Why We Are in the Sixth Extinction and What It Means to Humanity

Partha Dasgupta (Cambridge University) and Paul Ehrlich (Stanford University)

Introduction

The annihilation of biological diversity is one of the most severe human-induced global environmental problems. Species and populations are being driven to extinction every year at so high a rate, that Earth's assemblage of plants and animals is now well into a sixth mass extinction episode.[1] The most recent Live Planet Index has estimated that wildlife abundance on the planet dropped by some 60% between 1970 and 2012 (NI 1986). The richest biota the world has ever seen is disappearing in the blink of an eye from the perspective of geological time. And humanity is busily making it worse.

Why Preserve Biodiversity?

One reason humanity should care about the destruction of biodiversity is that it leads to the deterioration of ecosystem services upon which civilization is utterly dependent (Daily 1997, Ehrlich and Ehrlich 1981, Holdren and Ehrlich 1974). These services include preserving and regenerating soil, fixing nitrogen and carbon, pollinating crops, recycling nutrients, controlling floods, filtering pollutants, maintaining a genetic library, operating the hydrological cycle, controlling pests and disease vectors, maintaining the gaseous composition of the atmosphere, and providing cultural, intellectual, spiritual, and aesthetic inspiration. Enumerating those services indicates how deeply intertwined are the problems of improving the welfare of humanity (Arrow et al. 2014). Most of these ecosystem services cannot be replaced by artificial means. The few that can will incur extraordinary costs. It is far better to avoid destroying the services that nature provides for free, than to incur massive costs for replacements that will never be complete. Moreover, it is the poor of the world who are most directly dependent upon ecosystem services (Dasgupta 1993, Kumar 2010, ten Brink et al. 2012). Contemporary industrial activities, including industrial agriculture, usually have devastating impacts on local ecosystem services that are essential to the lives of poor, rural, and forest communities in developing countries. The economic benefits of those industrial works rarely filter back to the victims. Research has also drawn attention to the diversity of microorganisms crucial to our lives (Montgomery and Biklé 2015) That includes the microbiomes of soil and those involved in industry (what Professor Andrew Beattie[2] calls "production biodiversity") and the microbiomes of human bodies.

Ethics and Conservation

The arguments above focus on pragmatic reasons to maintain biodiversity. There are profound ethical reasons also. Below we identify the causes behind the ongoing sixth great extinction, the first in 66 million years. Whatever created this miraculous collection of life, it is morally reprehensible for humans to destroy it in the pursuit of unnecessary adornments and obscene wealth. Pope Francis (Francis 2015) has given expression to this in his magisterial encyclical:

"Each year sees the disappearance of thousands of plant and animal species which we will never know, which our children will never see, because they have been lost for ever. The great majority become extinct for reasons related to human activity. Because of us, thousands of species will no longer give glory to God by their very existence, nor convey their message to us. We have no such right."

Causes of the Destruction of Biodiversity: Habitat Destruction

Some of the proximal causes of the extinction process that is now destroying the life-forms that share Earth with Homo sapiens – the only known living beings in the universe – are obvious. The first is habitat destruction and its near synonym, "land use change." Natural ecosystems are converted by human activities into grazing lands, tree plantations, croplands, roads, railroads, airports, and cities. Natural ecosystems are cut down, ploughed under, poisoned, and paved over. All organisms depend on an appropriate environment to persist; a coral reef for many kinds of animals, a tropical forest for many others, a human bloodstream of some kinds of microbes. Few creatures can survive in ploughed fields or on pavement. With some 40% of Earth's land in crops and pasture[3] and another 2% paved or built over, and with every habitat changing in temperature and polluted by synthetic toxic chemical, it is not hard to see why many plants and animals are in trouble – especially in view of the projected increase in human numbers from 7.5 billion people today to some 11 billion by the end of the century, and the concurrent drive toward greater consumption, not only in poor regions (an entirely justifiable aim) but in the rich world too (see below). Toxification of the planet's ecosystems and the organisms within them is pervasive, with air and water transport of contaminants to the most remote landscapes in the world. Scientists have even found persistent organic pollutants in the crustaceans six miles under the sea in the bottom of the Marianas Trench.[4] The expanding human enterprise is relentlessly converting forests, wetlands, and grasslands into farmland, which destroys local biodiversity. Habitats are undergoing change today of a rapidity not seen in 66 million years, since the last mass extinction event that killed off all the dinosaurs (except for birds).

Total destruction of an environment is not necessary to push plants and animals to extinction. Cutting roads through tropical forests may make some of the resulting fragments too small to support populations of various animals, and cause microclimate changes, the consequent drying extending well inside the forest edge, thus destroying populations of plants and the animals dependent on them (Harper et al. 2007). In lakes, rivers, and oceans silting, rising temperatures, increasing acidification, chemical pollution, plastic debris, fish nets, and heavy ship traffic can amount to habitat destruction for organisms as diverse as plankton, river dolphins, marine plankton with calcified shells like foraminifera, and corals. The loss of coral reefs will be especially disastrous because of the rich array of other organisms they support. At concentrations in the water column of fewer than 100 parts per trillion, a common ingredient of sunscreens can initiate coral bleaching.[5]

Causes of the Destruction of Biodiversity: Overharvesting

A second cause of biodiversity destruction is harvesting renewable natural resources like plant and animal populations at rates that exceed their regenerative capacity. Examples that are frequently cited are disappearing mega fauna. Overharvesting has reduced such iconic animals as gorillas, rhinos, elephants, and whales to a relatively few remnant groups. Some 99% of African elephants have been destroyed by Homo sapiens (Safina 2015). We exterminated all of the mammoths and mastodons before people settled and developed a global ivory trade that persists to this day. Many species of endangered animals such as various pangolins, mammals whose skin is covered by keratin scales, are threatened because of oriental (largely Chinese) demand for their meat and scales (thought by some to have medicinal value; (Xu et al. 2016). Sharks and swordfish are also endangered by overfishing, and the main reason why great whales are so scarce now compared to the 18th century was the western demand for whale oil in the 19th. It is not only animals that suffer overharvesting – so do cacti, where populations can be extirpated by removing them from nature for planting in gardens, indoor decoration, medical, recreational and religious use (Robbins 2003).

Resources and Pollutants

To identify the proximal causes behind the Sixth Extinction with habitat destruction and over-harvesting is to model the biosphere as a renewable natural resource. However, the underlying model covers pollution as well (application of pesticides; contemporary carbon emissions into the atmosphere; and so on). Pollutants reduce the capacity of the sink into which they are discharged. The way to conceptualize pollution economically is to view it as the depreciation of a sink. The latter is a capital asset. As examples: acid rains damage forests; carbon emissions into the atmosphere trap heat; industrial seepage and discharge reduce water quality in streams and underground reservoirs; sulfur emissions corrode structures and harm human health; and so on. The damage inflicted on each type of asset (buildings, forests, the atmosphere, fisheries, human health) should be interpreted as depreciation. In the case of natural resources, depreciation amounts to the difference between the rate at which they are harvested and their regenerative rate; in the case of pollutants, the relevant depreciation is the difference between the rate at which they are discharged into the sink and the rate at which the sink is able to recover, in quality or quantity. The task in either case is to estimate those depreciations. It follows that the analytical structures of resource management problems and pollution management problems are the same. Roughly speaking, “resources” are “goods”, while “pollutants” (the degrader of resources) are “bads”. Pollution is the reverse of conservation.

Causes of the Destruction of Biodiversity: The Irony of Agriculture

That conversion to agriculture is so destructive to habitats is ironic, since agriculture is deeply dependent on biodiversity and the ecosystem services it delivers – from the soil microbes that recycle nutrients that nourish crops to surrounding vegetation that regulates the hydrological cycle. For example, coffee farms in Costa Rica do much better if natural forest is left unmolested nearby. The forest provides habitat for bees that pollinate the coffee, adding substantial value to the crop (Ricketts et al. 2004). Farms commonly destroy habitat for birds, bats, frogs, predacious insects and other enemies of crop pests; and to replace these natural pest controlling ecosystem services, industrial farming operations spread deadly poisons far and wide. As a result, pesticides now affect populations of animals from pole to pole. Polar bears suffer from production of food in California (Sonne 2010). Honeybees that originated in southern Asia now pollinate crops around the world, but they and native bee species are threatened by the worldwide use of neonicotinoid pesticides (Goulson 2013, Goulson et al. 2015). The application of pesticides and land-use change are elements in the pollination crisis humanity has begun to experience. “Wild pollinators are in decline, and managed honeybees cannot compensate for their loss". (Tylianakis 2013). Wild schemes to produce artificial drones to replace bees in pollination are appearing in the news, but they are far too expensive to take to scale. Artificial fertilizers devastate the microorganisms and invertebrates that help give soil its fertility, and ploughing helps overtax critical soil resources (Montgomery and Biklé 2015).

Agriculture is far from the only source of chemical pollution that assaults biodiversity. A dazzling array of novel synthetic organic compounds, including hormone disrupting chemicals with impacts on the reproductive biology of people and other vertebrates (Maffini et al. 2006), has been and continues to be released into the environment so rapidly that the releases outpace other well-known agents of global change (Bernhardt et al. 2017). Persistent organic pollutants such as DDT and PCBs now coat the massive amounts of tiny plastic pellets accumulating in the oceans and are carried on them into the food chains that support ocean life and lead to human beings (Rios et al. 2007). Industrial extraction of ores from Earth's crust spreads heavy metals and other naturally-occurring toxics widely, bringing them into contact with organisms, including people, that have not evolved defences against them.

Climate Disruption and Other Causes

One of the most serious assaults on biodiversity obviously is the discharge of large quantities of carbon dioxide and other greenhouse gases into the atmosphere. The climate disruption it causes is, of course, a threat to organisms with tight requirements of temperature regimes within which they can survive. Thermal limits on animal distributions are well known but poorly understood (Sunday et al. 2012), and heating itself can be trouble for plants (Heskel et al. 2016). Plants and animals have long been known to migrate in response to changing climates, or gradually to evolve new tolerances, or to go extinct (Dorf 1955). Today's situation is unique, with substantial human barriers to migration and rates of change sufficiently rapid to prevent evolution in situ for organisms whose generation times are in years. Furthermore, in addition to heating the oceans, humanity is, as noted above, also acidifying them. Sea level rise caused by ocean warming will eventually flood huge areas of coastal land, thus further threatening terrestrial biodiversity, including ourselves. Climate warming also is not independent of global pollution problems.

Among other things it increases the release of toxic pollutants trapped in ice or sediments (Obbard et al. 2014).

Besides spreading toxic chemicals globally, humanity is also changing the distributions of organisms, sometimes to the disadvantage of members of the recipient ecosystems. Even though redistribution adds to the diversity of a local site, by forcing natives to extinction, global diversity may be reduced (Crowl et al. 2008). Some cases are dramatic. The transfer of a European fungal pathogen to North America, perhaps by spelunkers, has devastated American bat populations (Warnecke et al. 2012), lessening the ecosystem service of controlling crop pests and disease vectors. Spreading fungal diseases now pose a serious threat to biodiversity (including Homo sapiens) (Fisher et al. 2012), having already participated in a wave of amphibian extinctions (Phillott et al. 2013, Rowley et al. 2007).

One possible cause of major destruction of biodiversity is nuclear war. Even a small war would likely damage global civilization hugely (Toon et al. 2007). Conventional warfare also often harms biodiversity (Hanson et al. 2009), but ironically can sometimes help protect it by making overexploitation more difficult (McNeely 2003). That, of course, in no way reduces the need for humanity to give up battle as an instrument of policy.

In sum, the driving force of extinction, the ultimate cause of the current sixth mass extinction crisis is much too high a level of aggregate consumption – produced by human numbers multiplied by too high a level of consumption among the rich.[6] Biodiversity is a critical (and much neglected) part of humanity's natural capital, which civilization is rapidly depleting (Ceballos et al. 2015b, Pimm et al. 2014). Such degradation of a natural resource base (destruction of native populations of flora and fauna) affects the volume of biomass production. It has been found in experiments in field stations that species-rich plots yield greater biomass than species-poor ones, which would indicate that the total productivity of an assemblage of species is greater than the sum of the productivities of any individual species grown in isolation. This reflects a form of synergy (Tilman et al. 2001). Loss of species richness not only affects the quality of ecosystem services, but also challenges the system's resilience, which is its capacity to absorb disturbances without undergoing fundamental changes in its functional characteristics. Thus diversity itself may contribute to preservation of natural capital in the long run, and extinctions can comprise the ability of capital to be restocked after calamity. As with other natural resources, humanity is now living on its capital rather than the interest from that capital (Klare 2012). The need to dangerously degrade our living capital stock is one of the surest signs of expansion of the human enterprise, overconsumption by the rich, and approaching collapse (Ehrlich and Ehrlich 2013).

The Biosphere in the Anthropocene

We measure humanity's impact on the biosphere, and thus on biodiversity, in terms of the demands we make on it, both as a source of goods and services and as a repository of the waste we produce. Those demands can be measured in terms of the volume and composition of our economic activities. GDP is the most commonly-used index of those activities. A large GDP signals a large demand on the biosphere, a small GDP in turn signals a small demand. But global GDP is, trivially, the product of global population and global GDP per capita. The tension between numbers and demand per person for Nature's finite flow of goods and services is reflected in that simple arithmetic fact.

Studying biogeochemical signatures over the past 11,000 years has provided a sketch of the human-induced evolution of soil nitrogen and phosphorus inventories (more specifically of polyaromatic hydrocarbons, polychlorinated biphenyls, and pesticide residues) in sediments and ice (Waters et al. 2016). The authors reported a sharp increase in the middle of the 20th century in the inventories. Their work shows that the now-famous figure of the "hockey stick" (Mann 2012) that characterizes time series of atmospheric carbon emission also characterizes a broad class of geochemical signatures, and signal a sharp increase in the rate of deterioration of Earth's life support system. It has been proposed (Waters et al. 2016) that mid-20th Century should be regarded as the time we entered the era now widely named the Anthropocene. Not coincidentally, it roughly corresponds with the rapid expansion of the sixth mass extinction event.

These readings are consistent with macroeconomic statistics. World population in 1950 was 2.5 billion and global GDP was a bit over 7.5 trillion international dollars (at 2015 prices). The average person in the world was poor, with an annual income of a bit over 3,000 international dollars. Since then the world has prospered materially beyond recognition. Life expectancy at birth has risen from a global average of 49 years to 71 years, population has increased to 7.4 billion and world output of final goods and services (global GDP) is now 110 trillion international dollars; meaning that per capita global income is about 15,000 international dollars. The proportion of the world's population in absolute poverty (regarded by the World Bank to be below 1.9 international dollars a day) has fallen so dramatically (it is now just over 10% of the world's population, down from about 50% in 1980 but still, disgracefully, some 750 million individuals in a world replete with rich people), that enthusiasts predict that within a generation the blight will have been eliminated (Jamison et al. 2013). Set against those achievements, however, is that the 15-fold increase in global output over a 65-year period reflects not only the stresses to the Earth system in general and biodiversity in particular that we have just reviewed, but also that humanity's demands from the biosphere have for some time exceeded its capacity to supply them.

But demand cannot exceed supply indefinitely. Translated into the language of equity, humanity's enormous success in recent decades is very likely to have been a down payment for future failure. The trade-off is between living standards today and living standards in the future. Our immediate success in raising both human numbers and the average standard of living has created a conflict between us and our descendants. Nevertheless, contemporary success receives the far greater hearing in public discourse. If you worry about environmental degradation, you will be told that Nature does not represent much more than 5% of global wealth (a figure derived from the share of agricultural income in global output at market prices in rich countries) and that natural capital can be so shifted round in the contemporary world, that dwindling supplies in one place can be met by imports from another. Intellectuals and commentators use the terms "globalization" and "flat Earth" to imply that location doesn't matter. The view emphasizes the prospects offered by trade and investment and says if they aren't enough, technological progress can be relied upon to solve the problems arising from environmental degradation. Today Malthus, the "pessimistic parson", is seen as a "false prophet", remaining as wrong as ever (*The Economist*, 15 May 2008); and books celebrating humanity's achievements read as breathless expressions of triumphalism.[7]

The reason the intergenerational conflict we have identified here is not widely appreciated is that it remains hidden. And it remains hidden because it has become customary to interpret success as economic success, and economic success as growth in GDP. The notion of sustainable development in the Brundtland Commission Report was designed to reflect a balancing of the interests of the present and future generations. Economic progress should therefore mean growth in what we may loosely call a society's "productive capacity". GDP does not reflect productive capacity. It instead measures the magnitude of economic activity at a point in time (a year usually), estimated at market prices; whereas productive capacity points to an economy's portfolio of assets. GDP is a flow, whereas assets are stocks. An economy's portfolio of assets reflects its capacity to produce goods and services, now and in the future.

The assets in question include not only manufactured capital (roads, buildings, machines) and human capital (health and education), but also living natural capital (pollinators enriching human diets, enemies of crop pests keeping humanity able to practice high-yield agriculture, songbirds giving us pleasure, wetland plants purifying water and preventing floods,, life-rich estuaries playing nurseries to oceanic food fishes, forests sequestering dangerous carbon dioxide, grasslands supporting game herds, vegetation guarding water sources allowing us to produce crops, tiny creatures in soil nourishing crops; more broadly the composition of the biosphere).

The social worth of an economy's stock of capital assets is its wealth. It can be shown that wealth reflects an economy's productive capacity (Dasgupta 2004, 2007). When environmental degradation exceeds the accumulation of manufactured and human capital, wealth declines. Normative economics tells us that the indicator we should deploy for assessing the sustainability of human development is the magnitude and distribution of the wealth of nations relative to their population size (Dasgupta 2004; Arrow et al. 2012), not the per capita GDP of nations, nor the Human Development Index of nations.[8] Intergenerational well-being is shaped by the balance humanity strikes between population size and the portfolio of productive assets. Wealth and its distribution, relative to population size, is a measure of that balance.

GDP is incapable of saying much about future possibilities because of the qualifier "gross", which signals that the depreciation of assets, especially degradation of the biosphere, is ignored. Nevertheless, GDP has assumed such prominence in public discourse today, that if someone mentions "economic growth", we know they mean growth in GDP. Governments today regard GDP growth to be above all else on their list of objectives. The mainstream media extol it and the public succumb to it. That could be why it has become customary to regard an economy whose GDP is large as wealthy.

But that's to make a mistake. Because GDP is a flow (so many dollars worth of the flow of goods and services in a year), whereas wealth is a stock (so many dollars worth of assets, period), it could be that a country produces lots of goods and services by running down its assets. Lack of depreciation in national accounts of natural resources in general, and of biodiversity in particular reflects this error. In classic work depreciation of timber supplies was analysed but not that of non-timber forest products (Repetto 1989), which might include defaunation (Dirzo et al. 2014), another depreciation of biodiversity. In that case GDP and wealth would be pointing in opposite directions. GDP could rise over a period of time even as the economy's wealth declines. But that couldn't go on forever, any more than one can continually write ever larger checks without paying attention to the balance in the account. With a dwindling and deteriorating stock of natural capital, even GDP would eventually have to take a beating. GDP growth wouldn't be sustainable. Indeed, a return to sustainability could be very difficult, since unlike manufactured and human capital, natural capital (especially biodiversity) can be extremely difficult to restock. That GDP doesn't include the depreciation of capital explains why the phrase "Green GDP" is a misnomer and why to call for indefinite GDP growth and to demand sustainable development at the same time is to seek two incompatible objectives.

Global Ecological Footprint as a Basis for Estimating Sustainable Consumption

In a review of the state of the Earth's life support system, WWF (2012) reported that in the early years of this century, humanity's demand for ecological services exceeded by 50% the rate at which the biosphere is able to supply those services to us. The figure is based on the idea of "global ecological footprint", which is the surface area of biologically productive land and sea needed to supply the resources a human population consumes (food, fibres, wood, water) and to assimilate the waste it produces (materials, chemicals, gases). The Global Footprint Network (GFN) regularly updates their estimates of the global ecological footprint.[9] A footprint in excess of 1 means meeting the demand for ecological services requires depleting capital. GFN's most recent estimate is a footprint of a bit over 1.6. Sustainable development would require that the footprint over time must on average equal 1.

The greatest contributors to the ecological-footprint overshoot, and thus to the demise of our living companions and supporters, are the OECD countries (a club of rich nations). Estimating national footprints poses enormous conceptual and practical difficulties (among other things owing to imports and exports of goods and services). And without notional prices to guide us, it isn't possible to estimate the value of the future environmental impact of an average new birth. But for the global economy the matter is less opaque. That's because errors in measuring national footprints that arise on account of trade in goods and services cancel in the aggregate.

Assuming that the global ecological footprint is 1.6, we may conclude that to maintain the global average living standard at the prevailing distribution of income, we would need 1.6 Earths. No doubt estimates of global ecological footprint are crude. Moreover, in contrast to estimates of such development indicators as GDP, population size, life expectancy, and literacy, which are made by a multitude of national and global institutions, we are obliged here to rely on the estimates of a solitary research group. But that group relies on estimates of many factors made by numerous other groups, including United Nations agencies, the U.S. Government, and other governments as well as many NGOs. Those estimates are often not included in economic analyses. In any case, that there is an overshoot (ecological footprint in excess of 1) is entirely consistent with a wide range of evidence on the state of the biosphere, some of which we have reviewed above. As the figures are the only aggregated ones on offer, we make use of them.[10]

We assume for simplicity that demand from the biosphere is proportional to income. Global income in 2015 was approximately 110 trillion international dollars. With current technologies and under contemporary institutional arrangements, a footprint of 1 would require that global income be approximately 70 trillion international dollars (110 trillion/1.6 international dollars). To put it in the crudest of terms, 70 trillion international dollars represent today the outer limit to global economic activity if the biosphere is to be protected against further damage. We make use of this figure subsequently when estimating what could be done to achieve that without undue stress to the global community.

Externalities as Drivers of the Human Predicament

Previously we noted that habitat destruction and overharvesting have been and continue to be the main proximal causes of bio-diversity loss. Being proximal, they cry out for explanation. How can it be, it may be asked, that humanity has chosen to drive the global socio-ecological system toward destruction? An easy answer is myopia (more generally, greed), or more charitably, irresponsible behavior. We eschew that line of thought here because there are deeper reasons. We argue below that people can be thoughtful and considerate and try to behave responsibly and yet fail hopelessly as a collective at protecting the biosphere for the future.

Processes driving the balance between population size and the portfolio of assets we hold harbor externalities, which are the unaccounted for consequences for others of actions taken by one or more persons. The qualifier "unaccounted for" means that the consequences in question follow without prior engagement with those who are affected.

The way we have formulated the notion of externalities could appear ineffective. One could argue that our actions inevitably have consequences for future generations, but that they by the nature of things cannot engage with us. In fact future people engage with us constantly, albeit indirectly. Parents care about their children and know that they in turn will care about their children. By recursion, thoughtful parents take the well-being of their descendants into account when choosing the rates at which they save for their children and invest in them. Intergenerational engagement would be imperfect if parents choose without adequate concern for their children (e.g. if they discount the future well-being of their children at overly high rates). Externalities across the generations would be rampant in that case. As just mentioned, we ignore that line of analysis here. Here we study systematic reasons why choices made even by thoughtful parents do not reflect adequate engagement with other people's descendants. As they are symptoms of institutional failure, externalities cannot be substantially reduced without considered collective action. That is why responsible parenthood and consumption decisions at the individual level can nevertheless result in collective failure.

There are two broad categories of externalities of significance here. One consists of the consequences of household consumption and reproduction that work through those components of the biosphere to which access is free; that is, "open access resources", or, more simply "the commons". That's the familiar variety of externalities, much noted and studied by environmental economists (e.g. Baumol and Oates, 1975). Institutional failures in this class of externalities arise from an absence of appropriate property rights to Nature's goods and services, many supplied by biodiversity. By property rights we mean not only private rights, but communitarian and public rights too. One reason rights over natural capital are difficult to define, let alone enforce, is that Nature is constantly on the move (the wind blows, particulates diffuse, rivers flow, fish swim, birds and insects fly, and even earthworms are known to travel undetected). No person can contain the atmosphere he or she befouls. That means the price paid by someone for environmental services (that's the private cost) is less than the cost borne by all (that's the social cost). In cases involving the global commons, such as the atmosphere as a sink for our carbon emissions, the damage an individual suffers from her own emissions is negligible even though the damage to all from the climate change that is triggered from everyone's emission is large and positive. From the collective point of view there is excessive use of a part of humanity's natural capital – the atmosphere as a carbon sink. The externalities our use of open access resources gives rise to are adverse. To reduce them would require a suitable combination of environmental taxes and regulations, social norms of behaviour, and above all the development of an educational system that teaches us the value of biodiversity – both innate and functional.

The other category of externalities has been less recognized in the literature. It arises because our consumption choices and our desire for parenthood are both to some extent influenced by attention to others. No doubt a single household cannot much influence others, but the aggregate effect of all households on one another is not negligible. And they are unaccounted for.

In his contribution to the symposium, John Bongaarts will be addressing regional and global population projections. He will speak to women's reproductive rights and the extent to which their responsible desires continue not to be met. Here we concentrate on consumption.

Consumption in the Rich World

The World Bank in its World Development Indicators 2016 reports that the 1.4 billion people living in its list of high-income countries enjoy a per capita income of 40,700 international dollars. Thus, the richest 19% of the world's population consume over 51% of world income (57 trillion/110 trillion). Continuing to assume that humanity's impact on the biosphere is proportional to income, 51% of that impact can be attributed to 19% of world population. If the UN's Sustainable Development Goals (SDGs) are to be met, consumption patterns in these countries have to alter substantially.

Consumption behavior is influenced both by our urge to compete with others (Veblen's "conspicuous consumption") and by our innate desire to conform. Each is a reflection of socially embedded consumption preferences for goods and services. As both drivers give rise to consumption externalities, the psychological cost to a person of a collective reduction in consumption is likely to be far less than what it would be if she were to reduce consumption unilaterally. The aggregate cost could even be negative, especially if the working poor were less poor relative to the working rich; as the former are far greater in number.

An analysis of one set of global surveys of "stated happiness" and their relationship with household incomes has revealed that in countries where per capita income is in excess of 20,000 international dollars, additional income is not statistically related to greater reported happiness (Layard 2011).[11] Imagine that the 1.4 billion people in today's high-income countries were to reduce their average consumption (or income) to 20,000 international dollars. The drop of 20,700 international dollars (40,700-20,000 international) per person in a population of 1.4 billion adds up to a total of 31 trillion international dollars (Dasgupta and Dasgupta 2017). Other things equal, world income would then be 79 (i.e. 110-31) trillion international dollars, a figure for global economic activity that is not far above the 70 trillion dollars we obtained as a crude estimate for sustainable global income with present technology under contemporary social institutions.

A further route to sustainable dependence on the biosphere is technological progress. The thought here is that with the right kind of technological progress humanity could increase aggregate economic activity without exceeding the biosphere's capability to supply goods and services. Economic historians of the Industrial Revolution point to the role institutions have played in providing incentives to create the technological innovations that have been responsible for reducing natural resource constraints.[12] But we can be sanguine about the character of technological advances only if the biosphere is priced appropriately. Entrepreneurs economize on the expensive factors of production, not the cheap ones. So long as Nature's goods and services remain underpriced, technological advances can be expected to be rapacious in their use. Moreover, technological advances that are patently good can have side effects that are not benign. The ability to use fossil-based energy at large scales has transformed lives for the better, but it has created the unintended consequence of global climate change. Bulldozers and chain saws enable people to deforest land at rates that would have been unimaginable 250 years ago, and modern fishing technology devastates large swathes of sea beds in a manner unthinkable in the past. If technological progress is our hope, it has to come allied with reducing environmental externalities.

Conclusion: The Ultimate Drivers of Destruction

The short-range solutions to the problem of preserving biodiversity are many, and dealt with extensively in the literature of conservation biology (Sodhi and Ehrlich 2010). But these will all prove to no avail unless the basic drivers of extermination – continued population growth, policies seeking economic growth at any cost, overconsumption by the rich, and racial, gender, political, and economic inequity (including failure to redistribute) – are addressed. Collectively addressing these are possibly the greatest challenges civilization has ever faced.

Acknowledgements

We thank Aisha Dasgupta, Anne Ehrlich, and Pete Myers for helpful comments.

References

Arrow, K.J., P. Dasgupta, L.H. Goulder, K.J. Mumford, and K. Oleson (2012), "Sustainability and the Measurement of Wealth", *Environment and Development Economics*, 17(3), 317-355.

Arrow KJ, Ehrlich PR, Levin SA. 2014. Some perspectives on linked ecosystems and socioeconomic systems. Pages 95-119 in Barrett S, Mäler K-G, Maskin ES, eds. *Environment and Development Economics: Essays in Honour of Sir Partha Dasgupta*. Oxford, UK: Oxford University Press.

Barnosky AD, et al. 2010. Has the Earth's sixth mass extinction already arrived? *Nature* 471:5157.

Baumol, W.M. and W.E. Oates (1975), *The Theory of Environmental Policy* (Englewood Cliffs, NJ: Prentice Hall).

Beattie A, Ehrlich PR. 2013. *De-extinction: Moral hazard writ large*. MAHB Blog November 14.

Bernhardt ES, Rosi EJ, Gessner MO. 2017. Synthetic chemicals as agents of global change. *Frontiers in Ecology and the Environment*.

Brandt LJ, Aroniadis OC, Mellow M, Kanatzar A, Kelly C, Park T, Stollman N, Rohlke F, Surawicz C. 2012. Long-term follow-up of colonoscopic fecal microbiota transplant for recurrent Clostridium difficile infection. *The American Journal of Gastroenterology* 107:1079-1087.

Ceballos G, Ehrlich AH, Ehrlich PR. 2015a. *The Annihilation of Nature: Human Extinction of Birds and Mammals.* Johns Hopkins University Press.

Ceballos G, Ehrlich P, Dirzo R. 2017. The real sixth mass extinction: Biological annihilation signaled by population losses and declines in vertebrates. *Science Advances.* In press.

Ceballos G, Ehrlich PR, Barnosky AD, García A, Pringle RM, Palmer TM. 2015b. Accelerated modern human–induced species losses: Entering the sixth mass extinction. *Science Advances* 1:e1400253.

Crowl TA, Crist TO, Parmenter RR, Belovsky G, Lugo AE. 2008. The spread of invasive species and infectious disease as drivers of ecosystem change. *Frontiers in Ecology and the Environment* 6:238-246.

Daily GC, ed. 1997. *Nature's Services.* Island Press.

Dasgupta P. 1993. An Inquiry into Well-Being and Destitution. Clarendon Press (Oxford)

Dasgupta P. 2004. *Human Well-being and the Natural Environment*. Oxford University Press.

Dasgupta P. 2007. Economics: A Very Short Introduction. Oxford University Press.

Dasgupta, A and P Dasgupta 2017. Socially Embedded Preferences, Environmental Externalities, and Reproductive Rights. I-NET Discussion Paper, Faculty of Economics, University of Cambridge.

Deaton, A. (2013), *The Great Escape: health, wealth, and the origins of inequality* (Princeton, NJ: Princeton University Press).

Dirzo R, Young HS, Galetti M, Ceballos G, Isaac NJ, Collen B. 2014. Defaunation in the Anthropocene. *Science* 345:401-406.

Dorf E. 1955. Plants and the geologic time scale. Geological Society of America Special Papers 62:575-592.

Ehrlich PR. 2014. The case against de-extinction: It's a fascinating but dumb idea. *Yale Environment* 360 http://bit.ly/1gAIuJF

Ehrlich PR, Ehrlich AH. 1981. *Extinction: The Causes and Consequences of the Disappearance of Species*. Random House.

Ehrlich PR, Ehrlich AH. 2013. Can a collapse of civilization be avoided? *Proceeding of the Royal Society B* http://rspb.royalsocietypublishing.org/content/280/1754/20122845

Ehrlich PR, Harte J. 2015. Food security requires a new revolution. *International Journal of Environmental Studies* http://dx.doi.org/10.1080/00207233.2015.1067468:1-13

Fisher MC, Henk DA, Briggs CJ, Brownstein JS, Madoff LC, McCraw SL, Gurr SJ. 2012. Emerging fungal threats to animal, plant and ecosystem health. *Nature* 484:186-194.

Francis P. 2015. *Laudato si*: On care for our common home. *Our Sunday Visitor.*

Goulson D. 2013. Review: An overview of the environmental risks posed by neonicotinoid insecticides. *Journal of Applied Ecology* 50:977-987.

Goulson D, Nicholls E, Botías C, Rotheray EL. 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science* 347:1255957.

Hanson T, Brooks TM, Da Fonseca GA, Hoffmann M, Lamoreux JF, Machlis G, Mittermeier CG, Mittermeier RA, Pilgrim JD. 2009. Warfare in biodiversity hotspots. *Conservation Biology* 23:578-587.

Harper GJ, Steininger MK, Tucker CJ, Juhn D, Hawkins F. 2007. Fifty years of deforestation and forest fragmentation in Madagascar. *Environmental Conservation* 34:325-333.

Heskel MA, O'Sullivan OS, Reich PB, Tjoelker MG, Weerasinghe LK, Penillard A, Egerton JJ, Creek D, Bloomfield KJ, Xiang J. 2016. Convergence in the temperature response of leaf respiration across biomes and plant functional types. *Proceedings of the National Academy of Sciences* 113:3832- 3837.

Holdren JP, Ehrlich PR. 1974. Human population and the global environment. *American Scientist* 62:282-292.

Kitzes, J., M. Wakernagel, J. Loh, A Peller, S. Goldfinger, D. Cheung, and K. Tea (2008), "Shrink and Share: Humanity's Present and Future Ecological Footprint", *Philosophical Transactions of the Royal Society*, B, 363(25 July), 467-475.

Klare MT. 2012. *The Race for What's Left: The Global Scramble for the World's Last Resources.* Metropolitan Books.

Kolbert, E. 2014. *The Sixth Extinction: An Unnatural History.* Henry Holt and Company, New York.

Kumar P. 2010. *The economics of ecosystems and biodiversity: ecological and economic foundations*. UNEP/ Earthprint.

Landes, D. (1998), *The Wealth and Poverty of Nations* (New York: W.W. Norton).

Layard, R. (2011), *Happiness: Lessons From a New Science* (London: Penguin).

Le TX, Munekage Y. 2004. Residues of selected antibiotics in water and mud from shrimp ponds in mangrove areas in Viet Nam. *Marine Pollution Bulletin* 49:922-929.

Lomborg, B. ed. (2014). *How Much Have Global Problems Cost the World? A Scoreboard from 1900 to 2050* (Cambridge: Cambridge University Press).

Maffini MV, Rubin BS, Sonnenschein C, Soto AM. 2006. Endocrine disruptors and reproductive health: the case of bisphenol-A. *Molecular and Cellular Endocrinology* 254:179-186.

Maisels F, Strindberg S, Blake S, Wittemyer G, Hart J, Williamson EA, Aba'a R, Abitsi G, Ambahe RD, Amsini F. 2013. *Devastating decline of forest elephants in Central Africa*. PLoS ONE 8:e59469.

Mann ME. 2012. *The Hockey Stick and the Climate Wars: Dispatches from the Front Lines*. Columbia University Press.

McNeely JA. 2003. Biodiversity, war, and tropical forests. *Journal of Sustainable Forestry* 16:1- 20.

Micklethwait, J. and A. Wooldridge (2000), *A Future Perfect: The Challenge and Promise of Globalization* (New York: Random House).

Montgomery DR, Biklé A. 2015. *The Hidden Half of Nature: The Microbial Roots of Life and Health.* WW Norton & Company.

NI T. 1986. *Living Planet Report* 2016.

Norberg, J. (2016), *Progress: Ten Reasons to Look Forward to the Future* (London: One World).

Obbard RW, Sadri S, Wong YQ, Khitun AA, Baker I, Thompson RC. 2014. Global warming releases microplastic legacy frozen in Arctic Sea ice. *Earth's Future* 2:315-320.

Phillott AD, Grogan LF, Cashins SD, McDonald KR, Berger L, Skerratt LF. 2013. Chytridiomycosis and seasonal mortality of tropical stream#associated frogs 15 years after introduction of Batrachochytrium dendrobatidis. *Conservation Biology* 27:1058-1068.

Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, Raven PH, Roberts CM, Sexton JO. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. *Science* 344:1246752.

Rees, W.E. (2001), "Ecological Footprint, Concept of," in S.A. Levin, ed., *Encyclopedia of Biodiversity*, Vol. 2 (New York: Academic Press).

Rees, W.E. (2006), "Ecological Footprints and Biocapacity: Essential Elements in Sustainability Assessment," in J. Dewulf and H.V. Langenhove, eds., *Renewable-Based Technology: Sustainability Assessment* (Chichester, UK: John Wiley & Sons).

Rees, W.E. and M. Wackernagel (1994), "Ecological Footprints and Appropriated Carrying Capacity: Measuring the Natural Capital Requirements of the Human Economy," in A.M. Jansson et al., *Investing in Natural Capital: The Ecological Economics Appropriate for Sustainability* (Washington, DC: Island Press).

Repetto R, Magrath, W., Wells, M., Beer, C., Rossini, F. 1989. *Wasting Assets: Natural Resources and the National Income Accounts.* World Resources Institute.

Ridley, M. (2010), *The Rational Optimist: How Prosperity Evolves* (London: 4th Estate).

Ricketts TH, Daily GC, Ehrlich PR, Michener CD. 2004. Economic value of tropical forest to coffee production. *Proceedings of the National Academy of Sciences of the United States of America* 101:12579-12582.

Rios LM, Moore C, Jones PR. 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. *Marine Pollution Bulletin* 54:1230-1237.

Robbins CS. 2003. *Prickly trade: trade and conservation of Chihuahuan desert cacti.* TRAFFIC North America, WWF.

Rowley JJ, Chan SKF, Tang WS, Speare R, Skerratt LF, Alford RA, Cheung KS, Ho CY, Campbell R. 2007. Survey for the amphibian chytrid Batrachochytrium dendrobatidis in Hong Kong in native amphibians and in the international amphibian trade. *Diseases of Aquatic Organisms* 78:87-95.

Safina C. 2015. Beyond Words: What Animals Think and Feel. Henry Holt.
Sodhi NS, Ehrlich PR, eds. 2010. Conservation Biology for All. Oxford University Press.
Sonne C. 2010. Health effects from long-range transported contaminants in Arctic top predators: An integrated review based on studies of polar bears and relevant model species. *Environment International* 36:461-491.

Sunday JM, Bates AE, Dulvy NK. 2012. Thermal tolerance and the global redistribution of animals. *Nature Climate Change* 2:686-690.

ten Brink P, Mazza L, Badura T, Kettunen M, Withana S. 2012. Nature and its Role in the Transition to a Green Economy. A TEEB report. Forthcoming www.teebweb.org and www.ieep.eu.

Tilman D, Reich PB, Knops J, Wedin D, Mielke T, Lehman C. 2001. Diversity and productivity in a long-term grassland experiment. *Science* 294:843-845.

Toon O, Robock A, Turco RP, Bardeen C, Oman L, Stenchikov G. 2007. Consequences of regional-scale nuclear conflicts. *Science* 315:1224-1225.

Tylianakis JM. 2013. The global plight of pollinators. *Science* 339:1532-1533.

Warnecke L, Turner JM, Bollinger TK, Lorch JM, Misra V, Cryan PM, Wibbelt G, Blehert DS, Willis CK. 2012. Inoculation of bats with European Geomyces destructans supports the novel pathogen hypothesis for the origin of white-nose syndrome. *Proceedings of the National Academy of Sciences* 109:6999-7003.

Waters CN, Zalasiewicz J, Summerhayes C, Barnosky AD, Poirier C, Ga#uszka A, Cearreta A, Edgeworth M, Ellis EC, Ellis M. 2016. The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* 351:aad2622.

Wittemyer G, Northrup JM, Blanc J, Douglas-Hamilton I, Omondi P, Burnham KP. 2014. Illegal killing for ivory drives global decline in African elephants. *Proceedings of the National Academy of Sciences* 111:13117-13121.

Wilson, E.O. 1992. *The Diversity of Life*. Harvard University Press.

WWF – World Wildlife Fund (2008), *Living Planet Report* 2008 (Gland: WWF International).

WWF – World Wildlife Fund (2012), *Living Planet Report* (Gland: WWF International).

Xu L, Guan J, Lau W, Xiao Y. 2016. Traffic An Overview of Pangolin Trade in China.
Zoomers A. 2010. Globalisation and the foreignisation of space: seven processes driving the current global land grab. *The Journal of Peasant Studies* 37:429-447.

[1] See for example Ehrlich and Ehrlich (1981), Wilson (1992), Pimm et al. (2014), and Ceballos et al. (2015, 2017). Kolbert (2014) provides and excellent non-technical account.

[2] http://mahb.stanford.edu/blog/dont-overlook-whats-underfoot/

[3] http://bit.ly/1p6fvzJ

[4] http://go.nature.com/29gRisU

[5] http://bit.ly/2lyoLqu

[6] There is also one especially dangerous human activity that threatens all of biodiversity. It is the promotion of “de-extinction,” the idea that molecular biology will allow humanity to simply to recreate extinct organisms from DNA samples. Even if the molecular job could be done (it can’t), the scale of the problem and the steady attrition of habitats into which to release the products make the idea less than silly (Beattie and Ehrlich 2013, Ehrlich 2014). The financial resources that would be required to take this approach to scale are mind-boggling, and the opportunity costs of using those finances for this as opposed to realistic conservation efforts are simply unacceptable. The big danger here is moral hazard – that talk and laboratory experimentation with de-extinction

will allow people to care less about the biological holocaust now under way. “Why should we care about tigers – if they are driven to extinction, molecular biologists will simply recreate them?”

[7] See for example Micklethwait and Wooldridge (2000), Ridley (2010), Deaton (2013), Lomborg (2014), and Norberg (2016).

[8] The latter index was proposed by UNDP (1990) and has been revised and updated by the organization ever since

[9] For pioneering work on the idea of ecological footprints, see Rees and Wakernagel (1994) and Rees (2001, 2006). See also Kitzes et al. (2008).

[10] The quantitative estimates that follow are taken from Dasgupta and Dasgupta (2017).

[11] 20,000 international dollars is the per capita income in Mauritius, a widely admired country.

[12] Landes (1998) is the classic on the subject.