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Introduction

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Humanity's future will be shaped by the portfolio of capital assets we inherit and choose to pass on to our descendants, and by the balance we strike between the portfolio and the size of our population. So it makes sense to include population on the list of a society's assets and build an overarching study of our relationship with our descendants and with nature by dividing assets into three categories: *produced capital* (buildings, roads, ports, machines, instruments), *human capital* (population, health, education, knowledge and skills) and *natural capital* (biodiversity, ecosystems, subsoil resources). In this Introduction we offer a perspective on the chapters that follow by summarising salient aspects of humanity's troubled relationship with the biosphere.

The Biosphere as a Mosaic of Ecosystems

We may think of the biosphere as a mosaic of ecosystems. Ecosystems combine the abiotic environment with biological communities (plants, animals, fungi and microorganisms) to form functional units. Individual actors in ecosystems include organisms that pollinate, decompose, filter, transport, redistribute, scavenge, fix gases and so on. Most of the organisms that help to produce those services are hidden from view (a gram of soil may contain as many as 10 billion bacterial cells), which is why they are almost always missing from popular discourses on the environment. But their activities enable ecosystems to maintain a genetic library, preserve and regenerate soil, fix nitrogen and carbon, recycle nutrients, control floods, mitigate droughts, filter pollutants, assimilate waste, pollinate crops, operate the hydrological cycle and maintain the gaseous composition of the atmosphere.

* In preparing this Introduction we have drawn on Dasgupta (2019).

Ecosystems can regenerate, but suffer deterioration (worse, exhaustion) when the rates at which we expropriate the goods and services they produce and the rates at which they are converted directly into produced capital exceed the rates at which they are able to provide a sustainable supply of those goods (e.g., collapse of fisheries). By the same token, restoration and conservation measures (e.g., creating protected areas for marine fisheries) help to increase the biosphere's productivity, as measured by quality or quantity (or both).

There is more to the biosphere of course – technically, it's the part of Earth occupied by living organisms – but regarding it as a gigantic mix of renewable natural resources is a useful way of conceptualising it. Agricultural land, forests, watersheds, fisheries, fresh water sources, estuaries, wetlands, the oceans and the atmosphere are some of the interlocking constituents of the biosphere. We will refer to them generically as 'ecosystems' and, so as to draw attention to populations of species in their habitats, we shall speak of them also, more narrowly, as 'biological communities'.

Ecosystems differ in composition and extent. They can be defined as ranging from the communities and interactions of organisms in your mouth or those in the canopy of a rain forest to all those in Earth's oceans. The processes governing them differ in complexity and speed. There are systems that turn over in minutes, and there are others whose rhythmic time extends to hundreds of years. Some ecosystems are extensive ('biomes', such as the African savanna); some cover regions (river basins); many involve clusters of villages (micro-watersheds); others are confined to the level of a single village (the village pond). In each example there is an element of indivisibility. Divide an ecosystem into parts by creating barriers, and the sum of the productivity of the parts will typically be found to be lower than the productivity of the whole, other things being equal (Loreau et al., 2001; Sodhi et al., 2009; Worm et al., 2006). The mobility of biological populations is a reason. Safe corridors, for example, enable migratory species to survive.

Population extinctions disrupt essential ecosystem services. In tropical forests, for example, dung beetles play an essential role in recycling nutrients. Excessive hunting of mammals in the forests has been found to be a cause of local elimination of dung-dependent beetles (Brook et al., 2008). When subject to excessive stress, once flourishing ecosystems (e.g., biologically rich estuaries) flip into unproductive states (dead zones, resulting from pollution). The stress could be occasioned by an invasion of foreign species or of foreign substances, or it could result from the loss of population diversity in the ecosystem (see below), or it could be triggered by the demise of a dominant species (see below), and so on. Ehrlich and Ehrlich (1981) likened the pathways by which an ecosystem can be tipped out of a stable regime into an unproductive state to a flying aircraft from which rivets are removed, one at a time. The probability that it will crash increases very slowly at first, but then at some unspecifiable number it rises sharply to 1.

Broadly speaking, an ecosystem's productivity and resilience (the flow of goods and services they offer us and their ability to withstand shocks) increases with the diversity of the functional characteristics of its species populations; a mere headcount of species can mislead. Mutual dependence among the species is a reason. For example, many trees produce large, lipid-rich fruits that are adapted for animal dispersal, which means the demise of fruit eating birds can have serious consequences for forest regeneration. Similarly, in a study in Costa Rica, Ricketts et al. (2004) found that coffee yield declined with distance from the forest edge because native forest bees aid pollination. The authors reported that the bees increased coffee yield by 20 per cent in fields within 1 km of the forest edge. Looking elsewhere, about one-third of the human diet in tropical countries is derived from insect-pollinated plants. Consequently, a decline in forest-dwelling insects has an adverse effect on human nutrition. And so on.[1]

In food webs, the relationships are unidirectional. Primary producers in the oceans (phytoplankton, sea weeds) are at the bottom of the food chain, with species at higher trophic levels consuming those that are below. Species whose impact on a community structure is large and disproportionately large relative to their abundance are called 'keystone species' (Power et al., 1996). Keystone species usually occupy the top rungs of a given food chain. When human consumption reduces their populations substantially, the community flips to a different state as prey populations explode. That in turn reduces the diversity of a given community's functional characteristics, and can lead to drastic changes both in its structure and in the species that it can continue to support.

Biological communities can influence their abiotic environment. The Amazon for example generates about half of its own rainfall by recycling moisture 5–6 times as air masses move from the Atlantic across the basin to the west. Mathematicians call this a positive feedback.

Deforestation of the Amazon would be expected to reduce rainfall and to lengthen dry seasons in the region. One estimate has it that 20–25 per cent deforestation of the Amazon can be expected to flip the forests in the east to savanna vegetation (Lovejoy and Nobre, 2018). Palm oil trees are planted increasingly in the Amazon so as to provide substitutes for fossil fuels, only to contribute to a sharp decline in the ability of the Amazon forest to absorb carbon dioxide from the atmosphere. The irony will not escape readers.

In a path-breaking set of publications assessing the state of the world's ecosystems, MEA (2005a, 2005b, 2005c, 2005d) constructed a four-way classification of goods and services we enjoy from them: (1) provisioning services (food, fibre, fuel, fresh water); (2) regulating services (protection against natural hazards such as storms; the climate system); (3) supporting services (nutrient cycling, soil production); and (4) cultural services (recreation, cultural landscapes, aesthetic or spiritual experiences). Cultural services and a variety of regulating services (such as disease regulation) contribute directly to human well-being, whereas others (soil production) contribute indirectly (by providing the means of growing food crops).

The view that the biosphere is a mosaic of renewable natural resources also covers its role as a sink for pollution, contemporary carbon emissions into the atmosphere being an example. Pollutants are the reverse of natural resources. One way to conceptualise pollution is to view it as the depreciation of capital assets. Acid rains damage forests; carbon emissions into the atmosphere trap heat; industrial seepage and discharge reduce water quality in streams and underground reservoirs; sulphur 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. For natural resources depreciation amounts to the difference between the rate at which they are harvested and their regenerative rate; for pollutants the depreciation they inflict on natural resources is the difference between the rate at which pollutants are discharged into the resource base and the rate at which the resource base is able to neutralise the pollutants. The task in either case is to estimate depreciation. 'Resources' are 'goods', while 'pollutants' (the degrader of resources) are 'bads'. Pollution is the reverse of conservation.[2]

Erosion of the Biosphere

Humanity's success in the Modern Era (post 1500 CE) in raising the standard of living has in great measure involved mining and degrading the biosphere. Habitat destruction caused by rising demand for nature's products is the proximate cause of the decline in the biosphere's ability to supply our needs on a sustainable basis. The conversion of land for the production of food, livestock and plantation crops is a prime cause of that decline. Conversion of land into produced capital (e.g., buildings, roads) is another cause.

Erosion of the biosphere usually goes unrecorded in official economic statistics because that most common measure of economic welfare, gross domestic product (GDP), does not record depreciation of capital assets. Destroy an open woodland so as to build a shopping mall, and the national accounts will record the increase in produced capital (the shopping mall is an investment), but not the disinvestment in natural capital. The example is a commonplace. While industrial output increased by a multiple of 40 during the twentieth century, the use of energy increased by a multiple of 16, methane-producing cattle populations grew in pace with human population, fish catch increased by a multiple of 35 and carbon and sulphur dioxide emissions rose by more than 10. It has been estimated that 25–30 per cent of the 130 billion metric tonnes of carbon that are harnessed annually by terrestrial photosynthesis is appropriated for human use (Haberl et al., 2007). Although the rise in the concentration of atmospheric carbon receives much the greater public attention, MEA (2005a, 2005b, 2005c, 2005d) reported that 15 of the 24 ecosystems the authors had reviewed worldwide were either degraded or are being exploited at unsustainable rates.

The statistics we have just summarised for sketching humanity's recent doings differ sharply from the ones that have been on offer in a string of recent books, in which intellectuals have redrawn our attention to the remarkable gains in the standard of living humanity has enjoyed over the past century (Micklethwait and Wooldridge, 2000; Ridley, 2010; Lomborg, 2014; Norberg, 2016; Pinker, 2018). The authors have collated data on growth in scientific knowledge and the accumulation of produced capital and human capital and argued that humanity has never had it so good. But with the exception of rising carbon concentration in the atmosphere, trends in the state of the biosphere accompanying those advances have gone un-noted by the authors. The problem is, global climate change is but one of a myriad of environmental problems we face today. And because it is amenable to technological solutions (e.g., innovating with cheap non-carbon sources of energy and, more speculatively, firing sulphur particulates into the stratosphere to reflect sunlight back to space; Pinker, 2018), it is not representative. Global climate change attracts attention among intellectuals and the reading public not only because it is a grave problem, but also because it is possible to imagine meeting it by using the familiar economics of commodity taxation, regulation and resource pricing without having to forgo growth in living standards in rich countries. The literature on the economics of climate change (e.g., Stern, 2006) has even encouraged the thought that with but little investment in clean energy sources (say 2 per cent of world GDP) we can enjoy indefinite growth in the world's output of final goods and services (global GDP).

And that's a thought to be resisted. At least as grave a danger facing humanity is the unprecedented rate of biological extinctions now taking place. Continued extinctions will damage the biosphere irreparably, and they cannot be prevented by technological fixes. Politics has intervened to prevent even the relatively small global investment that experts suggest is required to stall climate change. So we should expect the problem of biological extinctions to remain off the table, at least until citizens take the matter seriously.

The Biosphere as a Common Property Resource

Reproductive decisions and our use of the natural environment have consequences for others, including our descendants, that are unaccounted for under prevailing institutions and social mores (such as markets, government policy, communitarian engagements and religious injunctions). Economists use the term *externalities* to denote those consequences of our decisions for others that are not accounted for. The qualifier 'not accounted for' means that the consequences in question follow without prior, normative engagement with those who are, or who will be, affected. The required engagements don't have to be face-to-face. Many of our actions can be expected to have consequences for our descendants; but if the actions were taken with due care and concern (we take many actions – for example, saving for the future – with our descendants very much in our mind), they would not give rise to externalities. We begin to engage with future people when we deliberate whether current rates of carbon emissions into the atmosphere will place an unjust burden on our descendants. The presence of externalities explains why and how it can be that a people are settled on a pattern of reproductive behaviour and environmental-resource use they would all prefer to alter but do not because no one has the necessary motivation to change their behaviour unilaterally. Externalities raise deep ethical issues. Not only do they extend to contemporaries and can be expected to extend to future people, it is also that some people will be born in consequence of the decisions we take, while some who would have been born had we acted otherwise will not be born.

Today, growth in atmospheric carbon concentration is the canonical expression of adverse externalities, but humanity faces wider and deeper threats to our future from the species extinctions now taking place, which are also morally even more reprehensible. Proximate causes of extinctions are destruction and fragmentation of natural habitats and overexploitation of biological communities residing there. We are converting land into farms and plantations, destroying forests for timber and minerals, applying pesticides and fertilisers so as to intensify agriculture, introducing foreign species into native habitats and using the biosphere as a sink for our waste. And these activities are taking place at scales that are orders of magnitude greater than they were even 250 years ago.

Adverse externalities associated with our use of the biosphere in great measure arise because nature is mobile: birds and insects fly, water flows, the wind blows and the oceans circulate. That makes it difficult to establish property rights to key components of the biosphere. By property rights we don't only mean private rights, we include communitarian and public rights. This is why much of the biosphere is an 'open-access resource', meaning that it is free to all to do as we like with it. Hardin (1968) famously spoke of the fate of unmanaged common property resources as 'the tragedy of the commons'. But while Hardin's analysis was entirely appropriate for global commons (such as the atmosphere and the oceans), it was less than applicable to geographically confined resources such as woodlands, ponds, grazing fields, coastal fisheries, wetlands and mangroves. Because local commons are geographically confined, their use can be monitored by community members. There were exceptions of course, but in times past those resources were managed by communities, and they were not open-access resources. Reviewing an extensive literature, Feeny et al. (1990) and Ostrom (1990) observed that community management systems enabled societies to avoid experiencing the tragedy of the commons. Social norms of behaviour, including the use of fines and social sanctions for misbehaviour, have guided the use of local common property resources.

In poor countries the commons continue to supply household needs to rural people (such as water, fuelwood, medicinal herbs, fruits and berries, manure and fibres and timber for building material). Some products are also marketed (including fish, fuel wood, dung, wood and fibre products). But as in so many other spheres of social life, communitarian practices have over the years strengthened in some instances (e.g., community forestry in Nepal) and weakened in others. They weakened for example when communal rights were overturned by central fiat. In order to establish political authority after independence (and also to earn rents from timber exports), a number of states in sub-Saharan Africa and Asia imposed rules that destroyed traditional community practices in forestry. Villages ceased to have the authority to enforce sanctions on those who broke norms of behaviour. But knowledge of local ecology is held by those who work on the commons, not by state officials, who in addition can be corrupt. Thomson et al. (1986), Somanathan (1991) and Baland and Platteau (1996), among others, have identified ways in which state authority damaged local institutions and turned local commons into seemingly open-access resources. Then there are subtle ways in which even well-intentioned state policy can cause communitarian practices to weaken (Balasubramanian, 2008; Mukhopadhyay, 2008).[3]

Common Property Resources and Fertility Intentions

Even when commons are managed by the community and outsiders are kept at bay, we should ask whether access to the commons is based on household size or whether each household has a fixed share of its output. It can be argued that when larger households are entitled to a greater share of the commons' goods and services, households have an incentive to convert natural resources excessively into private assets. In sub-Saharan Africa larger households are (or until recently, *were*) awarded a greater quantity of land by the kinship group. That practice encourages fertility.[4] What is true in the case of local commons to which households have access regardless of their size holds true in the case of global commons, to which we all have access regardless of our household size. Even humane systems of property rights can give rise to adverse externalities.

How important are local commons in household income? Despite the importance of the question there is little in the form of quantitative evidence. Casual empiricism suggests they are less significant in advanced industrial countries than in poor rural societies. In the former, local resources are either owned privately or under the jurisdiction of local authorities or, as in the case of places of especial aesthetic value, are national parks. That is not so in rural areas in poor countries. In a pioneering work, Jodha (1986) reported evidence from semi-arid rural districts in Central India that among poor families the proportion of income based directly on local commons was 15–25 per cent. Cavendish (2000) arrived at even higher estimates from a study of villages in Zimbabwe: the proportion of income based directly on local common property resources was found to be 35 per cent, the figure for the poorest quintile being 40 per cent. To not recognise the significance of the local natural-resource base in poor countries is to not understand how the poor live.[5]

Global Ecological Footprint

Studying biogeochemical signatures of the past 11,000 years, Waters et al. (2016) tracked the human-induced evolution of soil nitrogen and phosphorus inventories in sediments and ice. The authors reported that the now-famous figure of the hockey stick that characterises time series of carbon concentration in the atmosphere is also displayed by time series of a broad class of global geochemical signatures. They all show a sharp rise in the middle of the twentieth century. Waters et al. (2016) proposed that the mid-twentieth century should be regarded as the time we entered the Anthropocene.[6]

Their reading is consistent with macroeconomic statistics. World population in 1950 was about 2.5 billion and global output of final goods and services a bit over 8.7 trillion international dollars (at 2011 prices).The average person in the world was poor (annual income was somewhat in excess of 3500 international dollars). Since then the world has prospered beyond recognition. Life expectancy at birth in 1950 was 45, today it is a little over 70. Population has grown to over 7.6 billion and world output of final goods and services is (at 2011 prices) above 110 trillion international dollars, meaning that world income per capita is now more than 15,000 international dollars. A somewhat more than 12-fold increase in global output in a 65-year period helps to explain not only the stresses to the Earth system that we have just reviewed, but it also hints at the possibility that humanity's demand for the biosphere's services has for several decades exceeded sustainable levels.

In a review of the state of the biosphere, WWF (2008) reported that although the global demand for ecological services in the 1960s was less than supply, it exceeded supply in the early years of the present century by 50 per cent. The figure is based on the idea of a 'global ecological footprint', which is the surface area of biologically productive land and sea needed to supply the resources we consume (food, fibres, wood, water) and to assimilate the waste we produce (materials, gases). The Global Footprint Network (GFN) updates its estimates of the global ecological footprint on a regular basis. A footprint in excess of 1 means demand for ecological services exceeds their supply. By GFN's reckoning, maintaining the world's average living standard at the level reached some 10 years ago (roughly 12,000 international dollars) would have required 1.5 Earths, and the number has since grown steadily to over 1.7.[7]

These are inevitably crude estimates. Figures for such socio-economic indicators as GDP, population size, life expectancy and adult literacy are reached by a multitude of national and global institutions, who exchange information and coordinate their work. They are revised regularly and governments and international agencies use them routinely when advocating and devising policy. We all take note of their figures and trust them. For estimates of our global ecological footprint, however, these are early days. What matters is not the exact figure but whether the footprint exceeds 1. On that matter there should be little question. That there is an overshoot in global demand for the biosphere's goods and services is entirely consistent with a wide range of evidence on the state of the biosphere that is summarised in the chapters that follow.

GFN's most recent estimate of the global ecological footprint is 1.76. Sustainable development would require that the footprint must on average be less than 1 over time. Global demand for ecological services