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Biodiversity and Economic Growth: Something Must Give

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Biodiversity and Financial Stability: Study Group Interim Report

Abstract

World economic activity driven by explosive growth in population and living standards since the late 18th century has reached utterly unprecedented levels under a longer-term view. Equally astonishing has been the pace of environmental degradation because of this expansion. According to recent NGFS scenarios, successful mitigation of climate change--the most salient dimension of such degradation-- need not materially affect world GDP in the long run, and thus chiefly constitutes a problem of risks, whose successful management would allow to achieve similar growth outcomes. This paper reviews the recent evidence on biodiversity loss and ecosystem degradation, an equally important but much less salient dimension of the environmental crisis. Simple calculations suggest halting its alarming recent trends will involve problems of both *first* as well as *second moments*: the transition will have to deal with risks, but even a successful management of these will probably require adjusting expectations about the possibilities of future economic and population growth. We believe this contrast should receive especial attention as the focus of environmental-economic modeling in general, and the seminal work of the NGFS in particular, expanding its scope to include biodiversity in macro-financial analysis. We also present new evidence consistent with the intuition that population growth dominates the negative impact of growth on biodiversity, especially since the second half of the 20th century. This supports the notion that territories rich in biodiversity, but poor and in the early stages of the demographic transition will be critical for the preservation of natural capital.

1. Introduction

Recently published NGFS climate scenarios span widely divergent paths for emissions, climate, and economic impacts, depending on the degree of policy ambition and international coordination. However, barring the crossing of tipping points in the next few decades, scenarios with high CO_2 reduction (for example, scenario "NZ 2050", in NGFS 2021) provide feasible trajectories towards a climate-friendly future in which population and living standards towards century´s end need not be

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markedly lower than in a “baseline scenario” –a scenario that ignores economic-environmental interrelations. The key insight behind this result is that decarbonization is mainly about reconverting the energy matrix of the world towards renewable technologies. While an ambitious transformation may be costly in the short/medium-term, it need not materially affect world GDP in the long run. It will, however, involve physical and transition risks for households, businesses, governments and the financial system. In this sense, climate change under a scenario where countries meet their current NDCs is mostly a problem of *second moments*: managing the risks, while aiming for similar growth outcomes. Of course, a failure in managing these risks could well precipitate a climate catastrophe with dramatic implications for human destiny and life in the planet.

The growing concern towards climate change, while welcome, has clouded an equally pressing environmental emergency: the degradation of nature and the corresponding loss in biodiversity (Wilson, 2002). From a purely anthropocentric perspective, biodiversity is a key input for the services provided by nature: ecosystem services – many of which we receive for free and often take for granted (Dasgupta, 2021). As documented by IPBES (2019) and many others, the exponential growth of human population and per capita consumption over the last few centuries has caused a mirroring exponential damage on nature. According to a growing and alarming body of scientific work, the window for stopping and reverting the damage to biodiversity is closing fast (Rockström et al., 2009). Despite the hurdles involved in the identification of Nature’s services, as well as the measurement of their contribution to people´s material well-being, is clear that their destruction jeopardizes the ability of ecosystems to sustain life in general, and sooner or later will threaten Humankind survival.

Three key aspects contribute to the lingering neglect of this problem. First, when forming perceptions, we tend to overweigh the most recent past, and all but ignore the longer history of human development. This oversight obscures the fact that human population and economic growth over the last two centuries have been utterly astonishing and unprecedented. Our failure to recognize this contributes to a “business as usual” attitude towards environmental damage: we´ve been doing this for a long time, and nature has been fine all along. *Why is this time different?* Second, the increasing alienation from nature implied by urbanization keeps these problems out of our radar: most people are simply unaware about the extent to which nature and biodiversity have been degraded. Neglecting the human impact on nature is particularly troubling and consequential among economists and economy/finance ministries (Dasgupta, 2021). Third, we do not have enough scientific evidence to estimate impacts of losses of biodiversity on human livelihoods and material well-being. We have an idea of the losses of biodiversity, especially in the last half a century, but with the exception of a few cases, we do not have enough information about the short or long term impacts on humanity. The fact that we are beginning to think about colonization of other worlds, totally devoid of the nature we know, also helps to give the impression that perhaps humankind can survive and even thrive independently of the state of Nature. The political case for devoting already scarce resources to the protection of Nature is thus far harder to make than the case for fighting very specific and more salient catastrophes such as climate change.

In the context of the NGFS´s Interim Report on Biodiversity and Financial Stability (NGFS, 2022), this paper contributes to bridge our perception gap along these key issues. In doing so, it suggests that avoiding biodiversity *tipping points* may involve tougher tradeoffs in terms of population growth and per capita living standards, compared to the aforementioned benign climate change scenarios.

In Section 2 of the paper, we reconstruct measures of world GDP during the Holocene (since 10,000 BCE), to facilitate the appreciation of the stunning speed of economic growth (population and living standards) in just the last two centuries since the industrial revolution. Then, in Section 3, we survey the rapidly accumulating evidence about the damages caused by human activity on natural ecosystems and biodiversity, and the highly uncertain science of predicting ecosystem tipping points which would irreversibly affect the well-being of future generations. It also discusses how different measurement approaches conceptually come together under the unifying notion of *natural capital*.

In section 4, we explore which component of GDP growth –per capita GDP vis-à-vis population—contributes the most to biodiversity loss –finding evidence in favor of the latter. Building on these facts, section 5 sketches the consistency of different growth trajectories with achieving biodiversity conservation goals. To manage expectations from the outset, the growth pathways discussed are purely accounting exercises, devoid of any modeling structure. They are intended to give *orders of magnitude* to the following questions:

- **What are the “baseline” estimates of world per capita GDP and human population expansion --those which ignore economic-environmental interactions?** While the growth numbers may be familiar to most readers, *doing the math* about what they imply for the level of GDP towards century´s end provides a sobering picture about the feasibility of such growth trajectories. For instance, in a standard intermediate scenario global GDP would expand about five-fold in the next 80 years, including an increase in total population of 3 billion from current levels, an addition equivalent to the size of global population in 1960, while world per capita GDP would by 3.6 times higher than its current level.
- **Given recent trends in biodiversity and ecosystem degradation, are such growth scenarios feasible, under our current *natural capital efficiency* (natural capital intensity of GDP)?** The evidence of section 3 strongly suggests the answer is *No*.
- **How large must *natural capital efficiency gains* –the intensity of nature´s inputs underlying GDP—be to achieve the growth outcomes of the baseline scenario, while at the same time avoiding biodiversity and ecosystem *tipping points*?** While a precise answer to this question cannot be provided with the current state of economic-environmental modeling, simple accounting exercises suggest the answer is: *extremely large*, probably an order of magnitude larger than the growth levels observed for such efficiency growth in the last 60 years.
- **What growth scenarios are feasible, under moderate increases in natural capital intensity use, if we are to avoid further damage to biodiversity and ecosystem services?** This is the most relevant question from the list, as it describes the most likely situation we will face going forward –moderate efficiency gains, perhaps allowing positive yet much more modest growth rates within the limits implied by nature, while supporting a demographic transition as the one projected in the intermediate forecast provided by the UN population projections. We believe that they might allow positive per capita income growth, but far more modest than the ones in “normal” long-term projections. Even though we will not provide a definite answer to this question, we hope to motivate further analytical work that will enable tackling this key uncertainty going forward.

In summary, these simple calculations suggest halting and reversing biodiversity degradation may be more consequential for long-term growth than slowing climate change, notwithstanding the contribution of the latter to the first goal. That is, it will likely involve problems of both *first* as well as *second moments*: the transition will imply risks that must be managed, but even a successful management of these may require adjusting expectations about the possibilities of future economic and population growth, if humanity is to remain within a safe operating space.

2. Economic growth during the Holocene: *gradually, then suddenly*

It is impossible to place the current pace of world economic growth into proper perspective without looking at the past. This task is made difficult due to the challenges of measuring human population, as well the lack of systematic measurements of living standards, far back in time. The pioneering work of Angus Maddison (Maddison, 2007) and his followers in the Maddison Project at the University of Groningen have made this task possible to some extent. We begin with a brief description of the leading estimates in the literature to approximate these variables.

2.1 Population growth during the Holocene

A useful source of population estimates far back in time is provided by the Hyde project (History database of the Global Environment, see Goldewijk et al., 2017). This database estimates population in leading world regions since 10,000 BCE, besides from several other indicators to inform the reconstruction of land use change and its environmental impacts during the Holocene. Here we concentrate just on their population estimates. Figure 1 plots the estimated population for the (roughly) last 12,000 years.

Fascinating as it is to study population dynamics during the Holocene, such an ambitious enterprise is clearly beyond the scope of this paper. However, it is worthwhile mentioning a few simple facts for the purposes of the argument that will follow. First, compared to modern figures, population growth rates were extremely low at the beginning of the Holocene –at around just 0.02-0.03 *per cent* per year between 10,000 – 5,000 BCE. Indeed, at the estimated growth rates of 10,000 BCE, world population doubled every 3,000 years. As has been extensively discussed by many authors, this is mostly due to the high prevalence of child mortality, as well as lower life expectancy for adults (Maddison, 2007; Volk and Atkinson, 2013).[2] Indeed, according the HYDE project data, population growth averaged just 0.04% per year between 10,000 BC-1AD, and did not increase much all the way towards the late middle ages, growing just 0.05% per year on average between 1AD-1500 AD.

Second, while the coarse time resolution for the first 10,000 years of the Holocene impedes a clearer picture of population fluctuations, the 100y frequency after AD 1 is high enough to show several episodes of significant population declines, linked to either substantive socio-political events in main population centers –such as the Roman and Han Dynasty crisis of the third century--, changing climatic conditions –including the medieval warming period between 900-1300, during which Europe´s population roughly doubled--, and plagues –such as the Antonine Plague of the 2nd century

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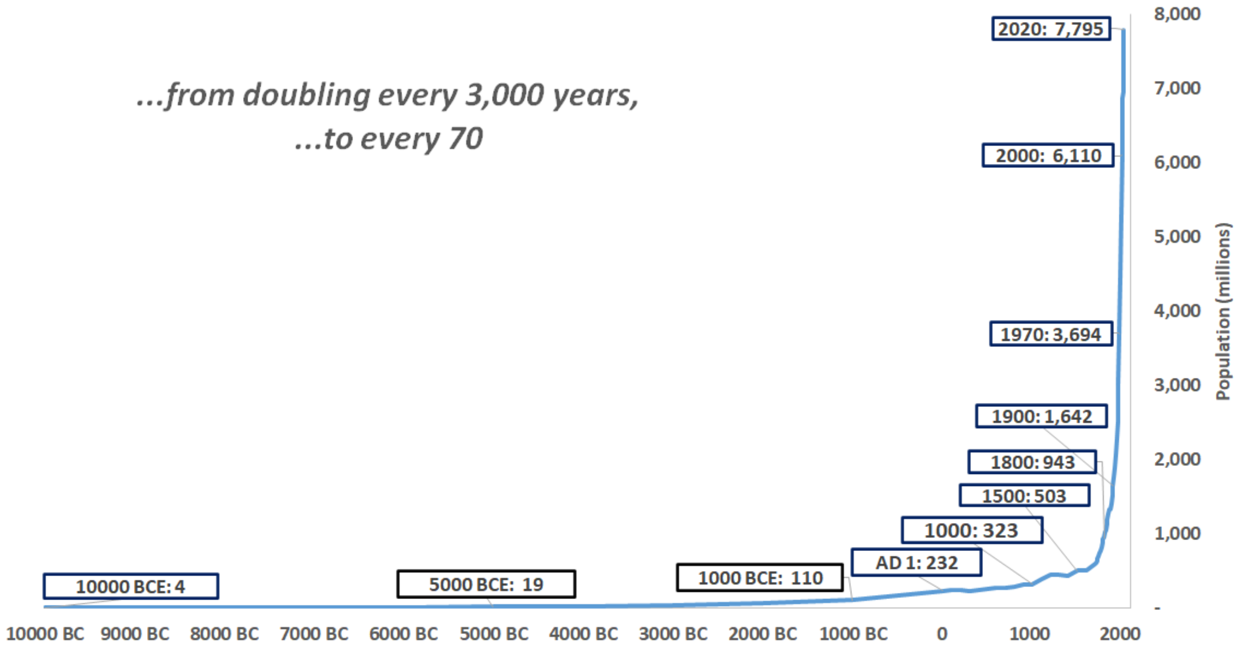
[2] For example, the studies compilated by Volk and Atkinson (2013), starting at around 400 BCE, show cross-study average for the infant mortality rate (before 1y age) of 27%, and for the youth mortality rate (before 15 y age) of 46%.

AD, or the black death around the mid 14th century. However, given the scale of expansion in the last 200 years, one is hard pressed to spot these fluctuations by simple examination of Figure 1.

Figure 1: Population estimates during the Holocene



Sources: HYDE project database for the period 10,000 BCE – 2017 (estimate resolution: every 1,000 years until AD 1; every 100 years between AD 1 and 1700; every 10 years between 1700 and 2000; yearly since 2000. 2018-2020 given by UN *World Population Prospects, 2019*.

Third, there is a marked acceleration in population growth that starts during the 18th century (average annual pop. growth rate 1700-1800: 0.47%), increases during the 19th (growth rate 1800-1900: 0.56%), and roughly doubles during the 20th (growth rate 1900-2000: 1.3%), with particularly high growth rates –even surpassing 2%-- around the 1960s-70s, in the aftermath of the *baby boom* population expansion. As is also well documented by several sources, the population explosion of the 20th century builds on several important socio-economic and scientific advancements, including key breakthroughs in agricultural productivity, the achievements of the medical revolution, as well as the increased sanitization of cities and households. These factors contributed to both dramatically lower child mortality rates, as well as increased adult life expectancy (see Fogel, 2004; and Gordon, 2016, and numerous references therein).

While it is true that population growth rates are starting to deaccelerate and the demographic transition is progressing in line with the diffusion of economic development, this will not be enough to stabilize de size of the global population before the end of this century. Even though fertility rates are falling below replacement ratios (2.1 children per woman) in China and the most dynamic countries in Asia, as well as in a majority of Latin America, there are many countries in Africa and

Asia – some of them with very large populations, such as India and Nigeria - where they are well above such ratios.

In consequence, while population doubled only every 2,000-3,000 years at the very beginning of the Holocene, at current rates it now doubles every 70 years. Such simple yet striking implications of the law of compounded growth rates will now be multiplied further when we add the trends in per capita living standards.

2.2 Living standards during the Holocene

Archeological evidence, as well as administrative and historical records, provide the foundation for the population estimates since the beginning of the Holocene referred above. Using these sources for a precise estimation of living standards far back in time is much more challenging –at least with the precision we have become familiar since the publication of the first set of consistent National Accounts. However, based on these sources of information, leading economic historians make the compelling case that it is reasonable to assume extremely low growth rates of per capita living standards since the beginning of the Holocene, all the way into the last decades of the 18th century. Indeed, many sources simply assume zero per capita growth between AD 1 and 1000, and minuscule growth rates (in the order of 0.05-0.1 *per cent*) between 1000 and the early 1800s.[3]

Of course, technological progress is not exclusive to the post-industrial world, and many of the transitions between key Holocene sub-periods are indeed defined by revolutionary innovations in the ability of humans to extract output from nature. These include the Neolithic, the agricultural revolution (8,000-4,000 BCE), the emergence of early states in Eurasia (4,000-2,000 BCE), the Bronze Age (3,000-1,000 BCE), and Iron Age (1,000 BCE-400 AD).[4] In fact, during the more heavily studied medieval period, there is abundant evidence of technological improvements in agricultural methods, which allowed both an increase in yields in current cultivated lands as well as progressive expansion into more marginal soils.

But as far as the cited sources can tell, such improvements mainly served to increase population, not living standards. Indeed, measured in terms of health outcomes (child mortality, life expectancy, nutritional quality), quality of housing, transportation, clothing, housing implements, etc., the average *serf* in late medieval Europe or China lived pretty much the same as the average farmer during the early Roman Empire, which in turn lived quite similarly to the average commoner in Egypt right before the Bronze Age collapse, and so on backwards. There were progressively more and more people, but they did not live better lives, at least according to these common metrics. In other words, the theory developed by Malthus (1798) in which any improvements in living standards were sooner or later to be diluted into feeding larger populations seem to apply remarkably well to antiquity. Moreover, as shown in Table 1, they continue to apply all the way to the start of the industrial revolution, as per capita GDP growth rates remain at or below just a tenth of a percent

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[3] See Maddison (2007), as well as Morris (2010) and Piketty (2014) for numerous references and a description of methodological approaches to estimate per capita GDP since the dawn of the Roman Empire.

[4] These are approximate dates, as even coarse turning points of technological adoption are substantially different across world regions. The chronology mentioned here builds on Brooke, 2014.

per year –an order of magnitude smaller than the impressive growth rates that began to materialize in the 19th and 20th centuries.

Table 1 summarizes the estimated per capita GDP growth rates from AD 1 to the present, confirming the extraordinary acceleration in living standards in the last 200 years. The table also captures the relative deceleration of growth rates in recent decades. However, stressing this aspect of the figures really misses the point of the analysis: over the longer span of the *Holocene*, humanity´s living standards have never grown as fast as they have since the Industrial Revolution, a trend that continues to the present despite recent deceleration. While this is a known narrative, it is worthwhile to reflect on what such acceleration in growth rates since the 1800s implies for the *level of GDP per capita*. In short, the average human being on the planet today enjoys roughly *20 times* the level of living standards faced around the beginning of the common era. And this development is quite recent, when put in the proper context.

Table 1: estimated world per capita growth rates, 1 AD – 2021

Period	Average per cap. growth	Cumulative per cap. GDP
0-1000	0.00	1
1000-1500	0.05	1.3
1500-1700	0.05	1.4
1700-1820	0.10	1.6
1820-1913	0.90	3.7
1913-1950	0.85	5.2
1951-1970	2.10	8.9
1971-1990	1.65	12.4
1991-2010	1.45	16.6
2011-2021*	1.39	19.3

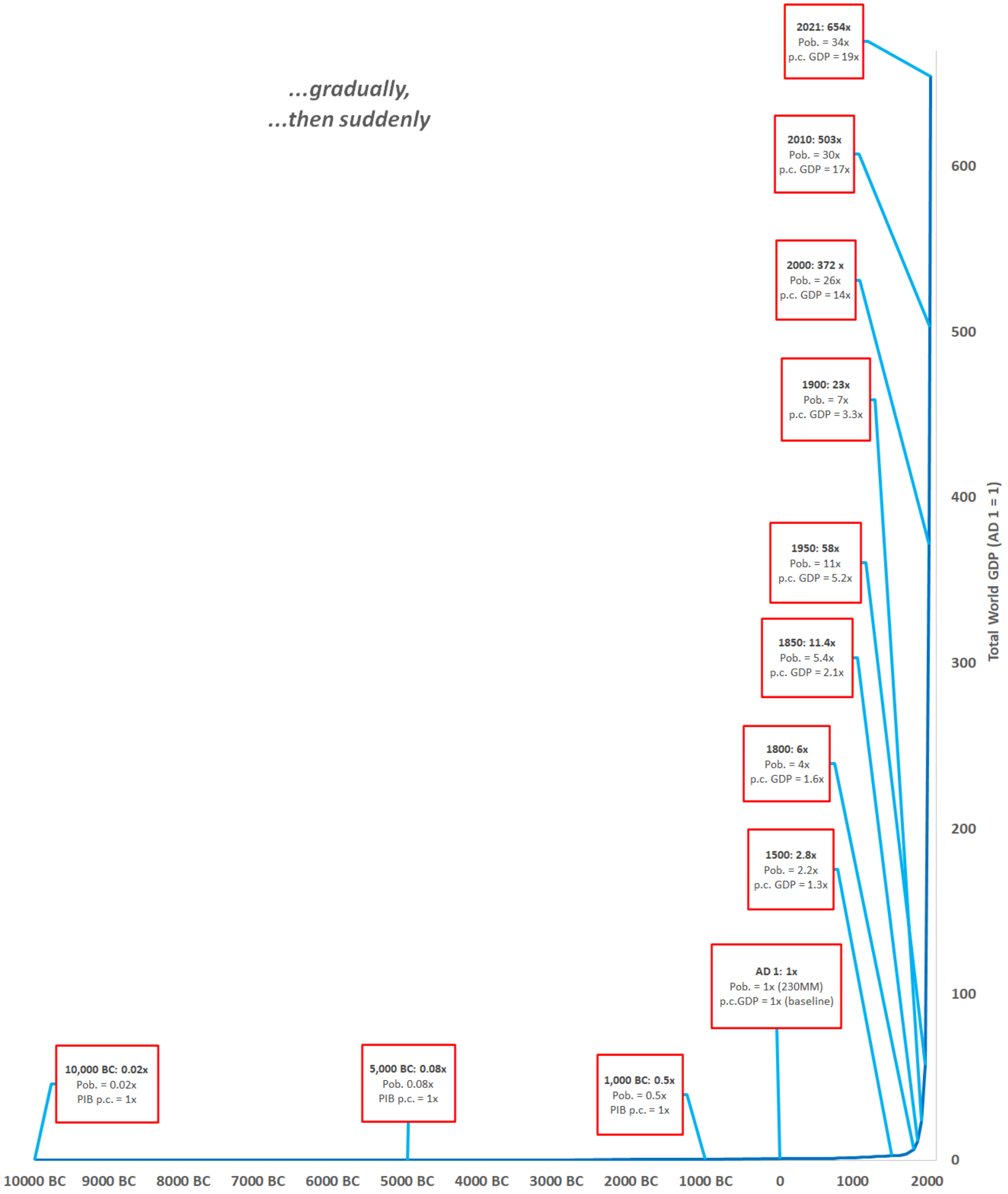
Source: own calculations using per cap. growth rates in Piketty (2014) from AD 1 – 1970; World Economic Indicators (World Bank) between 1971-2020, and World Economic Outlook (IMF) projections for 2021. Cumulative per cap. GDP is normalized to 1 at AD 1 levels.

2.3 Total world output during the Holocene

Figure 2 shows the evolution of world output that is implied by the preceding analysis, simply multiplying total world population by the estimates of per capita GDP. To facilitate comparison, total world output is normalized at 1 in the year AD 1. For example, given that world population in 10,000 BCE is estimated at just 4 MM, compared to around 230 MM in AD 1, and given the assumption of nearly constant per capita GDP levels, total output around that time is estimated at roughly 2% (0.02 times) the level at AD 1.

Closer to the present, the figure once again reveals the unforgiving logic of compounding growth rates during the last 200 years: while world GDP was estimated in 1800 to have grown just over 6.4 times the levels from AD 1 –essentially through population expansion, as discussed above--, towards 1900 it had already multiplied almost *four-fold*, to 24 times. Then, during the 20th century, as both per capita GDP and population reach truly astounding growth rates, world GDP expanded by another *sixteen-fold* (!) to reach no less than 372 times the levels of AD 1.

Figure 2: World GDP throughout the *Holocene* (normalized to AD 1 = 1)



Sources: own calculations, using *Hyde project* for population, per cap. growth rates in Piketty (2014) from AD 1 – 1970; World Economic Indicators (World Bank) between 1971-2020, and World Economic Outlook (IMF) projections for 2021. World output is normalized to 1 at AD 1 levels.

What´s more, in just the last 20 years, GDP has again almost doubled, growing to a whopping 648 times. That´s correct. Today, as far as the evidence collected by economic historians can tell, the size of human population is today about 34 times larger, and per capita human consumption of goods and services about 19 times larger, since the start of the common era. We now turn to the sobering consequences such expansion has had on nature.[5]

3 Measuring nature´s degradation

During most of the Holocene the expansion of Mankind had limited impacts on the environment, and when it had, they were mostly local, but large enough to be linked to the extinction of Megafauna. Even as recently as the beginning of the XXth Century Nature was still able accommodate the exponential growth of human population and the material improvements in living conditions. However, since the second half of that century the retreat of Nature has been evident[6], giving impulse to growing efforts to measure the effects of human activity on the state of the environment.

3.1 Conceptual considerations in the measurement of nature´s state

There are several ways to measure the condition of nature and to assess the impact from human activity. A first approach, pioneered by the Global Footprint Network, is based on comparing *extraction flows* (the ecological footprint) with the regenerative capacity of productive ecosystems (biocapacity). A key virtue of this method is that human economic activities can be directly linked with a standardized metric (global hectares) that can then be aggregated at different spatial units.

A second approach is based on measuring *natural stocks*, including either the state of preservation of different ecosystems (eg., habitat conservation for supporting biodiversity; GEO BON, 2015), or direct measures of biomass of living species (WWF, 2020). When compared across time, these measures are probably the best approximation about how human economic activities are degrading nature. Many of these measures also inform the global effort for biodiversity and ecosystem conservation lead by the UN´s *Convention on Biological Diversity* (CBD), whose flagship IPBES (2019) *Global Assessment Report* serves as an input for monitoring the global advances towards meeting the Aichi Biodiversity Targets (Secretariat of the Convention on Biological Diversity, 2020).

A third approach measures the state of nature by directly *valuing ecosystem services* received by humanity –including provisioning, support and regulation, and cultural services. The present discounted value of such services, which depends on the state of different ecosystems as well on appropriate “shadow prices” --often different from market prices in the context of externalities-- constitutes the notion of *natural capital* (see Dasgupta 2021, and UN 2021).

Each of these approaches has advantages and limitations, but together they complement each other to provide a consistent picture of the impact of human activity on nature. And the picture that

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[5] Sachs (2015) also provides a similar overview of the explosive rate of economic growth, in the context of his discussion about Sustainable Development.

[6] Meadows et al. (1972) were among the first to raise the alarm with a global impact, by rescuing the Malthusian notion that the accumulation of exponential demands for resources from a closed global ecosystem were unsustainable.

emerges is unequivocal. As well summarized by IPBES (2019): "*Humanity is now a dominant influence on nature worldwide, with many impacts having accelerated rapidly in the 20th century… Much of nature has already been lost, and what remains is continuing to decline*"[7]. We now briefly summarize the key findings that emerge from each approach.

3.2 A summary of key nature´s metrics

Extraction flow vs regeneration capacity: The Global Footprint Project

The global footprint project (Wackernagel and Beyers, 2019), essentially asks: how much do human activities take from nature each year? The answer to that question is termed the *ecological footprint* (demand). And crucially, how does this compare to availability of natural resources, given the ability of nature to regenerate in a sustainable manner? This is referred to as *biocapacity* (supply). The difference between the ecological footprint and biocapacity, if positive, is termed the *overshoot*.

The broad contours of the methodology are as follows. Stating with *biocapacity* (supply), the total surface of the earth is around 51 billion hectares. But large parts of it are either open oceans low in fish content, deserts, or ice sheets. Based on vegetation maps and estimations of marine productive ecosystems, the global footprint project estimates that roughly ¼ of the surface of the earth can be harvested in some way for human use, yielding roughly 12 billion hectares of global land surface, displaying an “average” level of hectare productivity. Of course, different areas show widely diverse biocapacity: tropical forests regenerate timber, nutrients, and fresh water much faster than the same surface of woodlands. The methodology thus assigns different *equivalence factors* for comparing biocapacity across different types of ecosystems, and also applies different *yield factors* that convert productivities of the same type of ecosystem across different regions (eg., a degraded tropical forest will have less biocapacity than a pristine one). Equivalence and yield factors are then expressed in terms of average productive hectares, called global hectares, so that a hectare of tropical forest will be measured as several times the global hectare, while an alpine region where regenerative capacity is low will probably fall below one global hectare. The parametrization of equivalence and yields factors ensure that, on aggregate, the biocapacity of the world corresponds to the 12 billion hectares available, by construction.

The *ecological footprint* (demand) is calculated by adding up all the uses that humanity extracts from this surface of productive land. As an example, take the country-level as unit of aggregation. All the demands imposed on nature are added up considering the intensity by which these resources are harvested, as well as the competing uses of human activity on nature. For instance, if forest area is felled or burnt for cropland at a faster rate at which it can regenerate, the ecological footprint linked to forests services in that country will exceed their biocapacity. Other large contributors to the ecological footprint are CO_2 emissions, counted by the methodology as one of the demand components –indeed, the largest, amounting in 2017 estimates to 12.7 billion hectares of ecological footprint, roughly 60% of the total. This means that the current level of CO_2 emissions by itself already marginally exceeds the total biocapacity of the planet, but of course, the other uses must also be added, which raises the total footprint to around *20 billion hectares*. In concrete terms, the

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[7] See Ch. 2 of the report: *Status and Trends –Nature*.

average citizen of the world uses resources in excess of what Earth can regenerate. How much? Approximately 1.75 times in 2017.

Over most of human history, biocapacity of the planet largely exceeded the human footprint, notwithstanding the fact that human expansion across the planet has been accompanied by the extinction of many species, including most of the mega-fauna. However, in the last couple of centuries, following the explosion in the size of population and living standards, the natural boundaries of the biosphere have been put to the test and the number of species under threat of extinction, or extinct, has accelerated dramatically (IPBES 2019). The problem is also reflected in the reduction of populations, even in species that are not in danger of extinction (Rosenberg et al., 2019). On the other hand, the size of the biomass of species domesticated by humans has risen quite significantly, displacing the rest.

Even though these limits are global, the human footprint is local and, only in some cases such as climate, have global implications. The balance between the ecological footprint and biocapacity varies widely among countries. In general, rich countries with large consumption footprints have the largest overshoot, while lower income nations, many of them rich in biodiversity and productive ecosystems, export some of their “surplus” to the former. At the global level, the Human Footprint Project estimates that demand for Nature´s services began exceeding supply in the early 1970´s, and the gap has been growing ever since. That is, the average citizen of the world consumes more than the earth can regenerate. How much more? Roughly 1.75 times more (at 2017 estimates). [8]

Figure 3 reproduces global biocapacity, ecological footprint, and the resulting overshoot in per capita terms. The overshoot has been positive and increasing since 1970s, which means the average person in the planet takes more out of nature than the rate at which nature can reproduce itself. At least, according to this metric.

However, as the authors of the Ecological Footprint convincingly argue, there are some important caveats about these calculations that suggest the estimation of the overshoot may be a lower bound of the actual overshoot. First, the data the projects builds upon is collected first by national authorities and then consolidated by the UN. However, it is not always the case that the accounting units properly reflect the state of ecosystems, as a very sparse woodland may still be classified as “Forest”, and this apparently is not always discounted by either equivalence or yield factors. Second, and perhaps more importantly, the measurement of biocapacity does not consider some important externalities that such biocapacity may be having on other ecosystem services. For instance, if industrialized farming techniques significantly increase crop yields, such increase in yields will appear as larger biocapacity of the hectares in question. Yet no discounting is applied for the fact that the over fertilization is polluting underground water reserves, which will end up hurting some other ecosystem function.[9]

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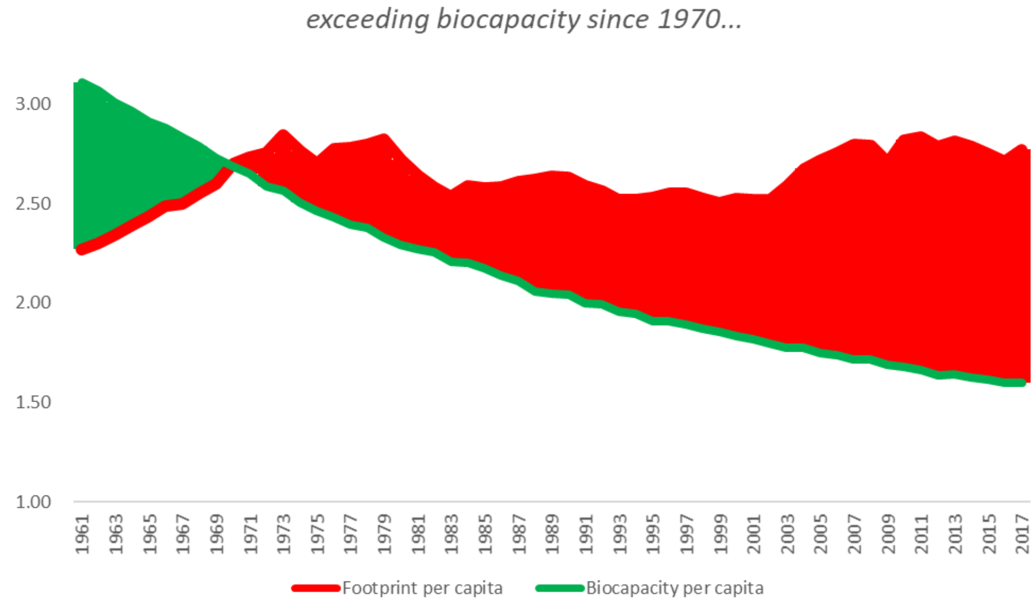
[8] An intuitive and effective way of communicating this imbalance is Earth Overshoot Day –the day of the year at which the ecological footprint is estimated to have surpassed the yearly capacity of the earth to regenerate. The latest calculation is July 29, for 2021 (https://www.overshootday.org/).

[9] See Wackernagel and Beyers (2019) for a more detailed discussion about the ecological footprint and biocapacity calculations.

Figure 3: Global Biocapacity, Ecological Footprint, and Overshoot (*global hectares*, per capita)



Source: Global Footprint Project. (https://data.footprintnetwork.org)

Besides from these caveats, one should consider that humanity´s use of biocapacity also competes with that of other living beings. Hence, the larger the footprint we hoard for ourselves and our domesticated animals, the smaller the fraction of nature we leave to the rest of the species. The consequences of this crowding out will be discussed below. That said, the ecological footprint constitutes a valuable approximation to the imbalance between extraction flows and regeneration capacity of the natural world that can be consistently compared across time and regions and linked more directly to different economic activities.

Natural stocks: measuring nature´s degradation directly

Nature, biodiversity, and ecosystems are interrelated concepts. The following definition (World Bank, 2021) serves as a useful starting point for defining the objects by which one can track nature´s state: *Nature refers to the ensemble of living organisms and the functions of the biosphere. The symbiosis between living organisms and the abiotic (nonliving physical and chemical) environment gives rise to ecosystems that control fluxes of water, carbon, energy, and nitrogen, among others. Biodiversity is the variability of genes, species, and ecosystems*.

It follows that one can measure the state of nature through alternative, complementary metrics. First, through direct measures of ecosystem extents and conditions, which will affect their capacity of providing ecosystem services. Second, through direct measurements of biodiversity. In what follows, we draw heavily from IPBES (2019), Secretariat of the Convention on Biological Diversity (2020), and WWF (2020).

Regarding ecosystem´s extent and conditions, IPBES (2019) documents that humans have already significantly altered around 75% of land area, while two-thirds of the ocean area is experiencing increasing cumulative impacts, and over 85% of wetlands area has been lost. On average, the report estimates a drop of 47% in ecosystems relative to their earlier estimated states (Figure SPM 2). Since the early 1970s, while the value of agricultural crop production has increased approximately threefold and raw timber harvest by 45%, several indicators of ecosystem regulating contributions --such as soil organic carbon and pollinator diversity-- have declined, pointing to the unsustainable nature of these dynamics. Land degradation has reduced productivity in 23% of the global terrestrial area, while loss of coastal habitats and particularly coral reefs –now estimated to have lost *half* its living coral cover area—significantly affect the associated marine biodiversity and the coastal protection, increasing the risk from floods and hurricanes.

This major reshaping of natural ecosystems can also be seen in the utter failure to meet the 20 Aichi Biodiversity Targets at the global level. For example, Target 5 states: "*by 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced*. In contrast, the report by the Secretariat of the Convention on Biological Diversity (2020) finds that "*the rate of loss has only been reduced by a third, with deforestation trends increasing in many areas. Loss, degradation and fragmentation of habitats remains high in forest and other biomes, especially in the most biodiversity-rich ecosystems in tropical regions. Wilderness areas and global wetlands continue to decline. Fragmentation of rivers remains a critical threat to freshwater biodiversity*." While these findings vary across regions, with degradation generally proceeding slower or even reverting in advanced economies, the aggregate patterns reported are highly concerning. Similar failures are found across the board, in dimensions spanning the sustainable harvesting of marine ecosystems and agricultural lands, the rate of pollution discharge, prevention of extinction of native species, among many others.

In terms of the effects on biodiversity, IPBES (2019) provides other alarming figures. Currently, "*the global rate of species extinction is estimated to be at least tens to hundreds of times higher than the average rate over the past 10 million years and is accelerating*," and a *whopping 25%* of all living animal and plant species are estimated to be at serious extinction risk (Figure SPM 2). While maintaining biodiversity does not necessarily mean keeping the existence and interactions between species unaltered --as such changes are a natural consequence of evolution-- the rate at which local and global extinctions of species are occurring today is considered too fast to maintain the resilience of ecosystems and their ability to provide their vital services to humankind (IPBES, 2019; Dasgupta, 2021). The main drivers of biodiversity losses according to IPBES (2019) are (in order of importance): i) land and sea use change; ii) direct species overexploitation; iii) climate change; iv) pollution, and v) invasive alien species –all of which can be directly tracked to human presence and economic activity.

Another widely cited metric for biodiversity degradation is the Living Planet Index, by the World Wildlife Fund and the Zoological Society of London (WWF, 2020). Since 1970, the index tracks average biomass of wildlife mammals, amphibians, reptiles, birds, and fish populations. Figure 4 plots the evolution of this index (normalized at 1970 = 1) against total GDP (also normalized at 1970 = 1) for the world and selected sub-regions. Overall, while real world GDP expanded by about four-fold between 1970-2016 (the last available year of the index), the average biomass of the included animal categories has *declined by 68%* (mid-point estimate). The loss is particularly alarming in Latin

America and the Caribbean, estimated at an almost surreal *ninety-four percent*, in a region that also saw a four-fold increase in overall GDP. Notice that, given the apparent trends, losses may well be larger by now, as GDP has gained another 10% since 2016, the last year the LPI is available, while the rate of deforestation in the Amazon has increased.

Table 2 provides further statistics for all the regions included in the LPI calculation. A quick inspection of the table reveals that total GDP growth over the period is positively correlated with wild biomass loss, but such correlation is far from perfect (as far as it can be evaluated by 5 data points). For instance, the two regions with less damage in wildlife are Europe & Central Asia (the region with lowest GDP growth), followed by North America (the second lowest GDP growth). But then Asia-Pacific, which displays by far the largest overall growth, has an intermediate level of wildlife loss. At the other side, Latin America and Africa have the largest and second largest levels of nature degradation, while their overall growth is very close to the world average.

Table 2: Economic growth and wildlife loss

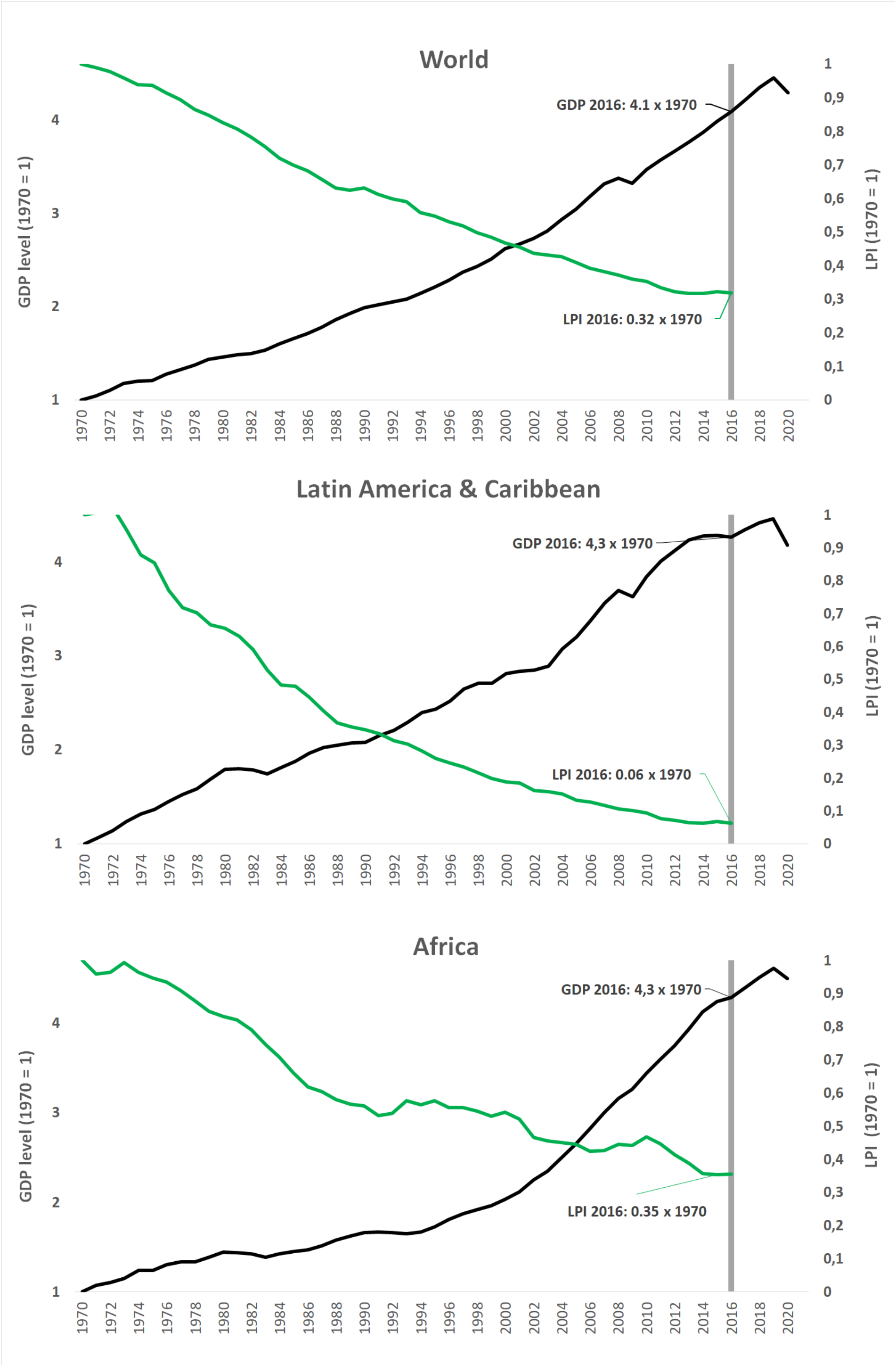
	GDP level	Population	Per Cap. GDP	Per Cap GDP/Pop.	Commodity X Share (%)	LPI change (%)
World	4.1	2.0	2.0	1.0	27	-68
Africa	4.3	3.5	1.2	0.3	78	-65
Northern America	3.6	1.6	2.3	1.4	26	-33
Latin America & Caribbea	4.3	2.2	1.9	0.9	49	-94
Europe & Central Asia	2.7	1.2	2.2	1.8	24	-24
Asia-Pacific	7.7	1.8	4.3	2.4	25	-45

Note: GDP level, population, and per cap. GDP are expressed as multiples of 1970 (1970 = 1). Commodity X share is the 1995-2019 average of the share of commodity to total exports, for each region.
Source: own calculations using WWF (2020) for the Living Planet Index and World Economic Indicators (World Bank) and UN population statistics.

One factor playing a role in this result is the fact that poorer regions tend to rely more on natural capital, compared to human and artificial capital (World Bank, 2018). At the same time, the poorest people tend to live in fragile natural ecosystems (Dasgupta, 2021). Since there is a well-established positive correlation between fertility and poverty, demographic pressure on biodiversity tends to be higher in poorer regions of the World, and some of them are especially rich in biodiversity now. As Wilson (2002) shows, regions that suffered large extinctions earlier on, tend to show slower loses later. So, the large remaining reservoirs of biodiversity are located in hard-to-reach areas, subject to little pressure from humans. As population in low-income areas grows, the pressure to use the main form of capital available (natural capital) rises.

On the other hand, low- and middle-income countries tend to rely more on raw commodity exports, as confirmed in Table 2 for the poorest two regions. According to IPBES (2019; Ch. 2), such trade patterns have shifted ecological footprints considerably, as global trade has increased nearly 10-fold since 1970. High income countries have thus managed to increase consumption while reducing their local ecological footprint, in line with better local institutions and environmental standards, by essentially importing raw commodities from low-middle income countries. Together, these elements explain the much worse GDP/environmental degradation relationship, as quantified by IPBES (2019) and World Bank (2021), for low and middle-income countries.

Figure 4: Economic growth vs. nature –the *Living Planet Index* and GDP (1970 = 1)



Source: own calculations using WWF (2020) for the Living Planet Index and World Economic Indicators (World Bank) for GDP.

Ecosystem services approach: towards a measurement of Natural Capital

A third approach to measure the impact of human economic activity on the state of nature is through the valuation of ecosystem services. As Dasgupta (2021) points out, one useful way of thinking about nature´s contribution to human welfare, which can be easily directly within standard economic analysis, is through the present discounted value of the services it provides, once these are valued at prices which correctly account for the presence of externalities –termed *accounting prices*. This gives rise to the notion of *Natural Capital*.

Earlier versions of natural capital are provided by the UN System of Environmental Economic Accounting, Central Accounting (UN, 2012), and feature prominently in the measures of the *Changing wealth of Nations* compiled by the World Bank (World Bank, 2018). These earlier attempts mainly focused on the market valuation of provisioning services –timber; agricultural products; minerals and other natural resources-- but left out many other ecosystem services of regulation and maintenance –such as carbon sequestration, water filtration, soil regeneration, pollination services and disease control, to name a few. While this approach is useful, especially to assess potential economic growth in resources-rich countries, it may severely underestimate the impact on nature of human activity, as often the extraction of provisioning services may severely degrade ecosystems.

In recent years the best practices of measuring natural capital have converged towards the concept of valuing the services provided by ecosystems, an effort led by the *Millennium Ecosystem Assessment* (2005). The ecosystem service approach is of enormous value conceptually, as it allows to express different nature´s services under a common metric, thus making a multidimensional problem more tractable and comparable, and the methodologies involved have made substantial progress since, building on the experiences from diverse pilot projects. However, they are yet to be applied on a systematic basis over specific countries or regions to keep track of the evolution of natural capital over time.[10]

The proposed methodology (UN, 2021) consists of five steps. First, measure the *extent* of different ecosystems of a particular geographical region. At a broad level, this typology considers *realms* (T: Terrestrial; F: Freshwater; M: Marine; S: Subterranean; Transitional) which are in turn subdivided into biomes (say, T1: Tropical-sub tropical forests; M1: Marine shelfs, etc.) and give rise to the basic unit of accounting: *Ecosystem Assets*. Second, appraise the condition of each ecosystem, relative to a baseline condition at which the ecosystem operates at full potential. Third, calculate the flow of different ecosystem services provided by each ecosystem asset, including services of provision; regulation and maintenance; and cultural. Fourth, assign *accounting* prices to these service flows, using market prices where available or through alternative methodologies that can better incorporate non-market valuations resulting from pervasive externalities (see Dasgupta, 2021). Fifth, use an appropriate rate of discounting to compute the present value of each ecosystem asset. Their aggregation gives rise to the value of *Natural Capital* of a given territorial extension-- say, at the country level.

This approach to valuing natural capital conceptually integrates several of the key aspects of the methodologies described above. For example, the extraction of timber provisioning services that

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[10] The UK´s *Natural Capital Committee* (2020) provides several examples of pilot projects, building on the framework proposed by the UN, 2021. See Tallis et al. (2011) for an overview of key methodologies and application experiences.

would be accounted for in the Ecological footprint will also leave a trace on natural capital, as it will be –at least in principle—measured as a reduction in either the extent or the condition of, say, the T1 ecosystem asset valuation. Crucially, it also connects well with the measurement of natural stocks described above. Indeed, to the extent that the extraction from or the handling of different ecosystem units negatively affect their condition –through contamination of underground water through excessive fertilization of agricultural land, for example—this will show up as a decline in the present value of related ecosystem services. What´s more, the monetary valuation approach offers a natural way of aggregating the multiple dimensions involved in the measurement of natural stocks, reducing them to a more manageable but at the same time comprehensive metric.

Admittedly, this approach is a highly anthropocentrically oriented one, but as described by Dasgupta (2021), a correct and systematic measurement of natural capital through this logic would be a major improvement on current practices of economic accounting –which largely ignore the impacts of economic activity on nature´s degradation. Also, it has the appealing property that maximization of inclusive wealth, which adds natural capital to physical and human capital, is equivalent to that of inter-generational welfare (see *Wealth/well-being equivalence theorem*, Ch. 13 in Dasgupta, 2021). Despite its numerous advantages, this approach to measuring Natural Capital has not yet been formally implemented at the national level by any country.

In the traditional economic approach, the fundamental problem is to allocate scarce resources to maximize the well-being of current and future generations. Despite the shortcomings of the current metrics to measure natural capital, they offer a far better alternative than the traditional approach: just ignore the existence of natural capital. By excluding natural capital in the economic decision-making processes we not only miscalculate contributions by other factors of production, but we also exclude the impact of damages to the biosphere from the risk analysis of our decisions on the well-being of future generations. As stated by Dasgupta (2021), the inclusion of these risks on natural capital in the allocation of other forms of capital is essential for preservation and increase of "Inclusive Wealth". In the next section we will refer to the risks we face today as a consequence of this neglect in past decisions on allocation of resources.

3.3 Is nature under serious risk of collapse?

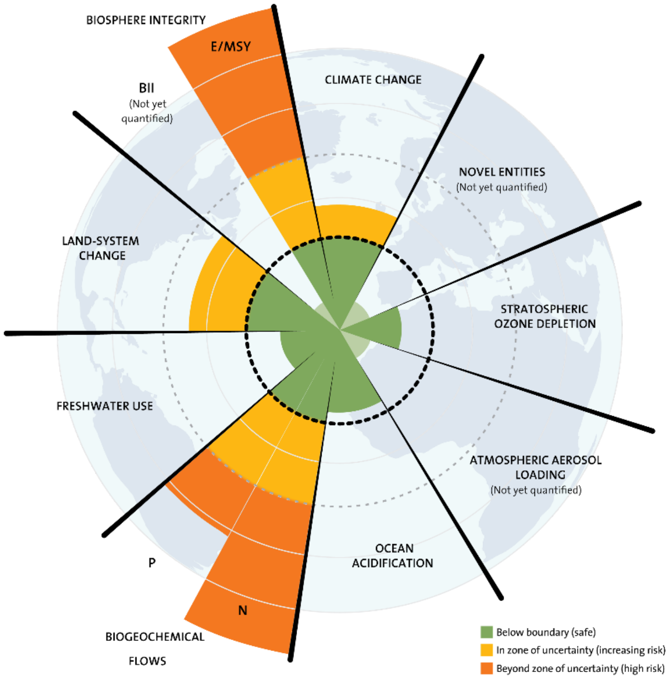
A useful way of combining the multiple dimensions of nature to assess this existential question is through the concept of *planetary boundaries*. In a highly influential paper, Rockström et al. (2009) categorize 9 dimensions that determine the self-regulating capacity of our planet. They include climate change, ocean acidification, biodiversity loss, land use change, freshwater availability, biogeochemical flows, ozone depletion, chemical pollution, and atmospheric aerosol loading. Using methods that build on many of the metrics discussed above, the authors place ranges across 7 of these 9 dimensions, which define the safe operating space for humanity.

The conclusion emerging from a quantification of 7 out of the 9 identified dimensions is highly disturbing. Humanity is currently operating outside of the "safety zone" in at least 4 of these 7 dimensions: *biogeochemical flows* –due to over-fertilization of agriculture--, climate change, biodiversity loss, and land system use change. For convenience, Figure 5 reproduces the current assessment of planetary boundaries in Steffen et al. (2015).

While distinct, these dimensions are highly interrelated. For example, land use change leads to deforestation and biodiversity loss, which in turn affects carbon sequestration capacity and thus climate change and ocean acidification. On the other hand, climate change is already affecting biodiversity and the state of nature in general, as extreme weather events are affecting the state of forests, availability of water, and living conditions for all forms of life, but specially in critical areas like the tropics. They are also subject to non-linear effects from human activity. For instance, it has been shown that coral reef living cover can cope relatively well with moderate increases in ocean acidification, but rapidly loose calcification capacity when approaching certain bounds.[11]

Perhaps most importantly, planetary boundaries are subject to tipping points –bounds beyond which ecosystems may fail to recover from, even if the underlying pressures driving their deterioration is reversed. For instance, the melting of permafrost would release large amounts of methane into the atmosphere, accelerating global warming and increasing the risk of forest fires and additional carbon emissions that could offset human reductions in emissions. Even more straightforward, the materialization of the existential threat to 25% of living species mentioned above would reduce dramatically the capacity of ecosystems to provide multiple services. Once extinction takes place, reversal is impossible.

Figure 5: Degrading at our own peril --*Planetary Boundaries*



Source: Steffen et al. (2015).

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[11] See Ries et al. (2010).

Concerns about the cumulative impact of human activity on the environment are not new, as reflected in the influential reports by the Rome Club (Meadows et al., 1972) and the Brundtland Committee (1987). The recent literature on planetary boundaries by incorporating, as far as feasibility allows, the impacts of feedbacks, non-linearities and tipping points, is sounding the alarm about time limits for action: It seems that we have just 10 to 20 years to reverse the damage to nature. If so, we just have 2 decades (at the most) to take decisive action to return to safe operating boundaries in each of these dimensions. Of course, scientists agree that there is significant uncertainty involved in calculations of specific time limits[12]. However, from a standard risk-averse perspective, such uncertainty should be an additional argument for pressing the need for early action to avoid slipping into these highly consequential tipping points, the crossing of which has the potential to alter the current conditions of the biosphere to such an extent to warrant a formal end to the *Holocene epoch* (Rockström et al., 2009).

4 Contribution of living standards and population growth to environmental degradation

To have a better idea of the relative contribution of changes in living standards vis-à-vis population growth to the deterioration of nature shown in section 3 we examine the evolution of an adaptation of the Living Planet Index for several groups of countries defined according to their level of economic development in 1970 for the period 1970-2014. For this purpose, we present results for a version of the global LPI as well as to the LPI for terrestrial species only. In what follows we will perform some statistical analysis of the relationship of per capita income and population growth with the evolution of land use as a proxy for pressures on biodiversity, which in the metric used is more closely related to terrestrial species.[13]

Figure 7 shows that the group of countries with the highest levels of income in 1970 had experienced a loss of biodiversity close to 40% of the initial level. On the other hand, countries at the middle income and lower income levels experienced significant more damage (60% and 80%, respectively). When we focus on the pressures on terrestrial species, the general trend is the same, but the differences among different initial income groups becomes smaller.

One possible interpretation of these results is that the speed of degradation of Nature falls as biodiversity losses occur. If a country or region developed earlier extracted more resources from Nature than less developed regions, it leaves less room for further degradation of Nature later. An extreme example is the extinction of species in a specific area. Once that happens, there will be no further losses linked to it. However, on a more positive note, there is also the possibility that the early increases in human and artificial capital might facilitate the substitution of natural capital. This might be reflected in higher productivity in agriculture, alleviating pressures to expand the agricultural frontier into biodiversity-rich regions. On the other hand, earlier economic development

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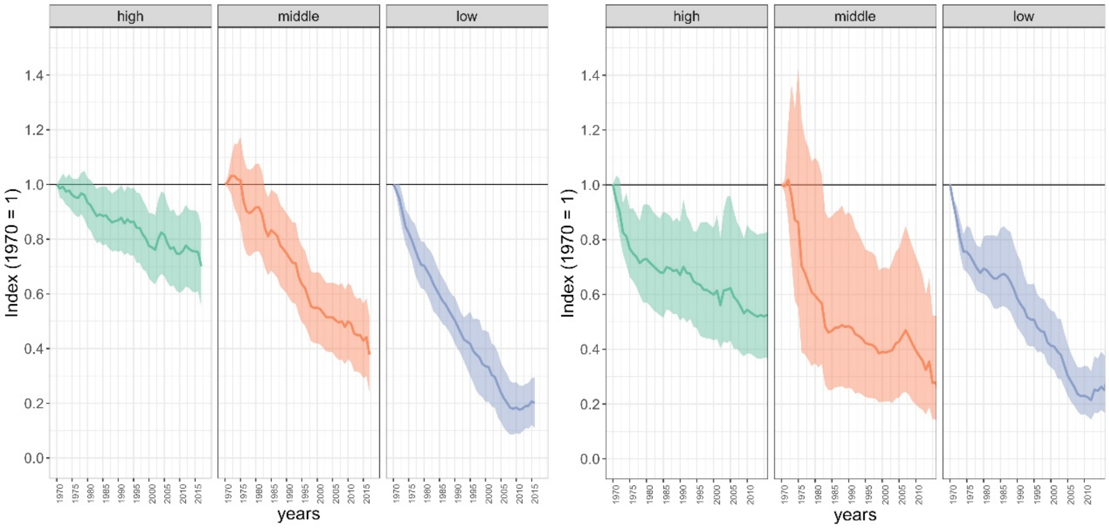
[12] See, for instance, IPCC (2021)

[13] See Annex for further details on the data used.

is also associated with an earlier demographic transition, so population growth in more advanced countries is significantly slower than in medium income and low countries.

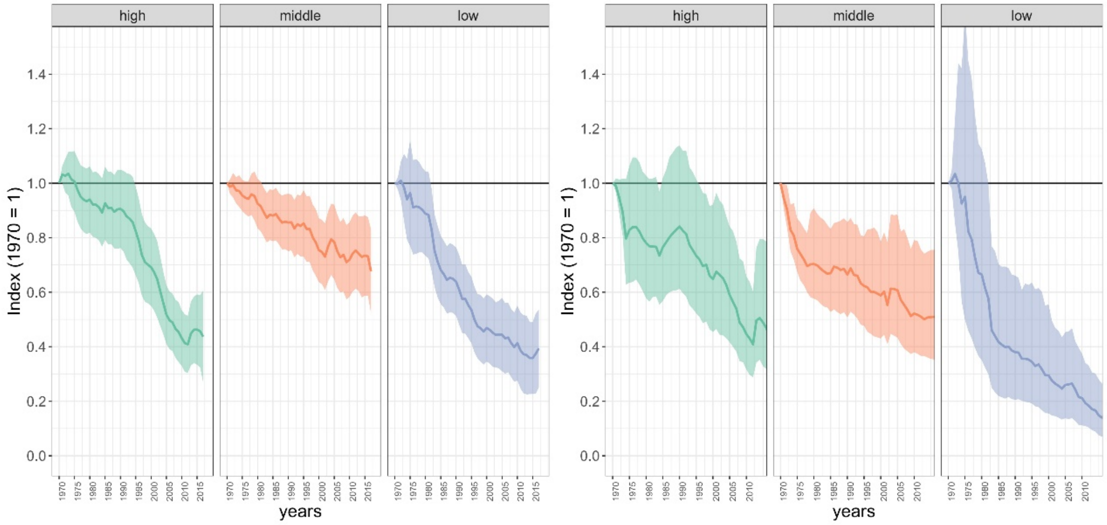
Whatever is the combination of explanations for the ***negative correlation between the initial level of per capita income and the deterioration of biodiversity,*** the practical consequence when looking into the future is that we might want to focus our attention in places (countries or regions) that today are poor and at the same time have high levels of biodiversity.

Figure 7: Evolution of LPI for countries in different starting income levels



Living Planet Index **LPI Terrestrial species**

Figure 8. Evolution of the LPI for countries with different rates of per capita GDP growth



Living Planet Index **LPI Terrestrial species**

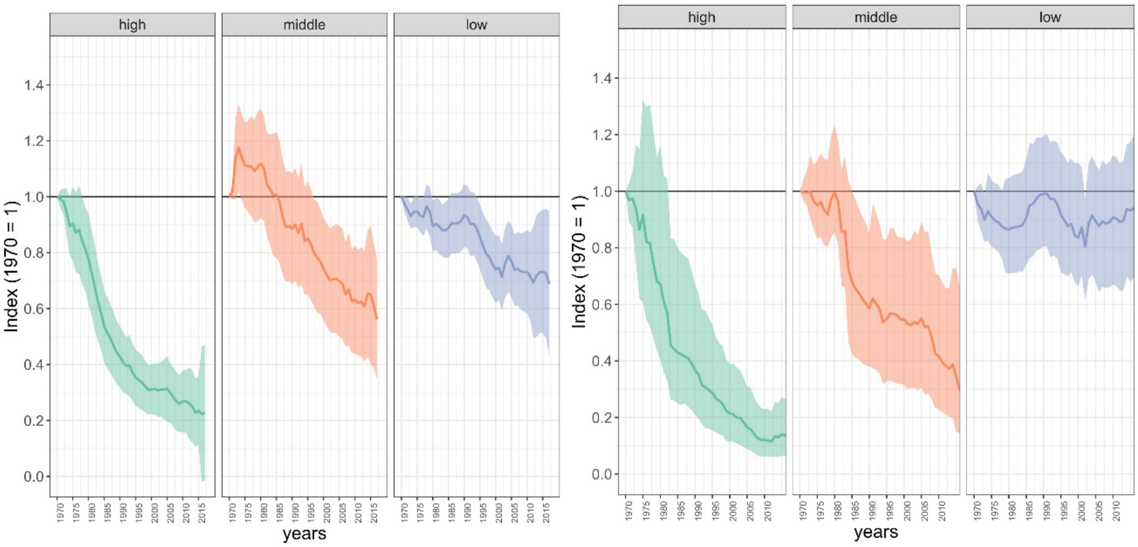
A second angle is to look at the correlation between GDP growth and losses in biodiversity. We do this by grouping countries according to their averages rates of growth for the period 1970-2014, as shown in Figure 8. These results are more of a surprise: the differences among groups are not that high and slow growth countries seem to be the ones that experienced the highest loss of biodiversity, followed for the fastest growing countries. Part of the explanation is that richer countries tend to exhibit positive but not extremely high growth, falling in the middle-growth group of countries. The differences between the LPI and the LPI for land-based species are smaller than in the previous case.

The main takeaway from this figure is that ***biodiversity loss is not closely correlated to the speed of per capita income growth, suggesting that other factors are also at play***.

Finally, Figure 9 compares the rates of biodiversity losses for groups of countries with different rates of population growth. In this case we see clear differences among the different groups, as well as for the different indices. If we take the aggregate index, there is a clear order: biodiversity losses are positively correlated with population growth. However, when we restrict our view to the LPI for terrestrial species we see smaller loses of biodiversity in countries with low population growth, while in those with medium or high rates of population expansion losses are higher and of similar orders of magnitude.

Figure 9. Evolution of the LPI for countries with different rates of population growth

Living Planet Index **LPI Terrestrial species**

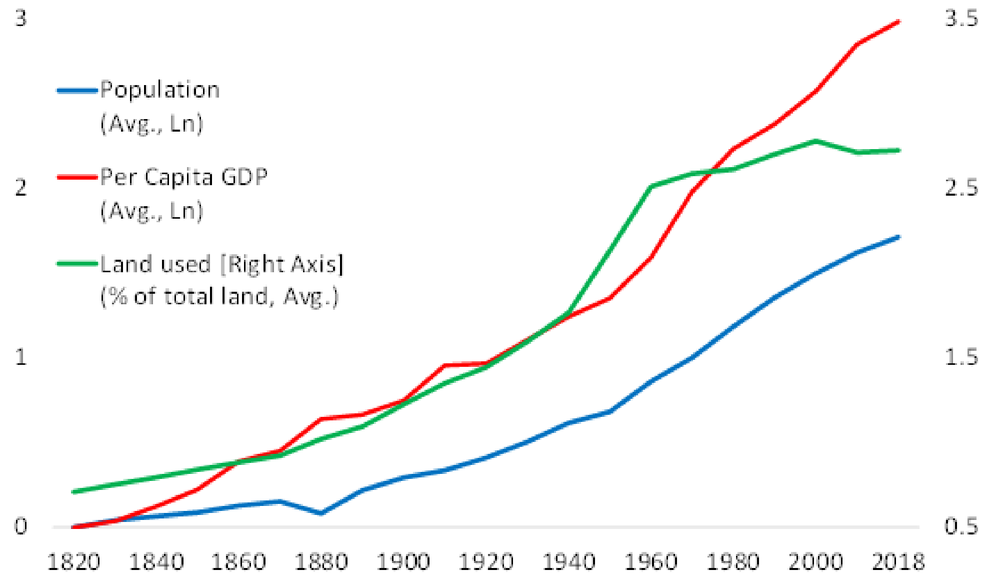


A natural next step is to try to disentangle the relative importance of population vis a vis per capita income on biodiversity. Since demographics evolve more slowly, we need to expand our time series, which comes at the cost of losing the broad measure of biodiversity loss represented by the LPI. Instead, we use change in land use from the Hyde Project as a (limited) proxy. This means that the results will be confined mostly to the impact of per capita income and population growth on the expansion of the agricultural frontier and only on the species living in terrestrial ecosystems. However, we gained enough granularity to examine these relationships across a far larger number of countries, grouped in 26 regions, and for a longer period (1820-2018).

Figure 10 shows that in most of the 19th Century land use moved in synch with population growth. That trend changed late in that century when land use rose faster than population, showing rates of growth similar to that of global per capita GDP growth. However, starting in the second half of the 20th Century, land use expansion slowed down significantly relative to both per capita income and population expansion.

This impression is corroborated by panel regressions exploiting the cross-country dimension, for the sample period as a whole and two sub-periods: 1820-1960 and 1960-2018 --shown in Table 3. While we confirm a positive and highly significant correlation between the two variables for the period as a whole, such relation breaks down when we split the sample in the temporal dimension –as anticipated, the significance is lost in the later subperiod. An optimistic explanation could be that land use productivity has risen faster since the second half of the 20th Century. An alternative, less optimistic interpretation, might be that we could be running out of land to use. It is worth noting that the LPI shows that, about the same time (1970) of the break in the correlation between GDP growth and biodiversity loss, we began to surpass the capacity of the biosphere to regenerate itself and started depleting the stock of natural capital. When we used per capita GDP and population separately, the goodness of fit did not change much, but there was a severe loss of significance, especially for per capita GDP, suggesting strong collinearity.

Figure 10. Land use, per capita income and population: world, 1820-2018



Notes: The blue and red lines show, respectively, the log of the region average of the population and per capita GDP series. Both series are expressed as the difference with respect to their values in 1820. The green line (right axis) is the region average of use of land (% of total land). *Source*: Hyde v.3.2, WDI, The Maddison Project Database, complemented with additional individual-country databases.

Table 3: Land Use and GDP

Dep. var.: land use (% of total) - FE regressions			
	1820-2018 (1)	1820-1960 (2)	1960-2018 (3)
GDP (ln)	0.316***	0.288**	0.193
	(0.112)	(0.112)	(0.134)
Obs.	477	321	180
Regions	26	24	26
R2 (within)	0.48	0.47	0.10

Notes: Regressions include region and year fixed effects. Robust standard errors in parenthesis. *, ** and *** indicate significance at 10, 5 an 1%, respectively.

We now break down the sample grouping countries according to their per capita income levels and the size of population (averages for the sample period), to limit the impacts of collinearity. The results shown in Table 4 are very suggestive. First, they confirm the breakdown of the relations for the latest part of the sample. Second, there is evidence that ***economic growth does not necessarily translate into expansions of the agricultural frontier in High and even Middle-Income countries***. On the other hand, ***population growth plays a significant role in the loss of natural spaces both in high and middle per capita income countries***.

One piece of good news is that most high-Income countries are well advanced into their demographic transition and several of them are already experiencing negative population growth (so the positive association means recuperation of natural land) while the rest already have fertility rates (number of children per woman) below 2%. For Middle Income countries there are mixed news: Most of them are advancing fast into their demographic transition, and some like China, Brazil and most of Latin America are expected to see declining populations in the coming decades. The negative part is that they concentrate ¾ of the global population, so the still-positive growth of population in this group of countries will exert critical pressures on natural capital, in accord with the increase of the impact of population on land use in the second half of the sample.

One important caveat when trying to explain these results has to do with the role of international trade. As we mentioned earlier, lower income countries tend to export goods intensive in natural capital such as agricultural products, minerals, timber, etc. (Dasgupta, 2021). Those same goods are imported by higher income countries, either for consumption or as inputs in the value chain of their exports. For this reason, and conditional on the specifics of trade in each country, it is reasonable to assume that a significant fraction of the disappearance of the relationship between biodiversity loss and GDP growth in high-income countries is due to the destruction of local habitats for biodiversity losses in low-income countries. However, it is also reasonable to expect some degree of substitution between natural capital and the other forms of capital (human and produced). This should be reflected in higher productivity of natural capital in the more advanced countries. This could be the case in agriculture where we observe higher rates of measured productivity per unit of land.[14]

Table 4 – Use of land, population & productivity: exploring differences by income
Reg. of *land use* on *pc GDP (ln)* & *Population (ln)*, splitting the estimation by pc GDP level

Dep. var.: land use (% of total) - FE regressions			
	1820-2018 (1)	1820-1960 (2)	1960-2018 (3)
GDP pc (ln) ***x*** [average per capita GDP level]			
High	-0.95***	-0.85***	-0.35*
	(0.274)	(0.278)	(0.173)
Middle	-0.62***	0.097	-0.14
	(0.219)	(0.270)	(0.109)
Low	0.272**	0.144**	0.265*
	(0.112)	(0.065)	(0.144)
Population (ln) ***x*** [average per capita GDP level]			
High	2.470***	2.199***	0.151
	(0.668)	(0.573)	(0.786)
Middle	1.883***	0.710	0.887**
	(0.646)	(0.765)	(0.411)
Low	-0.26**	-0.09	-0.48
	(0.103)	(0.076)	(0.330)
Obs.	477	321	180
Regions	26	24	26
R2 (within)	0.65	0.58	0.44

Notes: Regressions include region and year fixed effects. Robust standard errors in parenthesis. *, ** and *** indicate significance at 10, 5 an 1%, respectively.

One rather indisputable interaction is that higher per capita income is associated with higher consumption of goods and services. So, independently of geographic units used, if there is no radical change in consumption patterns at the global level, it will be impossible to prevent irreparable damages to nature (more on this in the next section). It is crucial to remember that the demand for goods and services is the underlying force governing the allocation of resources among the different

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[14] After controlling for other variables such as climate, soil, availability of water, etc.

forms of capital. Business pollute and destroy the environment in response to market signals reflecting consumers´ preferences. To effectively mobilize resources in accordance with natural limitations we need prices that reflect the true scarcity of natural capital. In the presence of market failures and externalities, this requires institutions to intervene to achieve that goal. We need to align market signals and incentives with the protection of the well-being of future generations.

5 Growth pathways under nature´s limits: managing expectations

5.1 Context: the state of economic-environmental modeling

How will the next 80 years look like, in terms of population and living standards growth across the world? This question has direct implications for the impact of human activity on nature´s degradation along several planetary boundaries. However, projection approaches in mainstream economics largely ignore the limits placed by such boundaries in the prospects for future population growth and economic living standards.

An exception is provided by the well-established literature using Integrated Assessment models (see Nordhaus, 2019, and numerous references therein), designed for analyzing the interrelation between economic activity and damages from climate change. They explicitly model the interaction between economic activity and GHG emissions, quantify the impact of those emissions on climate, and then model the adverse effect of a hotter world on economic activity (the damage function). These models have prominently been used to assess optimal carbon taxes, and usually imply modest effects on long-run activity levels.

More recently, the NGFS published scenarios designed to capture as realistically as possible the economic transformations in the energy and food production sectors that are consistent with achieving different levels of carbon reduction. They do so with a suite of modeling approaches, significantly more detailed –and thus more complex—in their description of these productive sectors. The cost of the added complexity is that most of the scenarios take as exogenous the level of socio-economic pathways –they are an input, rather than a general equilibrium object of the analysis. However, *barring the crossing of tipping points* in the next few decades, this assumption may not be so consequential, given the modest effects on long-term economic activity found in the IAM literature. Of course, there is a wide range of views about the economic effects of climate change damages, and such uncertainty/ambiguity has begun to be formally incorporated into policy analysis (Barnett et al., 2021).

In contrast to climate change modeling, there are very few projection exercises that analyze the interaction of economic activity and biodiversity and ecosystem loss. A notable exception is a recent publication by World Bank (2021). The *Global Earth Economy Model* developed by the authors starts from a Global Trade Analysis Project (GTAP) model, expanded to include detailed Agro-Ecological Zones. Crucially, the authors include a module that allows the valuation of ecosystem services at a high spatial resolution, which is key for assessing the impact in both economic activity and nature of different development scenarios and policy mixes.

Among the key findings, the authors document that a “business as usual” scenario will continue to degrade nature, which will in turn affect future economic possibilities. Several win-win policy measures can thus be combined to improve both economic outcomes and avoid more significant natural degradation. However, even in the best of cases (optimal policy mix), future output will be lower than the “baseline” case: a benchmark scenario where the analysis simply ignores the effects of human activity on nature´s limits. Also, given the complexity of the exercise, the model is dynamically limited, and only used to project consistent socio-economic and ecosystem pathways up to 2030.

As it stands, the state of the modeling literature has not come up with a unified framework to jointly assess socio-economic pathways, their impact on biodiversity and ecosystem degradation, and the feedback effect from such degradation to economic activity and welfare on the medium to long run.

5.2 Future growth accounting: basic orders of magnitude

The growth pathways exercised performed here are not intended to bridge this knowledge gap. They are purely accounting exercises, useful to give orders of magnitude to answer the following questions:

Q1: What are the “baseline” estimates of world GDP expansion?

Future climate change scenarios, such as the ones contained in the IPCC reports, build from assumptions regarding population and per capita growth rates –the so called shared socio-economic pathways (SSPs). More than projections, they are intended to provide a wide range of future socio-economic outcomes from which researchers can then study the associated future emissions, thus providing “book ends” to future climatic conditions (see IPCC, 2021).

With such a caveat in mind, it is nonetheless useful to consider their implications on future world GDP. SSPs 1 and 5 assume relatively fast average per capita growth rates (2.3 and 2.9%), with population actually decreasing (average annual growth rates of -0.17 and -0.08%, respectively).[15] At the other extreme, SSP 3 assumes a low growth rate for per capita GDP but a high one for population (annual averages of 0.66% and 0.6%, respectively), whereas SSPs 2 and 4 lie in between –with faster increase in living standards and lower population growth than SSP 3. Once again, while the assumed per capita GDP and population *growth rates* might not sound striking, their implication for total world GDP levels at century`s end are. These are reproduced in Figure 11: GDP towards 2100 will lie between 2.7 and 9.5 times 2021`s level, or between 1,770 and 6,200 times world GDP in AD 1.

Q2: How large must efficiency gains –reduction of “natural capital intensity” in GDP-- be in order to achieve growth outcomes similar to the baseline scenario, but under manageable impact on biodiversity and ecosystem services?

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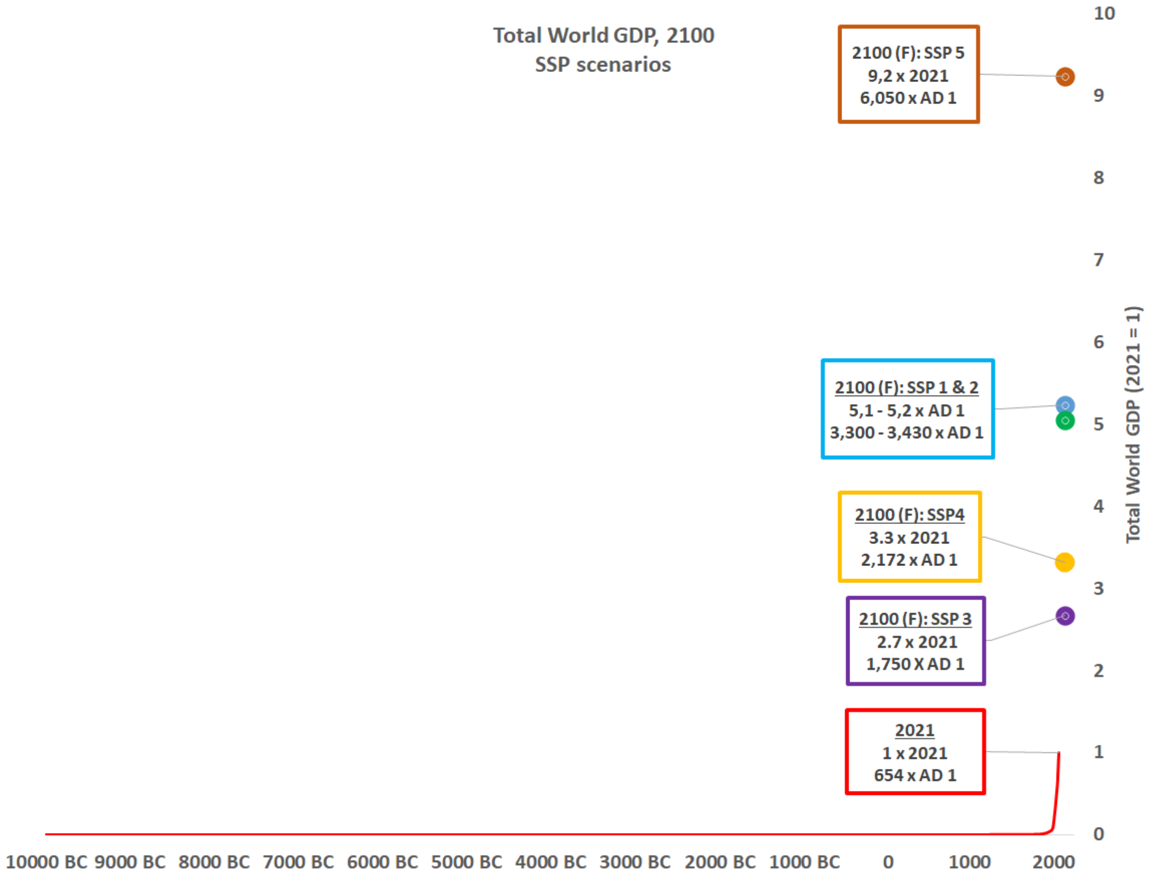
[15] Here we use a value of 7.872 million people in 2021, which is a 1% higher global population in said year with respect to the UN`s population estimate in 2020.

Figure 11: GDP under baseline SSP scenarios (normalized to AD 1 = 1



Source: own calculations, using Hyde project, Picketty (2012), and SSP projections for population and per capita levels from 2021-2100 (see © SSP Public Database (Version 2.0) https://tntcat.iiasa.ac.at/SspDb).

A robust answer to this question would require a full-fledged model incorporating two-way feedback between socio-economic dynamics and ecosystem conditions—a field still in its infancy, as discussed above. To provide (very) rough orders of magnitude, we instead apply some insights from the approach taken by the ecological footprint project. As Figure 3 shows, the per capita ecological footprint at a world-wide level has seen no clear trends since 1970, whereas per capita biocapacity has declined steadily, as overall biocapacity growth (annual average since 1970 = 0.4%) has consistently lagged population growth. We then ask: assuming a constant per capita footprint throughout the remainder of the 21st century, how large would the overshoot become in 2100? How fast must biocapacity grow, on average, to converge towards a sustainable extraction of resources (cero overshoot)? A tentative answer is provided in Table 6. Here, we operate under the stark assumption that all that matters for the ecological footprint (demand) is population size –an assumption partly motivated be the evidence of the preceding section. The table shows that, irrespective of the scenario chosen for comparison, biocapacity must grow consistently faster than its estimated rate since 1970. For SSPs with low population, naturally, the required increase in the growth rate is more modest (eg., 40% higher in SSP 1), while it becomes extremely large –more than three-fold—under the high population growth scenario of SSP3.

Table 6: Ecological footprint and biocapacity under SSP (population) scenarios

2100	Population (M)	Ecological Footprint[1] (M Ha)	Biocapacity[2] (M Ha)	Overshoot (% biocapacity)	Required Biocapacity Growth[3] (%)	Required/Avg. Growth (ratio)
SSP1	6.880	19.074	16.948	13	0,57	**1,4**
SSP2	8.998	24.946	16.948	47	0,91	**2,2**
SSP3	12.625	35.002	16.948	107	1,34	**3,3**
SSP4	9.266	25.690	16.948	52	0,95	**2,3**
SSP5	7.362	20.412	16.948	20	0,66	**1,6**

Notes: (1) The ecological footprint projection assumes a constant per capita value of 2.8 global hectares per person (its 2017 value), given no clear trends in per capita footprint since 1970. (2) Projected biocapacity assumes a constant rate of growth of 0.4% per annum (its average since 2017). (3) The required growth rate in biocapacity is the average annual growth rate that equates it to the ecological footprint in year 2100 under each scenario.

There are two reasons suggesting that these figures are the lowest bound for natural capital efficiency growth, if we want to revert the damage already done. First, the global footprint approach mentioned has some important limitations, such as overstating ecosystem conditions and the assumption of no adverse ecological effects from biocapacity growth (eg., nutrient runoff from over-fertilization). Second, the assumption that per capita GDP growth does not have in impact on the ecological footprint is extremely optimistic, given the relationship between per capita income and consumption.

Even so, if we assume these figures to be correct, they imply a sobering reality: socio-economic outcomes which give rise to the SSP scenarios, which at the same time halt the highly concerning trend of nature´s degradation, look rather unlikely. Or to put it differently, sustainable development under these scenarios is as likely to materialize as our chances of doubling or trebling the current growth rate of natural capital efficiency. If this process –very little understood and hardly documented empirically in economics—is at all comparable to the discussion of TFP in the literature of *growth accounting*, the reader might correctly anticipate that such odds don`t look good.

Q3: What growth scenarios are feasible, in order to avoid further damage to biodiversity and ecosystem services, under moderate increases in our natural efficiency factor?

This is, of course, the most relevant but also the hardest question to address. Answering it will require extending the state of economic-nature modeling, so that the socio-economic scenarios are not used merely as inputs for assessing their environmental consequences (as SSP are), but rather derived in general equilibrium from the limits placed by nature, under reasonable projections about our ability to limit the nature-intensity of our production processes.

The previous discussion closely follows the argument raised in the Dasgupta Review (Dasgupta, 2021): the impact inequality –the gap between the ecological footprint and biocapacity—will imply dire tradeoffs for humanity, in the sense that either population growth or per capita consumption (and probably both) need to significantly moderate, even contract, from current levels, even if we make great strides in the technological front. As Dasgupta puts it: “There are, however, limits to the extent our global demand can be reduced by being more efficient in our consumption of goods and services (…). Which is why our crude estimates say we must also invest in Nature and attend to two problems that are rarely addressed in the economics of growth and climate change: finding ways *to reduce global per capita consumption* (the required redistribution measures would be enormous) and *hastening the demographic transition* in countries and regions where larger families are the norm” (emphasis added).

The previous results are calculations at a very aggregated level, but in order to make efficient use of the available resources we should look into the differences, both in the initial stocks of Natural Capital, as well as levels of per capita income and the demographic situation for different regions and countries. We cannot do detailed scenarios with these levels of disaggregation at this moment, but at least we can hint to some directions for future work.

One priority would be to identify countries that are rich in biodiversity and are in the early stages of the demographic transition, since these are the places under greater danger of massive losses of the remaining natural capital. Almost all these countries are either poor, or in what is usually characterized as lower middle income. They comprise a large fraction of the global population and are concentrated in central and southern Africa as well as southern and eastern Asia, as well as part of South and Central America. Since there is a well stablished relationship between fertility rates and economic development, the above-mentioned results suggest that investing in human and artificial capital will be beneficial for speeding up the demographic transition, while at the same time increasing the productivity of natural capital.

Since most of these people live in or near the tropics, they are very vulnerable to increases in global temperatures and extreme weather events, so for them a quick transition to clean energies and a priority for investment for adaptation to climate change should be a critical component in their development strategies.

Unfortunately, most of these countries are also in the category of high financial risk countries, so they face major challenges to attract the much-needed amounts of Foreign Direct Investments, unless some form of political-economic risk insurance is developed. This represents a significant challenge for the global financial system, and as such warrants a closer look by the NGFS.

6 Conclusions

Growth in population and living standards have been truly outstanding in the last 200 years. But such growth has destroyed nature at an equally staggering speed. The evidence is both undeniable and rather unnoticed by mainstream economics.

A key difference between biodiversity loss and environmental degradation with respect to the *Climate Change problem* is that we use nature not only to provide energy. Indeed, nature is embedded in almost everything we produce, which implies that breaking away from her is much harder than transforming the energy matrix that supports human consumption.

That said, enhancing our natural efficiency factor is possible, and it will be a necessary condition for avoiding further degradation in nature for any possible SSP going forward. Just as carbon emissions are the crux of the climate change problem, unsustainable land use change is the principal driver of biodiversity loss, pointing to significant gains to be made by either changing diets or improving the efficiency in which we grow our food sources. However, for this to happen, the costs to nature´s integrity of our food must be reflected in the market prices we pay.

The evidence also suggests that, given the primordial role of population growth in the degradation of the environment, speeding up of the demographic transition should take a prominent place in any strategy to achieve sustainable development at the global level. Those countries and territories rich in biodiversity, but poor and in the early stages of the demographic transition, will be critical for the preservation of natural capital, and the only way to succeed will be by accelerating economic growth in an efficient way, both in terms of the use of natural capital as well as expanding human and artificial capital.

All in all, it seems unlikely that technological progress by itself will be enough. We will probably need to start adjusting our expectations about future consumption –which has momentous implications for distributional issues—as well as our fertility choices.

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Annex: Data sources and transformations

Dataset for land use regressions:

The dataset incorporates variables from different databases including Hyde 3.2, the World Bank Development Indicators, Maddison Project Database and the UN population Prospects. It also includes 26 countries/regions in the analysis, based on the Hyde 3.2 structure and definition of territories.

Land use, cropland, grazing, irrigation variables are taken from Hyde 3.2 database. The original dataset contains information from -10.000BC to 2020, with different time frames between observations. First every 1.000 years until the year 0, after that the frequency is 100 years until 1700, then every 10 years until 2000 and after that every year until 2020. The dataset includes data for 26 countries/regions.

CO2 emissions, greenhouse emissions, agricultural land, total land, rural population, fertility rate, life expectancy, crop yield and forest land variables are from the World Bank Development Indicators dataset. This dataset includes information for 266 countries and aggregates and starts on 1960 (with different dates depending on variable) through 2020 (also with different dates depending on the variable).

GDP per capita and population are from the Maddison Project Database 2020 (MPD). The MPD contains data from the year 1 to 2018 for a set of 169 countries. To complete the observations through 2020, the UN population variation in these years were used and the same was done with the GDP data from the WB.

To construct the panel, these 4 datasets were merged using the Hyde region classification (26 countries/regions) and starting on the year 1820.

Given the number of missing values for some regions for the variables GDP per capita and population, some modifications from the original dataset where done. For instance, for Russia, considering that the data of GDP pc started on 1960, we use the GDP growth rates from the URSS as a proxy of GDP for the previous years. In the case of South Africa, population figures started on 1950. To include previous information in the analysis, data from the Our World in Data (OWD) population database was used. Specifically taking the population growth rate and attributing it to our original series. The same process was applied in the case of Brazil, Middle East and Korea.

For all regions, data on Total Land for early dates is extrapolated from the first available figure.

Data interpolation

In order to minimize the number of missing observations in the panel, we interpolate or impute some data. Specifically, for Korea, Northern Africa, Western Africa, and Russia in 1910; Turkey and South Africa in 1910 and 1920; Ukraine and Asia-Stan in 1970; India in 1820, 1830, 1840, 1860 and 1880; and Japan in 1880 we impute or interpolate population or GDP data with the nearest available data (in no case the difference is more than 6 years).

Once the panel is defined at the 10-year frequency, GDP and population data on a number of region-dates are interpolated:

- Mexico: 1830-1840, 1860; 1880 (only GDP).
- Rest Central America: 1830-1840, 1860; 1880-1890.
- Brazil: 1830-1840, 1860.
- Northern Africa: 1830-1860, 1880-1900, 1920-1940.
- Western Africa: 1880-1900, 1920-1940.
- Central Europe: 1830-1840, 1860; 1880.
- Turkey: 1830-1860, 1880-1900.
- Middle East: 1830-1840, 1860, 1880-1890, 1910, 1930.
- Korea: 1830-1840, 1860, 1880 (population).
- China +: 1860, 1880.
- Southern Asia: 1830-1840, 1860, 1880.
- Japan: 1830-1840, 1860.
- Rest of South Asia: 1830-1840, 1860.

Additionally, some data with typos or extraordinary changes between periods (without proper explanation) are replaced with interpolated rates. Thus, we replace some abnormal figures in Japan and Korea land use data in 1950; some population figures in South Asia before 1940, and in South America in the XIX century; and GDP data in China + in 1910-1920 and 1940.

Estimations based on the Living Planet Index (LPI):

For the calculus of the Living Planet Index (LPI) we use the data and follow the methodology of the Living Planet Report 2020. Specifically, we estimate the LPI for different groups of countries (e.g. based on their income level, income growth, or population growth) using data from the *Living Planet Database*[16] and the official *rlpi* package[17] (R), that calculates indices using the Living Planet Index methodology introduced by McRae *et al.*(2017)[18].

In order to calculate the indices for subsets of countries different to those defined by McRae *et al.*(2017) and by the LP Report, we make slight modifications to the R-code. First, using the same structure of the code and data, we define three different groups of countries (high, middle, and low)[19] based on:

1. Their per capita GDP (PPP, USD 2010) *level* in 1970 (or the nearest year with available data);
2. Their per capita GDP rate of *growth* between 1970 (or the nearest year with available data) and 2014; and
3. Their average population *growth* rate between 1970 (or the nearest year with available data) and 2014.[20]

Given that the availability of data across countries and regions is highly heterogeneous, we define the thresholds of the ranking variables (respectively, per capita GDP *level* and *growth*, and population growth) to guarantee a minimum number of populations in each subgroup (*high*,

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[16] LPI 2020. Living Planet Index database. 2020. < www.livingplanetindex.org/>. Downloaded on 8 September 2021.

[17] Downloaded from https://github.com/Zoological-Society-of-London/rlpi.

[18] McRae, Louise, Stefanie Deinet, and Robin Freeman. "The diversity-weighted Living Planet Index: controlling for taxonomic bias in a global biodiversity indicator." *PloS one* 12.1 (2017): e0169156.

[19] Methodologically, the groups are defined in the code in the same way as the IPBES regions in the original data.

[20] We use GDP per capita income (PPP, USD 2010) and population data from WDI, complemented with UN data.

middle, and *low*), and thus allow the estimation of the LPI with limited confidence intervals. Table A1 presents the percentile intervals, and number of countries and populations series included in each of the subsets. Table A2 lists the classifications.

Table A1 – Percentile intervals, number of countries and population series included in LPI subsets

			Ranking variable		
			PC GDP 1970	**PC GDP Growth 1970-2014**	**Pop. Growth 1970-2014**
Subset	**Low**	**Perc. Interval**	[0,62)	[0,49)	[0,32)
		Countries	129	95	70
		Terrestrial Pop.	1,417	1,022	1,987
		Total Pop.	3,266	3,039	5,612
	Middle	**Perc. Interval**	[62,84)	[49,60)	[32,50)
		Countries	50	23	39
		Terrestrial Pop.	1,301	2,077	1,363
		Total Pop.	3,285	7,256	5,422
	High	**Perc. Interval**	[84,100]	[60-100]	[50,100]
		Countries	31	88	110
		Terrestrial Pop.	2,108	1,727	1,487
		Total Pop.	8,053	4,306	3,625
	Total	**Countries**	210	206	219
		Terrestrial Pop.	4,826	4,826	4,837
		Total Pop.	14,604	14,601	14,659

We also adjust the weights used to account for the fact that the LPI data do not necessarily represent actual species richness across geographic and taxonomic dimensions. Specifically, for each exercise (depending on the used ranking variable) we update tables 10-13 in McRae *et al.*(2017) based on the composition of each defined subset.

Table A2 – LPI Country Classifications

Country	pc GDP 1970	pc GDP Growth	Pop. Growth	Country	pc GDP 1970	pc GDP Growth	Pop. Growth	Country	pc GDP 1970	pc GDP Growth	Pop. Growth	Country	pc GDP 1970	pc GDP Growth	Pop. Growth
Afghanistan	Low	High	High	Dominica	Low	High	Low	Lebanon	Low	Mid.	High	São Tomé and Principe	Low	Mid.	High
Albania	Low	High	Low	Dominican Republic	Low	High	High	Lesotho	Low	High	Mid.	Saudi Arabia	High	Low	High
Algeria	Low	Low	High	Ecuador	Low	Mid.	High	Liberia	Low	Low	High	Senegal	Low	Low	High
American Samoa	Mid.	Low	Mid.	Egypt, Arab Rep.	Low	High	High	Libya	Mid.	Low	High	Serbia	Low	High	Low
Andorra	High	Low	High	El Salvador	Low	Low	Mid.	Liechtenstein	High		Mid.	Seychelles	Low	High	Mid.
Angola	Low	Low	High	Equatorial Guinea	Low	High	High	Lithuania	Mid.	High	Low	Sierra Leone	Low	Low	High
Antigua and Barbuda	Mid.	High	Low	Eritrea	Low		High	Luxembourg	High	High	Mid.	Singapore	Mid.	High	High
Argentina	Mid.	Low	Mid.	Estonia	Mid.	High	Low	Macao SAR, China	Mid.	High	High	Sint Maarten (Dutch part)			High
Armenia	Low	High	Low	Eswatini	Low	High	High	Madagascar	Low	Low	High	Slovak Republic	Mid.	High	Low
Aruba	Mid.	Mid.	Mid.	Ethiopia	Low	High	High	Malawi	Low	Low	High	Slovenia	Mid.	Mid.	Low
Australia	High	Mid.	Mid.	Faroe Islands	High		Low	Malaysia	Low	High	High	Solomon Islands	Low	Low	High
Austria	High	High	Low	Fiji	Low	Low	Mid.	Maldives	Low	High	High	Somalia			High
Azerbaijan	Low	High	Mid.	Finland	High	High	Low	Mali	Low	Low	High	South Africa	Mid.	Low	High
Bahamas, The	High	Low	High	France	High	Mid.	Low	Malta	Low	High	Low	South Sudan	Low	Low	High
Bahrain	Mid.	Low	High	French Polynesia			High	Marshall Islands	Low	Low	High	Spain	Mid.	Mid.	Low
Bangladesh	Low	Mid.	High	Gabon	Mid.	Low	High	Mauritania	Low	Low	High	Sri Lanka	Low	High	Mid.
Barbados	Mid.	Low	Low	Gambia, The	Low	Low	High	Mauritius	Low	High	Low	St. Kitts and Nevis	Low	High	Low
Belarus	Low	High	Low	Georgia	Low	Low	Low	Mexico	Mid.	Low	High	St. Lucia	Low	High	Mid.
Belgium	High	Mid.	Low	Germany	High	Mid.	Low	Micronesia, Fed. Sts.	Low	Low	Mid.	St. Martin (French part)			High
Belize	Low	High	High	Ghana	Low	Low	High	Moldova	Low	High	Low	St. Vincent and the Grenadine	Low	High	Low
Benin	Low	Low	High	Gibraltar			Low	Monaco	High	Mid.	Mid.	Sudan	Low	High	High
Bermuda	High	Low	Low	Greece	Mid.	Low	Low	Mongolia	Low	High	High	Suriname	Mid.	Low	Low
Bhutan	Low	High	High	Greenland	Mid.	High	Low	Montenegro	Low	Mid.	Low	Sweden	High	Mid.	Low
Bolivia	Low	Low	High	Grenada	Low	High	Low	Morocco	Low	High	Mid.	Switzerland	High	Low	Low
Bosnia and Herzegovin	Low	High	Low	Guam	Mid.	Low	Mid.	Mozambique	Low	High	High	Syrian Arab Republic	Mid.	Low	High
Botswana	Low	High	High	Guatemala	Low	Low	High	Myanmar	Low	High	Mid.	Taiwan, China	Low	High	Low
Brazil	Mid.	High	Mid.	Guinea	Low	Low	High	Namibia	Low	Low	High	Tajikistan	Low	Low	High
British Virgin Islands			High	Guinea-Bissau	Low	Low	High	Nauru	Low	High	Low	Tanzania	Low	High	High
Brunei Darussalam	High	Low	High	Guyana	Low	Low	Low	Nepal	Low	High	High	Thailand	Low	High	Mid.
Bulgaria	Low	High	Low	Haiti	Low	Low	High	Netherlands	High	Mid.	Low	Timor-Leste	Low	Mid.	Mid.
Burkina Faso	Low	High	High	Honduras	Low	Low	High	New Caledonia			High	Togo	Low	Low	High
Burundi	Low	Low	High	Hong Kong SAR, China	Mid.	High	Mid.	New Zealand	Mid.	Low	Mid.	Tonga	Low	High	Low
Cabo Verde	Low	High	Mid.	Hungary	Mid.	Mid.	Low	Nicaragua	Low	Low	High	Trinidad and Tobago	Mid.	High	Low
Cambodia	Low	High	Mid.	Iceland	High	Mid.	Mid.	Niger	Low	Low	High	Tunisia	Low	High	Mid.
Cameroon	Low	Low	High	India	Low	High	High	Nigeria	Low	Low	High	Turkey	Low	High	High
Canada	High	Mid.	Mid.	Indonesia	Low	High	High	North Macedonia	Low	Low	Low	Turkmenistan	Low	High	High
Cayman Islands	High	Low	High	Iran, Islamic Rep	Mid.	Low	High	Northern Mariana Islan	Mid.	Low	High	Turks and Caicos Islands	Mid.		High
Central African Republi	Low	Low	High	Iraq	Low	High	High	Norway	High	High	Low	Tuvalu	Low	Low	Mid.
Chad	Low	Low	High	Ireland	Mid.	High	Low	Oman	Mid.	Low	High	Uganda	Low	High	High
Channel Islands			Low	Isle of Man	Mid.	High	Low	Pakistan	Low	Mid.	High	Ukraine	Low	Low	Low
Chile	Mid.	High	Mid.	Israel	Mid.	Low	High	Palau	Mid.	Low	Low	United Arab Emirates	High	Low	High
China	Low	High	Mid.	Italy	Mid.	Low	Low	Panama	Low	High	High	United Kingdom	High	High	Low
Colombia	Low	High	Mid.	Jamaica	Mid.	Low	Low	Papua New Guinea	Low	Low	High	United States	High	Mid.	Low
Comoros	Low	Low	High	Japan	High	High	Low	Paraguay	Low	High	High	Uruguay	Mid.	High	Low
Congo, Dem. Rep	Low	Low	High	Jordan	Low	Low	High	Peru	Low	Low	High	Uzbekistan	Low	High	High
Congo, Rep.	Low	Low	High	Kazakhstan	Mid.	High	Low	Philippines	Low	Low	High	Vanuatu	Low	Low	High
Costa Rica	Low	High	High	Kenya	Low	Low	High	Poland	Mid.	High	Low	Venezuela, Bolivarian Republi	Mid.	Low	High
Côte d'Ivoire	Low	Low	High	Kiribati	Low	Low	Mid.	Portugal	Mid.	High	Low	Vietnam	Low	High	Mid.
Croatia	Mid.	Mid.	Low	Korea, Dem. People's F	Low	Low	Mid.	Puerto Rico	Mid.	High	Low	Virgin Islands (U.S.)	High	Low	Mid.
Cuba	Low	High	Low	Korea, Rep.	Low	High	Low	Qatar	High	Low	High	West Bank and Gaza	Low	Mid.	High
Curaçao			Low	Kosovo	Low	High	Low	Romania	Mid.	High	Low	Yemen, Rep.	Low	Low	High
Cyprus	Mid.	High	Mid.	Kuwait	High	Low	High	Russian Federation	Mid.	Low	Low	Zambia	Low	Low	High
Czech Republic	Mid.	Low	Low	Kyrgyz Republic	Low	Low	Mid.	Rwanda	Low	Low	High	Zimbabwe	Low	Low	High
Denmark	High	Low	Low	Lao PDR	Low	High	High	Samoa	Low	Low	Low				
Djibouti	Mid.	Low	High	Latvia	Low	High	Low	San Marino	High	Low	Mid.				

<u>Biocapacity and footprint tables:</u>

The Global Footprint Network's Public Data Package, 2021 Edition was used. The dataset provides a cross-sectional dataset for 184 countries and includes the variables Biocapacity, Biocapacity balance and Ecological Footprint, which were used to construct the tables above. To these variables, the latest available data of fertility rate (2019) from the World Bank Development Indicators was incorporated.

The groups included in the analysis where constructed based on:

- Income: based on the World Bank income categorization (High income, low income, upper middle income and lower middle income)
- Fertility Rate: based on the 2019 fertility rate reported by the World Bank Development indicators. High fertility rate includes countries with fertility rate above 3, middle fertility rate includes countries with fertility rate above 2 and equal or below 3. Low fertility rate includes countries with fertility rate equal or below 2.
- Biocapacity pc: Based on the variable Total biocapacity reported in the Global Footprint Network database. High biocapacity includes the third of the countries in the sample that has the highest biocapacity indicator, middle biocapacity includes the third of the sample in the middle of the distribution and low biocapacity includes the third of countries in the bottom of the distribution of this variable.
- Biocapacity balance: Based on the Biocapacity (Deficit) or Reserve reported in the Global Footprint Network database. Positive balance includes countries with a positive number in this variable. Negative balance includes countries with a negative number in this variable.

banco
central
Chile