Kenya's case, there is ever less biocapacity remaining within the country to enable biodiversity to persist. This contrast with countries such as Switzerland, who have larger biocapacity deficits, but are able to keep their own landscape pristine, since their higher than world-average income allows them to buy additional biological resources(such as soy for thier cattle, or beef) from abroad.

The situations for all countries can be viewed at the open data portal data.footprintnetwork.org. Still it is worth highlighting

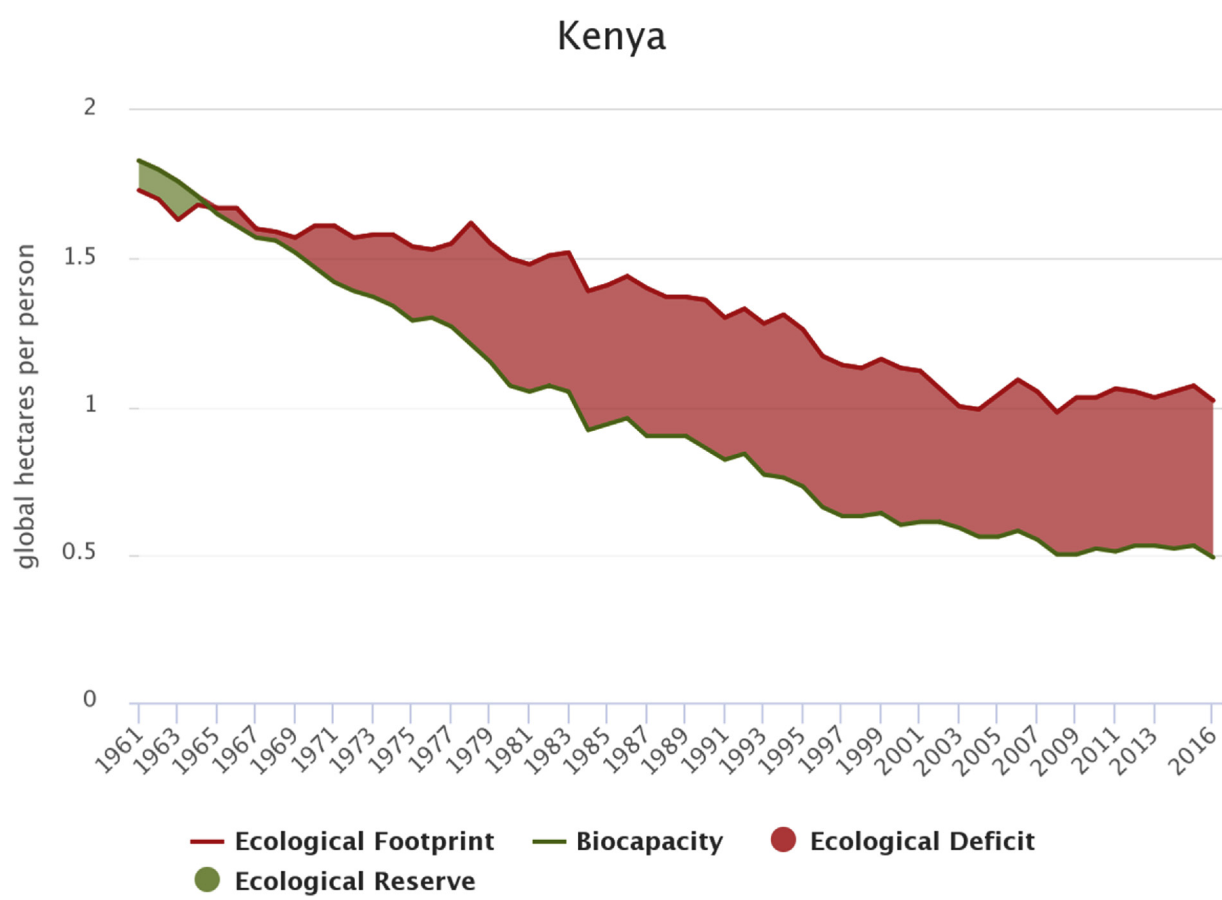

Fig. 3. The trends of human demand on nature of Kenyan consumption (Kenya's Ecological Footprint per resident) compared to how much ecosystems in Kenya can renew (Kenya's biocapacity per person). Both are expressed in global hectares per person. The graphs reveal that growing populations have led to less biocapacity per person, even though biocapacity as a whole increased in Kenya due to agricultural intensification. Just that population increased more rapidly, from about 8 million people in 1961 to over 53 million today, reflecting an excessively slow “demographic transition.” Persistently low income has not allowed Kenyans, on average, to fully compensate the resource demand with supplies from the outside. The growing ecological deficit makes it increasingly difficult to implement lasting biodiversity strategies in countries like Kenya (data source: data.footprintnetwork.org).

China, as it presents particularly interesting trends. China is one of the countries that has recognized the challenge of rapid population growth and invested the benefits of smaller families into accelerating economic activities. As a result, China has experienced one of the most stunning increases in material throughput, in absolute terms as well as per person. This material increase manifests itself in their rapid urbanization with advanced building stocks, and vast-scale modernization of their transportation infrastructure. Fig. 4 presents the trends for China. These figures provide a number of insights:

- The rapid per person increase in human demand, particularly since the turn of the Millennium, seems to have leveled off more recently, albeit at a high per person level.
- Human demand in China to satisfy their consumption is now 3.7 times higher than what Chinese ecosystems can renew.
- Human demand per person in China is now 25 percent higher than world average. If everybody world-wide were consuming at the rate of Chinese residents, on average, it would take 2.2 Earths.
- At the same time, there are still large numbers of people living in China who need more material resources in order to have productive and healthy lives.

These insights demonstrate the challenges we are facing. Overcoming them requires focus on foresight and sustainability innovation, qualities for which China has been a world leader.

Sweden represents another extreme on the Footprint and income spectrum (Fig. 5). With its low population density, it has nearly six times more biocapacity per person than the world as a whole. In contrast, its demand on nature, its Ecological Footprint per resident, is 80 percent higher than that of China, and 130% higher than the world average. This higher demand in Sweden can be explained by the high income per person in Sweden. Nevertheless, Sweden's large biocapacity per person means that it is running a biocapacity reserve. Such a reserve will be an ever more significant asset in a world of increasing climate change and resource constraints, even though the markets currently give it little value (Wackernagel et al., 2019). It also enables more wildlife preservation in Sweden.

Overseas interests often take what whatever they can with little thought given to the fate of the people living in the countries they are importing from. Within them, people will not be able to pursue conservation schemes developed by individuals and organizations with a high-income mindset. Meaningful trend reversal requires nothing less than overcoming short-sightedness, recognizing the unequal distribution of income around the world as a threat to everyone, and collaborating globally on the basis of a fair and thriving future for all.

At any rate, the growth in human populations; the expansion and intensification of our agricultural activities; ongoing climate change; and the seemingly unrelenting demand for ever-higher levels of consumption, including the growing commercial exploitation of many plant species (Kew, 2016, 2017) will make it difficult

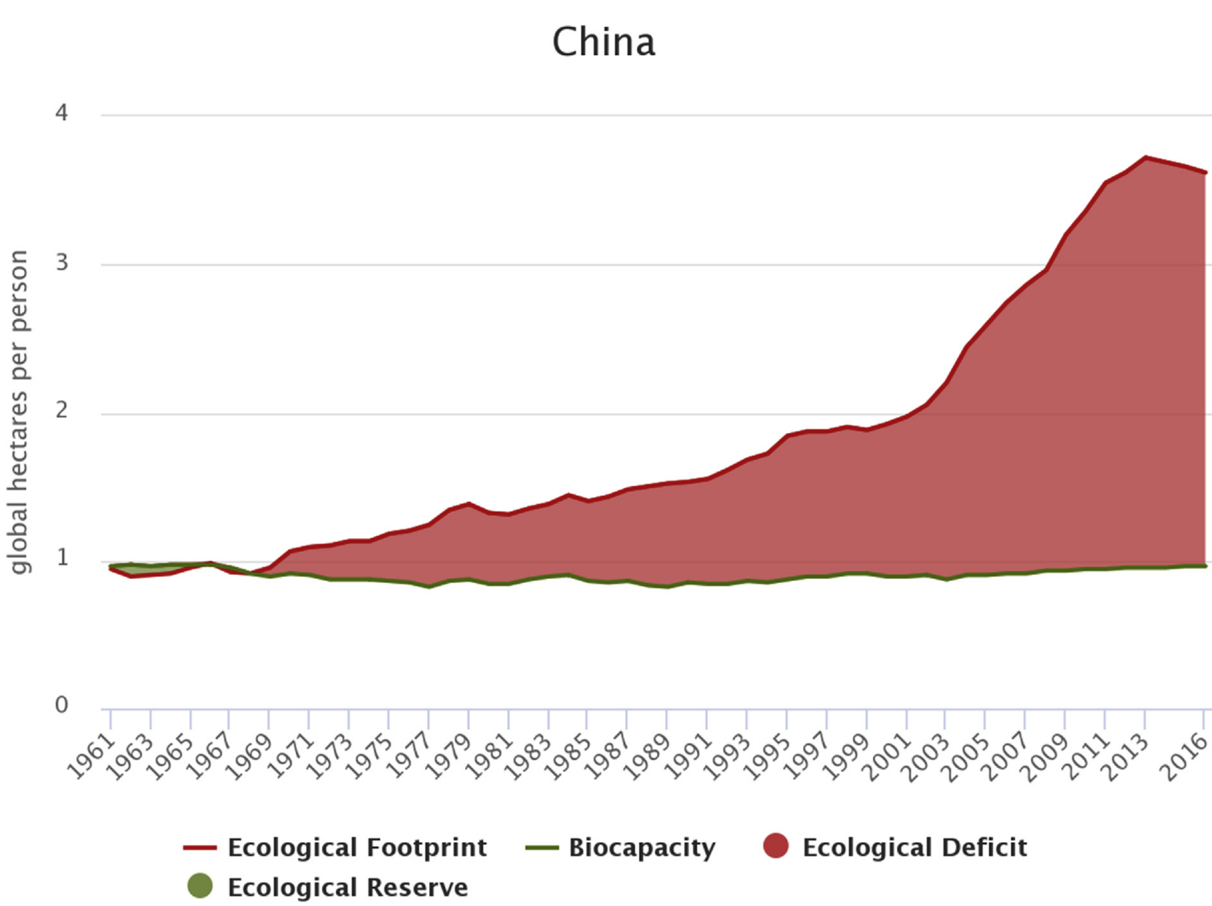

Fig. 4. The trends of human demand on nature of Chinese consumption (China's Ecological Footprint per resident) compared to how much ecosystems in China can renew (China's biocapacity per person). Both are expressed in global hectares per person. The graphs depict rapid expansion of demand in this century, and an apparent flattening off in recent years. Currently China's Ecological Footprint is 3.7-fold larger than its own biocapacity. Much of its Footprint is attributable to carbon emissions (data source: data.footprintnetwork.org).

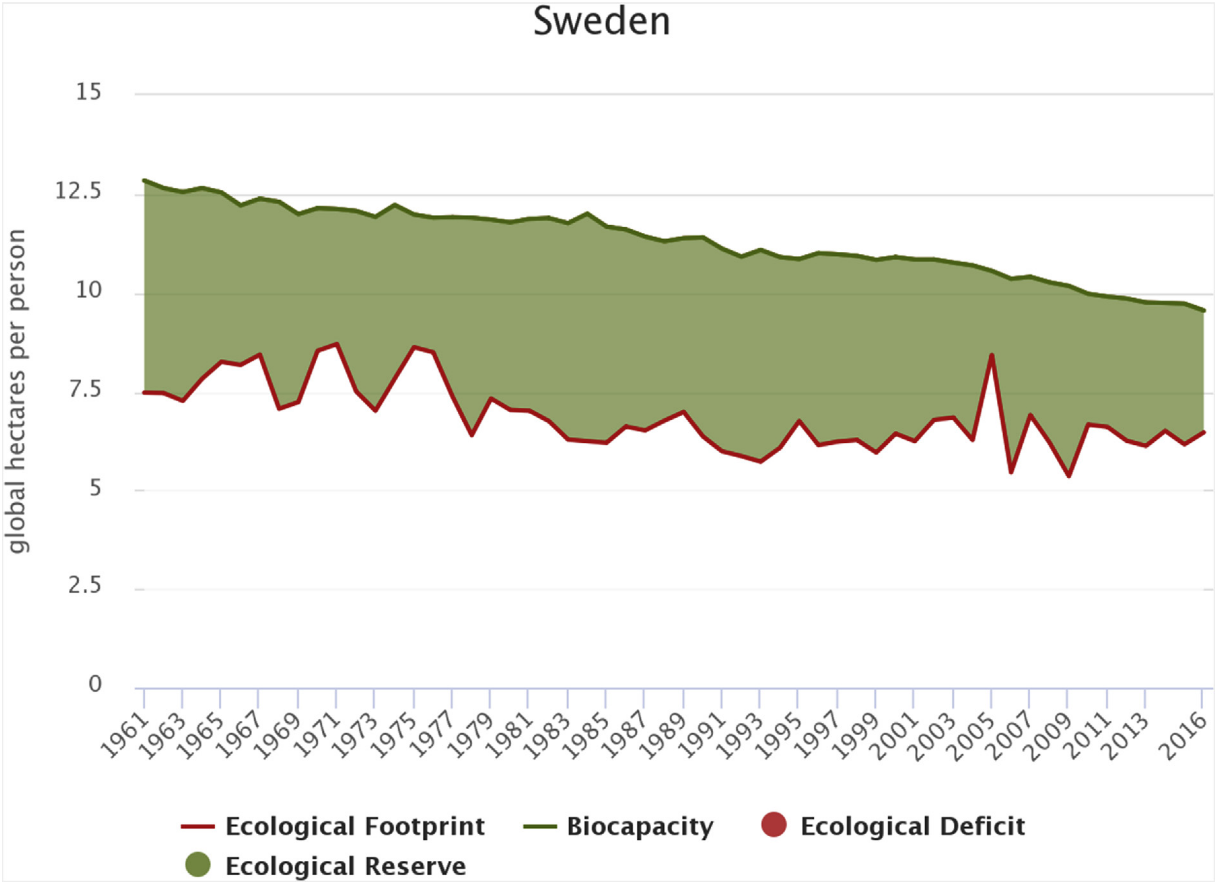

Fig. 5. The trends of human demand on nature of Swedish consumption (Sweden's Ecological Footprint per resident) compared to how much ecosystems in Sweden can renew (Sweden's biocapacity per person). Both are expressed in global hectares per person. Sweden's per person demand is 80% higher than China's and 130% than the world average Footprint per person. The high per person Footprint in Sweden is still exceeded by an even higher per person biocapacity of that country, leaving Sweden with an ecological reserve (data source: data.footprintnetwork.org).

to preserve much of the existing tropical forests, even until the end of this century. Specifically, conservation schemes that assume a forthcoming acceptance of our common need for global stability strong may not be successful unless humanity gives up its outdated and ecologically uninformed habits of economic thought, and its lack of recognition that our countries are interdependent.

For plants, indispensable to the maintenance of ecosystems, we have the possibility of effective ex situ conservation in botanical gardens, seed banks, and tissue culture centers. Some 120,000 species of plants, about a third of the known species, are already in cultivation in gardens, and at least half that number preserved in seed banks (summary in Raven, 2020B). Unfortunately, the species that we have not yet detected and named are more likely to be rare than those already known, and our chances of finding them in nature in time must often be limited. In addition, we can certainly reintroduce some plants into nature when their habitats are stable enough, but this will require attention to the major drivers of extinction (Volis, 2019). If they are successfully re-introduced and the habitats do remain stable, the plants will persist in them without human intervention. As in all conservation considerations, however, a lot depends on how we deal with climate change.

7. Conclusions

Overall, the flood of extinction has already begun. Its pace has increased to a point where many biologists have concluded — notably Ceballos et al. (2017) - that we have already entered the world's Sixth Major Extinction Event, the first since the end of the Cretaceous Period. At that time, the character of life on Earth changed permanently. Many biologists and conservationists agree that a similar irrevocable trend is underway at present. Will humanity be willing to address the deeper causes that we would have to address to make genuine progress to global stability?

Everything about our situation now calls for collaboration and the development and pursuit of appropriate collective goals. It ultimately demands recognition by our governments of the madness of maintaining their myopia in the face of the disasters we are facing together. Anything else would not suffice in saving the biological richness with which our world has been endowed, and indeed would not be worthy of us. As our colleague, Dan Janzen, put it recently, “If we don't save it now, we can't save it later.” It is time to get even busier, more focused, and collective in our thoughts and actions. If we do not decide to study, understand, and save the plants that make up the backbone of all of our natural systems, as well as the many consuming species these plants support, there will not be room for life's diverse richness, and ultimately perhaps not even for us.

Author contributions

PR and MW conceptualized and co-wrote the paper: PR lead on the biodiversity front, MW lead on the biocapacity analyses.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

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