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Article

Biodiversity, Extinction, and Humanity's Future: The Ecological and Evolutionary Consequences of Human Population and Resource Use

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Abstract: Human actions have altered global environments and reduced biodiversity by causing extinctions and reducing the population sizes of surviving species. Increasing human population size and per capita resource use will continue to have direct and indirect ecological and evolutionary consequences. As a result, future generations will inhabit a planet with significantly less wildlife, reduced evolutionary potential, diminished ecosystem services, and an increased likelihood of contracting infectious disease. The magnitude of these effects will depend on the rate at which global human population and/or per capita resource use decline to sustainable levels and the degree to which population reductions result from increased death rates rather than decreased birth rates.

Keywords: biodiversity; extinction; ecology; evolution; population ecology; human population; human carrying capacity; resource use; infectious disease

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1. Introduction

As a species, *Homo sapiens sapiens* has either already arrived or will shortly arrive at a fork in the road, and the route we choose will determine what sort of world our species will occupy. One road leads to a relatively biodiverse future in which a significant majority of today's non-domestic species persist. The other leads to a future in which the majority of today's non-domestic species are extinct. Along both courses, we suspect that global human population will likely stabilize below the current estimated total of slightly above seven billion. Our species has already experienced and, to a considerable extent, contributed to a significant extinction event, so both prehistoric and historic human actions have already shaped global biology. At issue now is the extent and direction of ongoing human effects on global ecology and evolution, including the probability that our species will be a long-term or short-term component of global biological communities.

In speculating about humanity's biological future, it is important to recognize that the details depend on how far into the future we opt to look. Ours is not an especially old species. Depending on the criteria used to differentiate modern humans from our ancestors, we are either at least a 200,000 year-old species (based on anatomy) or a 50,000 year-old species (based on behavioral criteria) [1]. Assuming a future of roughly the same duration as our past, we will generally look less than 100,000–200,000 years into the future. While that amount of time is vast from a human cultural perspective—and, indeed, from the ecological and evolutionary perspectives of microorganisms—from other perspectives, it is comparatively brief.

Two ecological topics provide a useful starting point for our consideration of humanity's future: population size and carrying capacity. Population size, abbreviated *N*, refers to the number of individuals of a particular species living in a particular place. Carrying capacity, abbreviated *K*, refers to the number of individuals of a particular species that a habitat can support without the species' use of that habitat rendering it less able to support that species in the future. For instance, a deer population in excess of a habitat's *K* might so thoroughly consume available plants that the soil is left bare, allowing erosion that leaves the habitat incapable of supporting the same numbers and types of plants and, consequently, the same number of deer as before. However, whether or not overpopulation degrades habitat, if a species' *N* exceeds a habitat's *K* for that species, the species' *N* must decline from an increased death rate, decreased reproductive rate, and/or emigration to other habitats.

Ecologists are frequently interested in the *N* of species and *K* of particular habitats for those species, but since organismal populations and habitat carrying capacities fluctuate (e.g., with season due to changes in temperature and precipitation) and are notoriously difficult to calculate, ecologists frequently wish for more and better data. Although *N* and *K* may initially sound like highly specialized academic subjects, they are a matter of overarching concern not simply for ecologists but for demographers, politicians, and, whether they realize it or not, the general public. At issue for all concerned parties are two unknowns: the *K* of planet earth for humans and the present and future human *N*.

2. The Problems of Human *K*, *N*, and Resource Use

Briefly put, the dilemma is that given uncertainties about future technological innovations, no one can provide a persuasive prediction of human *K* for the next 100–200 years. Vaclav Smil notes that technological innovation in the form of cheap, industrially produced fertilizer supports roughly 40% of the human population by radically increasing agricultural yields [2]. Nevertheless, industrially produced fertilizer will remain cheap only as long as the fossil fuels used to manufacture it do. Currently, we have no viable alternative to fossil fuels, and as human *N* and per capita human resource use both increase, dwindling fossil fuels will become more expensive. As that process continues, famine will no longer result from an inability to distribute existing global food supplies, as it does today. (Global food production is sufficient to meet the nutritional needs of every human on earth; the roughly one billion people who experience malnourishment today do so because of problems with food distribution [3]). However, in a future without a viable replacement for fossil fuels or some alternative means of sustainable food production, a lack of food will lead to increased death and/or decreased reproductive rates. Smil predicts that human *K* would then decline roughly 40%, to somewhere in the 3.6–4.2 billion range, with the lower figure assuming that the reduction should be computed from the human *N* of six billion, current in 1999 when Smil published his article, and the higher figure assuming that Smil's 40% figure would still hold in reference to today's human *N*. Either scenario involves a profound decline in human population, one of the order of two billion people.

Without technological advances in the areas of energy and food production and/or a radical shift in per capita resource use, the global human population must eventually fall below current levels. As a species with a global distribution, humans have extremely limited opportunities for emigrating to suitable, unoccupied habitat. At issue is the manner by which our species' population reduction will occur—in particular whether it will result primarily from increased death rates or decreased birth rates. While a population crash resulting from increased death rates might occur in a variety of disaster scenarios, population decline via decreased reproduction need not involve anything remotely apocalyptic, nor would a shift to a primarily plant-based diet. Since such a diet transfers a higher percentage of the energy captured by agriculture directly to humans rather than allowing for it to be lost by maintaining livestock, it could allow both for higher human *N* and more extensive resource use in other areas of lifestyle.

Ultimately, all of today's environmental problems proceed from unprecedentedly high global human *N* and per capita resource use. The Western, resource-intensive lifestyle has become a goal for many of the world's billions, with a range of interrelated negative consequences, from large scale production of disposable products to increased use of fossil fuels and consumption of the three protein sources whose production or harvest are the most resource-intensive: meat, dairy, and seafood. While recent trends indicate that per capita energy consumption—which can serve as a proxy for overall resource use—has decreased in many Western nations, that decrease is more than offset by increased consumption in the developing world [4].

As human *N* and resource use continue to increase, so does our alteration of global environments. Through the burning of fossil fuels, agricultural methane releases, and the release of industrial pollutants, humans have changed the atmosphere. While atmospheric composition and global climate have fluctuated throughout geologic time, the results of anthropogenic resource use and atmospheric alteration (e.g., the formation of holes in the ozone layer) have pushed beyond the limits of geologically recent natural cycles. Since all life on earth relies on the atmosphere, humans now affect all ecosystems. While some argue the current scope and effect of atmospheric alteration, if per capita resource use remains constant with a growing human *N*, the potential damage to existing ecological communities and human populations could easily range from locally problematic to globally catastrophic.

The effects of a warmer planet extend beyond higher sea levels. For instance, terrestrial organisms that rely on thermal cues in various parts of their life cycles would experience stresses, and warmer water contains less dissolved oxygen, which reduces its ability to support aerobic life. While symptoms of climate change (e.g., coral bleaching) have already been observed, the potential indirect, cascading effects of continued atmospheric alteration remain uncertain but troubling. It is important to note, however, that even though humans are manipulating the environment globally, smaller-scale habitat alteration and fragmentation (e.g., of the sort associated with agriculture) also play an important role. If global climate change continues to follow existing trends, an additional problem relating to species range shifts arises. During earlier periods of climate change, species could shift their ranges without having to cross barriers presented by human dominated landscapes. Given human *N* and per capita resource use, human dominated landscapes now represent significant barriers that will add additional stresses to already threatened species.

If per capita resource use continues at or near current levels, only a reduction in human *N* would reduce our species' environmental impact. One or two billion people using fossil fuels and monopolizing habitat for agricultural production at current rates might not significantly impact the survival of nonhuman, nondomestic species. At such a low population level, human resource use might not result in habitat fragmentation sufficient to reduce global species diversity or increases in atmospheric carbon dioxide levels sufficient to raise global temperatures. Yet, given current technologies, a population of more than seven billion people could avoid those effects only if its diet were mainly vegan and its members traveled primarily by walking, bicycling, and mass transit. Although societies could come to view such options as acceptable, we suspect that in balancing preferences between resource-intensive lifestyles and large families, the typical global goal for standard of living will tend toward material wealth. Along with biological factors relating to human-pathogen evolutionary ecology discussed below, technological and cultural factors will tend to reduce global human *N*.

3. Biodiversity, Extinction, and Evolutionary Potential

In biodiverse communities, a wide variety of species interact in a myriad of ways, thus driving the evolutionary process. The more species and more individuals of each species present, the greater the number of possible interactions. Conversely, the less biodiverse a community, the fewer the interactions it can support. Extinction is a natural phenomenon that is in some (but not all) respects analogous to the death of individual organisms [5]. As with individual deaths, timing and numbers are important. Mass extinctions, periods of heightened extinction rates across a wide variety of taxa, indicate crisis conditions for life.

By convention, biologists recognize five mass extinctions. The most severe, the Permian-Triassic event, occurred roughly 252.25 million years ago, ushering in what has sometimes been called the Age of Dinosaurs. The most recent was the Cretaceous-Tertiary event (occurring roughly 65.5 million years ago), when the last of the dinosaurs became extinct. On the basis of both documented extinctions and the probability of future extinctions occurring as a result of human actions, a sixth mass extinction is thought to be ongoing in which at least 60% of all species have become or will become extinct [6,7]. Contemporary humans have a dubious distinction and a problematic opportunity: the chance to document a mass extinction as it unfolds rather than having to reconstruct it based on fossil evidence.

The sixth mass extinction might well have started with large vertebrates (*i.e.*, those weighing more than 44–100 kg), particularly mammals, beginning during the late Pleistocene about 40,000 years ago in Australia and continuing globally until reaching the Americas. Although prevailing opinion about the cause of late Pleistocene extinctions has varied (e.g., initially focusing on climate change before favoring human activities, especially hunting), there is a growing consensus that humans contributed to at least some late Pleistocene extinctions, with greater or lesser contributions from other factor(s), particularly climate change [8,9]. Responsibility for the extinction of other species (e.g., the dodo, Steller's sea cow) as well as range contractions (of virtually all large felids, canids, and ursids) from later prehistoric into historical times rests more squarely on humans (e.g., due to hunting, capture for use in ancient Roman arenas, and conversion of land to agricultural use).

Continued hunting pressure on game and sport species (e.g., land and marine mammals, fish) that selectively target only the largest members of the species reduces their population sizes and exerts selection pressure resulting in reduced average size [10]. When European colonists first arrived in the Americas, a wide range of both vertebrates and invertebrates were larger in terms of both average mass and population size [11]. However, even the first Europeans to settle the Americas experienced a habitat missing most of the large animals that had been there less than 10,000 years earlier. The first humans in the Americas encountered a land far richer in large mammals—moreso even than nineteenth-century Africa—including large predators from saber-toothed cat, lion, cheetah, and short-faced bear and, among the herbivores, giant ground sloth, mammoth, and horse.

Past extinctions coupled with the more recent contraction and fragmentation of range for large vertebrates—which increase the extinction risk of the species that rely on them—raise the possibility that today's ecological communities are so short of large species that human activities have reduced not simply species diversity and ecological interactions but also the future potential of large mammal evolution [12,13]. As a result, at least the immediate human future will be far shorter of large terrestrial animals than the human past. These smaller populations of nondomestic species will also consist of individuals of smaller average size than earlier in history. Moreover such a result might represent a best-case scenario. Given current trends, the likelihood is that many of these species will simply be lost. If the evolutionary-ecological coin features extinction on one face, however, the other features speciation.

In natural environments, when extinction leaves a niche vacant, over time, adaptation to the niche by members of an existing species leads to evolution. Given sufficient time, a future world would support newly evolved species, but at the time scales that evolution requires, it is unclear whether humans would still be around to see them. The history of life on earth indicates that larger animals are more extinction-prone than their smaller counterparts, so we have some sense of how long it takes for new large species to evolve after extinctions. The Cretaceous-Tertiary extinction, for instance, involved the loss of numerous orders of large reptiles (e.g., dinosaurs; mosasaurs and plesiosaurs, two groups of marine species that filled the niche of today's toothed whales; and flying reptiles, the pterosaurs). Mammals speciated into many of the niches vacated by extinct reptiles, but the process of large mammals evolving from the available raw materials, which consisted mainly of mammal species with average weights well below 10–20 kg, required millions of years. Evolution of one large species from another can occur more rapidly, if it does not require too extensive a modification of the original species. For example, polar bears, the bear species most highly specialized for meat eating and hunting in and around pack ice, evolved in only 100,000–200,000 years from similarly sized and morphologically similar brown bears [14].

The history of vertebrate life suggests that large predators could once again evolve to fill the niches left vacant by recent or future predator extinctions. The difficulty is that such speciation would most likely take somewhere between 100,000 years (assuming that new, large species were to evolve from generally similar existing large species) to upwards of one million years (assuming that new, larger species evolved from smaller and/or morphologically dissimilar ancestors). Even the shortest end of that range estimate greatly exceeds the duration of human history. We have no direct experience in developing a perspective on such expansive periods of time.

As would be expected, a near-term future with a reduced human *N* and a more biodiverse world will tend to lead to a human future in which our species sees not simply more nondomestic species but more large nondomestic species. By contrast, a near-term future with an increased human *N* and a less biodiverse world will tend to lead toward a human future involving not simply fewer nondomestic species but fewer large animals. Although large terrestrial species are among the most visible components of ecological communities, others will also be affected. Human actions have taken and continue to take a profound toll on birds, both as a result of overhunting and introducing predators to islands populated by species that occur nowhere else. More recently, amphibians have also been in crisis, facing extinction threats greater than either mammals or birds [15]. Depending on how people opt to behave now and for the next several generations, in the future humans will experience either a significantly greater or lesser percentage of today's biodiversity.

4. Biodiversity, Ecosystem Services, and the Longevity of *Homo sapiens sapiens*

Ecologists recognize that the particulars of the relationship between biodiversity and community resilience in the face of disturbance (a broad range of phenomena including anything from drought, fire, and volcanic eruption to species introductions or removals) depend on context [16,17]. Sometimes disturbed communities return relatively readily to pre-disturbance conditions; sometimes they do not. However, accepting as a general truism that biodiversity is an ecological stabilizer is sensible—roughly equivalent to viewing seatbelt use as a good idea: although seatbelts increase the risk of injury in a small minority of car accidents, their use overwhelmingly reduces risk. As humans continue to modify natural environments, we may be reducing their ability to return to pre-disturbance conditions. The concern is not merely academic. Communities provide the ecosystem services on which both human and nonhuman life depends, including the cycling of carbon dioxide and oxygen by photosynthetic organisms, nitrogen fixation and the filtration of water by microbes, and pollination by insects. If disturbances alter communities to the extent that they can no longer provide these crucial services, extinctions (including, possibly, our own) become more likely.

In ecology as in science in general, absolutes are rare. Science deals mainly in probabilities, in large part because it attempts to address the universe's abundant uncertainties. Species-rich, diverse communities characterized by large numbers of multi-species interactions are not immune to being pushed from one relatively stable state characterized by particular species and interactions to other, quite different states in which formerly abundant species are entirely or nearly entirely absent. Nonetheless, in speciose communities, the removal of any single species is less likely to result in radical change. That said, there are no guarantees that the removal of even a single species from a biodiverse community will not have significant, completely unforeseen consequences.

Indirect interactions can be unexpectedly important to community structure and, historically, have been difficult to observe until some form of disturbance (especially the introduction or elimination of a species) occurs. Experiments have revealed how the presence of predators can increase the diversity of prey species in communities, as when predators of a superior competitor among prey species will allow inferior competing prey species to persist [18]. Predators can have even more dramatic effects on communities. The presence or absence of sea otters determines whether inshore areas are characterized by diverse kelp forest communities or an alternative stable state of species poor urchin barrens [19]. In the latter case, the absence of otters leaves urchin populations unchecked to overgraze kelp forests, eliminating a habitat feature that supports a wide range of species across a variety of age classes.

Aldo Leopold observed that when trying to determine how a device works by tinkering with it, the first rule of doing the job intelligently is to save all the parts [20]. The extinctions that humans have caused certainly represent a significant problem, but there is an additional difficulty with human investigations of and impacts on ecological and evolutionary processes. Often, our tinkering is unintentional and, as a result, recklessly ignores the necessity of caution. Following the logic inherited from Newtonian physics, humans expect single actions to have single effects. Desiring more game species, for instance, humans typically hunt predators (in North America, for instance, extirpating wolves so as to be able to have more deer or elk for themselves). Yet removing or adding predators has far reaching effects. Wolf removal has led to prey overpopulation, plant over browsing, and erosion [21]. After wolves were removed from Yellowstone National Park, the K of elk increased. This allowed for a shift in elk feeding patterns that left fewer trees alongside rivers, thus leaving less food for beaver and, consequently, fewer beaver dams and less wetland [22,23]. Such a situation represents, in microcosm, the inherent risk of allowing for the erosion of species diversity. In addition to providing habitat for a wide variety of species, wetlands serve as natural water purification systems. Although the Yellowstone region might not need that particular ecosystem service as much as other parts of the world, freshwater resources and wetlands are threatened globally, and the same logic of reduced biodiversity equating to reduced ecosystem services applies.

Humans take actions without considering that when tugging on single threads, they unavoidably affect adjacent areas of the tapestry. While human population and per capita resource use remain high, so does the probability of ongoing biodiversity loss. At the very least, in the future people will have an even more skewed perspective than we do about what constitutes a diverse community. In that regard, future generations will be even more ignorant than we are. Of course, we also experience that shifting baseline perspective on biodiversity and population sizes, failing to recognize how much is missing from the world because we are unaware of what past generations saw [11]. But the consequences of diminished biodiversity might be more profound for humans than that. If the disturbance of communities and ecosystems results in species losses that reduce the availability of ecosystem services, human K and, sooner or later, human N will be reduced.

5. Humans, Biodiversity, and Pathogens: The Future of Infectious Disease

Although infectious diseases have been a part of human history from the beginning, the ability to treat them by targeting pathogens via vaccination and antibiotic, antifungal, or antiviral drugs is relatively recent, and increasingly insufficient to keep pace with pathogen evolution. Because pathogens have such short generation times relative to humans, natural selection allows them to rapidly respond to our control efforts. Other human difficulties result from misuse or overuse of antibiotics (e.g., in medical and agricultural contexts) that facilitate the evolution of drug-resistant varieties of established pathogens [24]. In a troubling epidemiological development, our species is also encountering a variety of new pathogens. The manner in which contemporary human-pathogen evolutionary ecological interactions unfold will shape the future of human infectious disease.

Once again, human *N* is the relevant factor. Nomadic humans made poor hosts for most infectious diseases: their populations were too small, insufficiently dense, not commonly in contact with disease reservoirs, and too mobile to remain in close contact with their own wastes for long periods [25]. Most infectious diseases of humans evolved from precursor livestock illnesses as agricultural societies developed; these early human diseases became established as dense, settled human populations became common [26,27]. Yet in the past 60 years, over 300 emerging human pathogens have been identified, including multi-drug resistant strains of established bacterial pathogens and other drug-resistant pathogens that have only recently made the evolutionary jump to human hosts [28]. To become dangerous to humans, emerging pathogens must repeatedly test the cells they target and our immune systems until they find the correct combination of traits necessary to co-opt the cellular machinery they need to reproduce. The evolutionary steps involved in that transition may take many pathogen generations and a number of distinct pathogen mutations (as demonstrated by HIV) or occur rapidly during one or very few pathogen generations and mutations (as with the appearance of SARS in 2002).

Although one hypothesis explains the recent upswing in emerging infectious disease as a result of an unusual increase in pathogen mutation rates, an alternative hypothesis suggests that as global biodiversity decreases, pathogens shift to new hosts. The recent emergence of new infectious diseases has occurred alongside a decline in species numbers unprecedented since the evolution of modern humans. This concurrence raises the possibility of a causal link between the two events and, with even larger future biodiversity declines expected, raises concerns for the future. Various investigators hypothesize that at the boundaries between areas of human habitation and human vacancy, animal biodiversity may prevent nonhuman pathogens from making the evolutionary transition to humans [29,30]. Nonetheless, animals in these areas still act as pathogen reservoirs that may contain organisms with the traits necessary to infect humans, a problem that becomes more acute as biodiversity and animal population sizes dwindle and pathogens or their vectors become more likely to encounter humans [31].

Biodiverse communities may reduce the likelihood of diseases transitioning from nonhuman species to humans through a number of factors relating to the dilution effect (e.g., reduced encounters between infectious carriers and uninfected hosts, reduced pathogen transmission from host to vector, and fewer susceptible hosts available for infection) [25,32]. For instance, pathogen vectors such as mosquitoes and ticks historically occupied habitats characterized by diverse species populations that could be targeted for blood meals. Since not all these species were susceptible to the pathogens carried by any given vector, the likelihood of pathogen success was reduced, with the result that even those rare pathogens capable of infecting humans were unlikely to have the opportunity to do so.

Recent investigations support the hypothesis that biodiversity protects humans from emerging infectious disease. Allan et al. [33] investigated regions with varying degrees of songbird diversity and found that as avian community diversity increased, the overall rate of West Nile virus infection decreased in both birds and humans. Since mosquito vectors pass West Nile virus between hosts, their findings are consistent with the dilution effect. In a different context, experimental investigation of *Batrachochytrium dendrobatidis*, a fungal pathogen that has devastated amphibian species globally, provides additional support for the dilution effect hypothesis. Investigators tested a susceptible North

American toad species, both in aquaria where it was the sole inhabitant and in aquaria where it was housed with one or two additional amphibian species with varying susceptibilities to the fungus. The prevalence of fungal infection was highest when only one species was present, intermediate in the presence of two species, and lowest when three species were present [34]. Although further research is necessary, the findings are suggestive and, once again, consistent with the notion that biodiversity reduces the likelihood of infectious diseases crossing species lines.

Since the 1940s, humans in industrialized nations have been relatively sheltered from the threat that infectious disease once posed. Modern antibiotics and antivirals have controlled pathogens that once devastated human populations, but these drugs often remain effective only briefly. Unprecedentedly large, dense human populations characteristic of modern societies coupled with rapid global travel create a situation in which emerging pathogens can move much more efficiently between hosts. Rates of future human mortality from emerging infectious diseases may depend on the levels of biodiversity that remain in unpopulated regions, which suggests that protection from novel infectious disease may be what has been, until recently, an overlooked benefit of biodiversity.

6. Conclusions

We have assumed that humanity's future will unfold in a way that avoids any of a number of global disasters for *Homo sapiens sapiens*. An equally reasonable but less optimistic assessment could take exception to that position. A variety of things could go badly wrong for humanity. Global human N may not stabilize at or below where it stands now without being pushed there by some form(s) of crisis that result from humans exceeding global K. As a result, anthropogenic factors from the intentionally harmful (e.g., warfare) to the unintentionally disastrous (e.g., agricultural practices leading to topsoil erosion and desertification) could occur singly or in conjunction with one another, with a variety of natural disasters (e.g., volcanic eruptions, earthquakes), and with disasters that straddle the boundary of natural and anthropogenic, the sorts of scenarios that otherwise could have been avoided or their impacts lessened with more forethought (e.g., outbreaks of infectious disease that move easily through dense human population centers and cannot be readily treated due to pathogen drug resistance). Although we cannot rule out such eventualities, speculation about the future of humanity is inherently more interesting if it proceeds on the assumption that the species will be at least moderately successful beyond the short- to medium-term. However, it may not, and the potential failure of our species has considerable biological implications.

From an ecological or evolutionary perspective, few events are good or bad in absolute terms: they simply favor different organisms. So while we would view a precipitous drop in human N, perhaps even human extinction, as bad news, a more objective position would see it as bad news only for one particular primate and the minority of species (e.g., cockroaches, Norway rats) that thrive in the environments we maintain and the pathogens and parasites that rely on us for food and habitat. In areas where humans are partially excluded (e.g., demilitarized zones such as the one between North and South Korea), wildlife thrives [35]. The same would be true if humans were absent from much—or, indeed, all—of the world. Some of the richest speculations about future vertebrate evolution extend the time scale over which humans are absent to cover millions of years [36]. By and large, however, we consider a short-term perspective much more manageable.

In some respects, the human future will be very different from the human past. Regardless of whether human *N* and per capita resource use decrease sooner or later, future generations will see less wildlife than their ancestors. Organisms across a wide range of taxa, most visibly large mammals but also birds and amphibians, will become extinct due mainly to multiple stresses caused by human actions. For now, the full ecological and evolutionary consequences of these extinctions remain unknown, although the greater the magnitude of extinctions, the higher the likelihood that they will negatively impact human life. Future humans will inhabit a world in which some niches are liable to be left vacant until new organisms arise to fill them. What these species will be, how they will function in the communities they occupy, and what ecosystem services they will directly or indirectly provide or facilitate will depend on the magnitude of human impacts. At all time scales, species assemblages and associations characteristic of particular communities today will likely change. How much will depend on the pace at which human population growth and resource use change.

Nevertheless in at least one respect—and, again, regardless of which path humanity takes at the fork—the human future will be much more like the human past. Humans will regain concerns about infectious disease that dwindled at the beginning of the twentieth century. In the face of emerging diseases and drug-resistant pathogens, those people with the means to do so might, like Londoners of the sixteenth and seventeenth centuries, leave cities during disease outbreaks for the relative safety of the less crowded country. Perhaps more rural areas will retain higher degrees of habitat diversity and, consequently, biodiversity, providing both superior ecosystem services and biological buffers to reduce the effects of disease by limiting their spread.

Although the resource-intensive lifestyles of industrialized nations represent a goal for many people in developing countries, at least some reduction of per capita resource use remains likely, particularly in the areas of diet and food production. Those who have been considering the future of both the global and the U.S. diet, for instance, consider that the growing global population virtually guarantees that the elevated per capita meat and dairy consumption that became common after World War II will decline [37]. If so, pathogen spread will be reduced, provided that some reduction in human *N* also occurs. Food production in the industrialized nations, particularly North America, rely primarily on crop and livestock monocultures, and, just as early agriculture allowed for the evolution of human pathogens, larger and more dense aggregations of livestock and humans continue to pose the risk of developing new and potentially highly dangerous varieties of existing pathogens (e.g., influenza) [26,37,38].

From an infectious disease perspective, a shift in diet could have unexpected benefits for humans by reducing the number and severity of infectious disease outbreaks. Nevertheless just as single, unfortunate human actions can have multiple negative reinforcing consequences for biodiversity and evolutionary potential, single well-considered actions can have a variety of positive reinforcing consequences. If human diets contain less animal protein, agriculture will require less habitat, leaving more habitat for nondomestic species and, consequently, supporting greater biodiversity in regions where it is currently lacking. Assuming that shifts in habitat use occur sooner rather than later, they could preserve a higher percentage of today's biodiversity. To whatever extent this is possible, humanity's future might be both more biodiverse and better protected from infectious disease.

Although the biological details of humanity's future remain unknown, one fact remains certain: our current *status quo* of ever increasing *N* and per capita resource use is unsustainable. Many of our actions weaken our own species' stability by undermining the ecological communities and ecosystem services on which we rely. Concerns relating to human *N* and *K* will not remain matters of abstract, academic concern. Increasingly, they will become matters of general relevance as our species wrestles with the question of the sort of world we want to inhabit and the sort of world we want to leave for future generations.

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