Prologue: A Planet in Peril

Homo sapiens became established on planet Earth at least 200,000 years ago, and perhaps well before.[1] It took until the year 1800 or thereabouts for the human population to reach one billion. A second billion was added in only 124 years, with successive billions added at intervals of thirty-three, fifteen, twelve, twelve, twelve, and thirteen years,[2] surpassing eight billion in total in 2022. Most of the one billion humans living at the beginning of the 19th century had a very low material standard of living. Billions still do today, but for billions more living standards have increased by leaps and bounds, faster even than the increase in population. Meanwhile, the planet has not increased in size at all. Essentially the same amount of sunlight is intercepted by the Earth each year, providing life-giving energy which, through photosynthesis, supports virtually all life on Earth, including humans.

The combination of billions of people and the gargantuan quantities of materials we use to enrich our lives is imposing a burden on the Earth's ecological systems that cannot be sustained. It is in this sense that the planet is in peril. Earth itself is not in danger. It will be here long after humans have come and gone, but we are imperiling it as a home for our species and that of many others not because we want to, but because so far have been unable to stop depleting and degrading the capacity of the planet to sustain us all.

There is overwhelming evidence that human impacts on the zone of life on Earth—the biosphere—have surpassed sustainable levels in several crucial respects. We are in Earth overshoot. Of course, there are huge differences in how much different people and nations have contributed to overshoot and its effects, both historically and now. There is also a disturbing disconnect between those primarily responsible for overshoot and those most vulnerable to its consequences, and the situation is getting worse.

None of this is to deny the remarkable improvements in many aspects of people's lives experienced by the most recent generations. Material living standards have reached unprecedented levels for literally billions of people, though billions more still languish in abject poverty, still hoping for a better future for themselves and their children. Many believe that the technological advances, fuelled by cheap fossil fuel energy, that led from the steam age to the widespread, innovative uses of electricity, computerization, and remarkable achievements in the life sciences, will overcome any and all obstacles. But these advances have come at a cost. Great damage has been done and continues to be done to our Earthly home, and to the other species with which we share it. There have been occasional gains such as the reduction in acid rain in the 1980s and 90s in the USA and Canada, and the partial recovery of the stratospheric ozone layer, though not without strong corporate opposition and government hesitancy. However, despite the seemingly endless succession of international commitments and well-intended plans for reducing greenhouse gas emissions, protecting biodiversity and endangered species, and addressing numerous other aspects of overshoot, we are figuratively and literally losing ground. What is to be done?

There is no simple solution to such an entanglement of complex problems. But there are ways of thinking and acting that can help. Some of these come from economics, which has a rich stock of ideas and insights developed over the past two centuries as well as from more contemporary sources, from which we can draw. The aim of this book is to bring to a wide audience the fruits of several decades of research that describes and explains humanity's predicament and points towards a more attractive future than if current trends continue. The emphasis is on economics because the economic activities of production and consumption are so intimately related to overshoot, and as an economist, it is what I know best. But just as fire, police, and ambulance are routinely called to emergencies, we will need all the best ideas that humanity has to offer, not just from economics, to find an escape from overshoot. And the escape plan, to the extent that one can be synthesized by a single author, is intended primarily for high-income countries which, as a matter of justice and efficacy, should take the lead in reducing their impacts on planet Earth.

The book begins with an account of overshoot drawing on peer-reviewed and government sources. It tells a very disturbing story. Since we are concerned about the future, evidence for overshoot is followed by a discussion of the difficulty—impossibility even—of predicting the future. But prediction as normally understood is not the objective of this book. Any prediction of the future is contingent on what we decide and do today. This book is intended to help us make better decisions, informed by careful, systematic consideration of their possible and probable consequences. This is our best chance of finding an escape from overshoot and a better future for all.

The immediate cause of overshoot is the combination of the massive increase in the number of people and what we produce made possible by the rapid and grossly uneven experience of economic growth of the past two hundred years. In many parts of the world, economic growth has become virtually synonymous with the idea of progress. This did not happen without critical commentary, including some from influential economists, which was, however, largely ignored. In this book we will hear their voices once again and maybe this time we will listen more closely.

It is common in academic disciplines for members to coalesce around a few key ideas or principles, giving rise to different schools of thought. In mainstream, neo-classical economics, environmental problems have generally been seen as a problem in *microeconomics*—the economics of individuals and markets. The same is true of issues relating to the depletion of natural resources. From this comes useful insights about the failure of markets—where they exist at all—to register environmental damages and excessive rates of resource use. Policy proposals that flow from this microeconomic analysis emphasize the use of various types of emission charges such as a carbon tax, grounded in the belief that if we "get the prices right" markets will automatically yield the right quantities of polluting emissions and rates of resource utilization. An alternative approach arising from this neo-classical perspective, is to establish markets where none exist—say of permits to emit pollutants or to catch fish—and allow the permits to be traded with their price determined by demand and supply.

These microeconomic approaches to environmental and resource issues have a place in the menu of policy options, but they fall short of what is required to escape from overshoot. The reason for this is that emission charges and tradable permits are designed to make markets more efficient—to assign inputs of all kinds to their best uses. But overshoot is less a problem of efficiency in this sense than one of *scale*, of the physical size of the economy in relation to the physical size of the Earth and its ecological systems on which economies depend. Overshoot is first and foremost a problem of *macroeconomics*, of the whole economy. So, for this reason, most of the economics used to address overshoot in this book comes from macroeconomics, with its scope expanded to encompass this essential dependency of economies on the environment.

The predominant economic system in today's world is some form of capitalism and so we will compare, at a macro level, how several of these schools of thought analyze capitalism. We will see that they differ greatly in the different features of capitalism that they highlight, suggesting different obstacles to and possibilities for an escape from overshoot, though this was not their originators' main concern. However, it is the concern of several current proposals for more sustainable economies, such as steady-state economics, doughnut economics, and degrowth, from which we can draw elements of an escape plan. These proposals all draw on ecological economics, a new branch of economics founded on the understanding that economies are sub-systems of the biosphere, entirely dependent on Earthly supplies of materials (including fossil fuels), air, land, and water.[3] Ecological economics recognizes that inputs to the economy are transformed and degraded through production and consumption, which, when excessive, upset the balance between humans and the rest of nature.

One way of delineating future possibilities is to draw a conceptual map of the terrain based on key topics. The map of the future sketched in this book consists of points of interest such as consumption, technology, work, and equity but, like an ordinary printed map, it does not prescribe a particular route. Some routes—green growth and the circular economy for example—are promoted based on the questionable belief that economic growth can be permanently decoupled from resources and wastes. An alternative is to look forward to a post-growth future and the various forms that it might take, starting in high-income economies. Simulation of various scenarios are featured, culminating in a list of what needs to change to get the future we choose, rather than the one that ignorance, vested interests, and complacency will otherwise oblige us and those who follow to take. Examples of positive change are not hard to find, and we look at a few. Their very existence gives grounds for hope. The challenge is to ramp them up quickly to a level sufficient to escape from overshoot, and this book helps point the way.

Credit: NASA.

FIGURE 1.1.
The Earth from space 1972.

1

OVERSHOOT: A LOOK AT THE EVIDENCE

The first photographs of Earth from space were taken in 1946 from a sub-orbital V-2 rocket and only showed a small section of the planet, just enough to reveal its curvature. In the 1960s, when the space race between the USA and the USSR was in full swing, people saw for the very first time the entire planet in color. It was an astonishing sight. Seeing the Earth, bounded on all sides by space, brought home the fact that we live on a finite planet. Life on Earth is totally dependent on the materials carried on board spaceship Earth and the influx of solar energy that makes life possible, just like the capsules that took animals then humans into space and sent back mind-bending images.

Economist Henry George is thought to be the first person to liken Earth to a spaceship. Nearly 150 years ago he described the Earth as "a well-provisioned ship, this on which we sail through space."[4] In 1965, the year he died, Adlai Stevenson, U.S. Ambassador to the United Nations said, "We travel together, passengers on a little spaceship, dependent on its vulnerable reserves of air and soil; all committed for our safety to its security and peace; preserved from annihilation only by the care, the work, and, I will say, the love we give our fragile craft. We cannot maintain it half fortunate, half miserable, half confident, half despairing, half slave to the ancient enemies of man, half free in a liberation of resources undreamed of until this day. No craft, no crew can travel safely with such vast contradictions. On their resolution depends the survival of us all."[5] It was true then and is even truer today.

The need to resolve the contradictions that Stevenson spoke of is more pressing than ever.

In the more than half a century since Stevenson spoke those words, world population has increased by over 230 percent and world GDP, which measures the market value of final goods and services, by over 960 percent. The size of planet Earth remains unchanged while the on-board stocks of easily accessible materials have diminished, lands and water have been degraded, species extinction has accelerated while many more have become threatened, and the climate is heating up. Advances in science and technology have also been amazing. Equip-

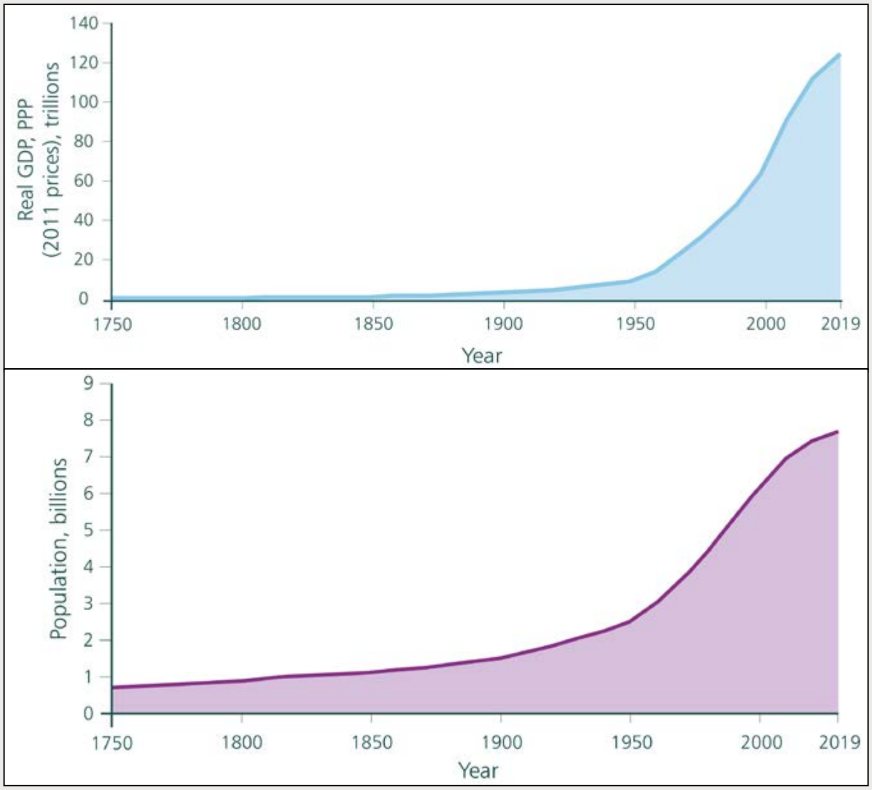


FIGURE 1.2. Global population and economic output 1750 to 2019.

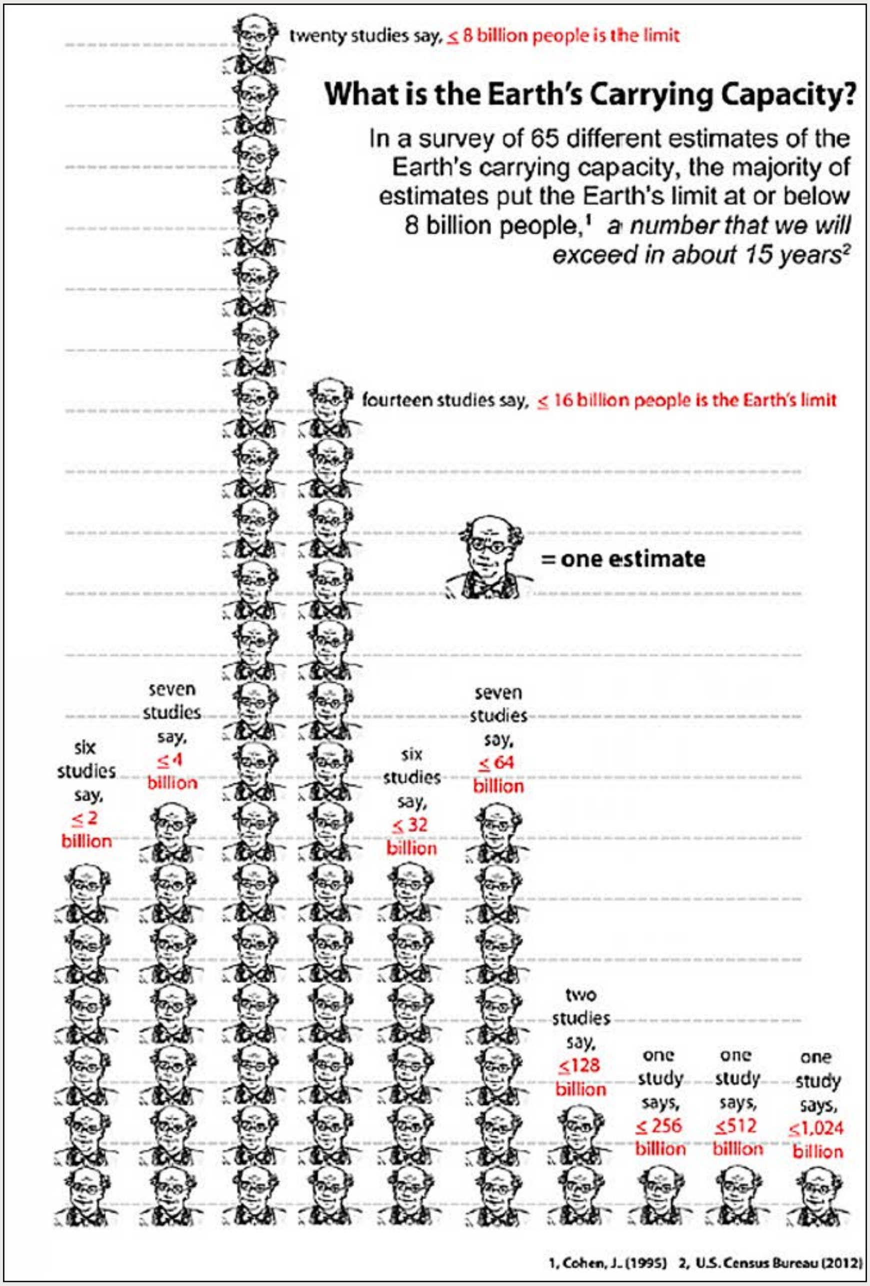
Credit: P. Dasgupta, (2021), The Economics of Biodiversity: The Dasgupta Review. Abridged Version. (London: H.M. Treasury).

ment has become more efficient, and new technologies such as nuclear power, genetic modification, and smart phones have been invented. The list is a long one. Innovation on all fronts continues such that many people pin their hopes for the future on developments in science and technology. But will it be enough to escape from overshoot?

Overshoot

Let's look a little deeper into the meaning of overshoot. When any organism exceeds the capacity of its environment to sustain it, it is in overshoot. This can be true of bacteria growing in a Petri dish with a limited food supply. It can also be true of humans when our use of what nature provides is greater than nature's capacity to regenerate. The accumulation of greenhouse gases in the atmosphere that could be irreversibly changing the climate means we are in overshoot. If more fish are caught than are reproduced by the remaining stock, we have overshot. Overshoot can happen to ecosystems at all scales from a single pond to the entire planet and to any species. Humans are no exception.

When a population exceeds the carrying capacity of its environment a combination of three things happens: (1) the death rate in the population increases, (2) the birth rate may change positively but usually negatively, and (3) habitat productivity may be degraded which reduces the habitat's carrying capacity. Many outcomes are possible. One is population collapse. Another is a combination of a reduction in the population and consumption levels until a smaller population consuming less is once again living within the depleted carrying capacity. Yet another possibility specific to humans is that carrying capacity can be and has been increased through massive growth in materials extraction, extensive land transformation, and increased access to energy, all made possible by developments in science and technology, but too often at the expense of disadvantaged communities and other species. This ability of humans to change carrying capacity to their benefit is a major reason why there is such a wide range of estimates of the Earth's human carrying capacity. A survey of 65 estimates in 2012



Credit: B. Pengra, One Planet, How Many People? A Review of Earth's Carrying Capacity, UNEP 2012.

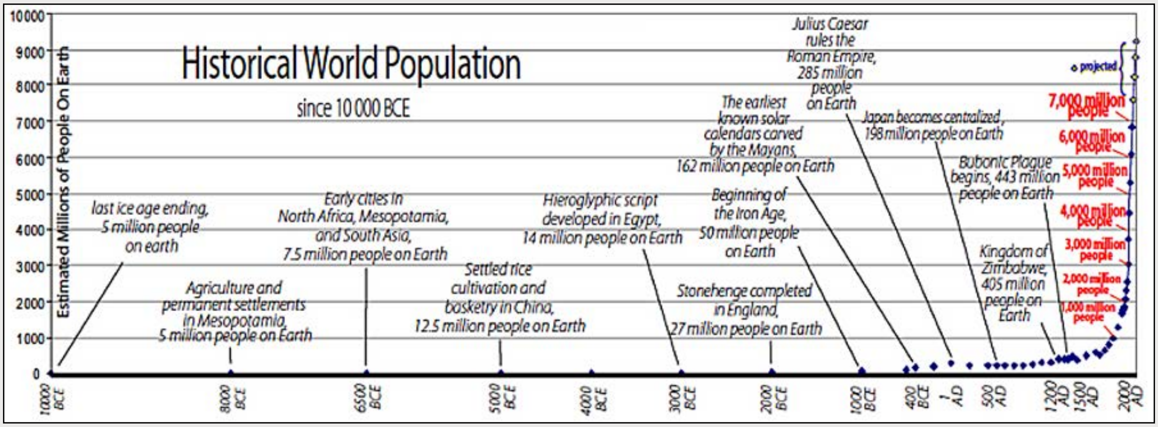
FIGURE 1.3. Estimates of Earth's carrying capacity.

showed most estimates at or below 8 billion, which is about where we are now, and rising.

To put these estimates of human carrying capacity in historical context, it is useful to look at population growth further back than the start of industrialization, all the way to the end of the last ice age around 10,000 BCE. At that time about five million people are estimated to have been living on Earth, which is about the same as the number living today in the Washington metropolitan area in the USA, making it only the 77th largest city in the world, less than one seventh the size of Tokyo. It took some twelve thousand years for the human population to reach one billion around the year 1800, but only 220 years since then to add another seven billion. The rate of population growth has begun to slow, but we are still adding a billion more people every 14 years.

A population cannot remain in overshoot indefinitely. The population and the carrying capacity of its environment eventually must rebalance, unless, as some technological optimists believe, human ingenuity can keep expanding carrying capacity faster than growth in the human population. But even then, who would want to live in an increasingly crowded planet, unless those holding this belief that technology will save us are counting on the rapid colonization of space?

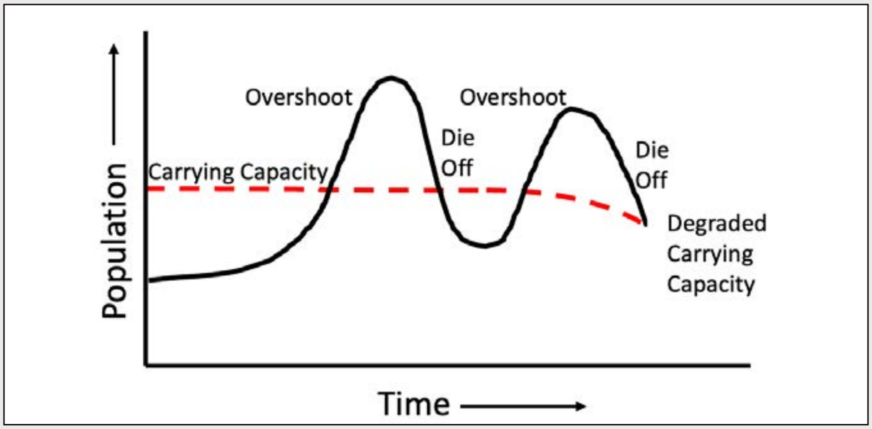
FIGURE 1.4. Historical world population since 10,000 BCE.



Credit: B. Pengra, One Planet, How Many People? A Review of Earth's Carrying Capacity, UNEP 2012.

There are many paths that can bring population back into balance with carrying capacity. One possibility is that overshoot leads to increased deaths, reducing the population below carrying capacity, and possibly reducing carrying capacity as well. If this leads to increased births the system may return to overshoot and if it continues with diminishing fluctuations and declining carrying capacity a new balance can be reached.

Other possibilities are that overshoot leads to a relatively smooth process of adjustment, such as the one described in Chapter Seven, or to chaotic and catastrophic changes from which recovery is difficult, painful, even impossible, and these changes can happen locally, regionally, and globally, particularly where humans are involved. A lack of food, for example, which used to be a local phenomenon for isolated groups of hunter gatherers, and later for small, largely separate communities, has, with the increase in human mobility and numbers of people, become regional and potentially global. At the same time, increasing connections among humans, especially through the international movement of goods and much better communications, has made it possible for many nations to import food from others to fill



Credit: Based on DGRNews Service 15 April 2020.

FIGURE 1.5. Exponential growth of population with overshoot.

gaps in what they produce themselves, providing they have something to export and can pay. Otherwise, they must depend on foreign aid which is not always forthcoming. But global integration has its downsides too. The rapid spread of COVID-19 around the world, in its original and mutating varieties, is the most obvious recent example of what in earlier times might have been contained locally, simply because of a smaller population living with less human interaction.

In the early 1990s Professor William Rees and his doctoral student Mathis Wackernagel turned carrying capacity on its head. Instead of asking what size of population can be supported by a given carrying capacity, they asked how much of the regenerative capacity of the biosphere—its biocapacity—was being used to support human activities.[6] They called this the ecological footprint. To measure the ecological footprint of individuals and groups, Rees and Wackernagel converted different types of land to a common spatial unit—global hectares (gha)—taking account of differences in the biological productivity of different land uses (e.g., forests compared to pasture) and in yields within the same land use (e.g., tropical forests compared to boreal forests). They used global hectares to measure the biocapacity of the planet (and regions within it) and the demand placed on biocapacity for materials and the absorption of excess emissions of carbon dioxide globally, regionally, and individually. This demand is measured by the ecological footprint. Biocapacity and ecological footprints have been estimated for over two hundred countries going back to 1961, based on databases from the United Nations and UN-affiliated organizations and from peer-reviewed science publications and reports.[7]

The data reveal a startling fact. Around 1970 the global ecological footprint began to exceed global biocapacity, marking the beginning of global overshoot. What humans were demanding from the biosphere had begun to exceed what the biosphere could provide through its capacity to regenerate. By 2018 the global ecological footprint was exceeding global biocapacity by 75 percent. In other words, the human population in 2018 required the biocapacity of 1.75 Earths to sustain it, but with only one Earth available something must give. Individual

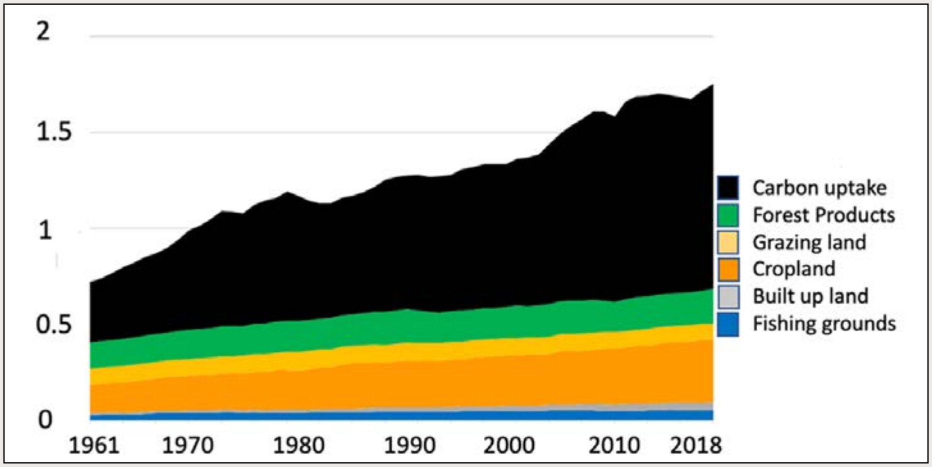


FIGURE 1.6. World ecological footprint divided by biocapacity.

Credit: York University Ecological Footprint Initiative & Global Footprint Network. National Footprint and Biocapacity Accounts, 2022 edition, https://www.footprintnetwork.org/footprint-initiative-york/

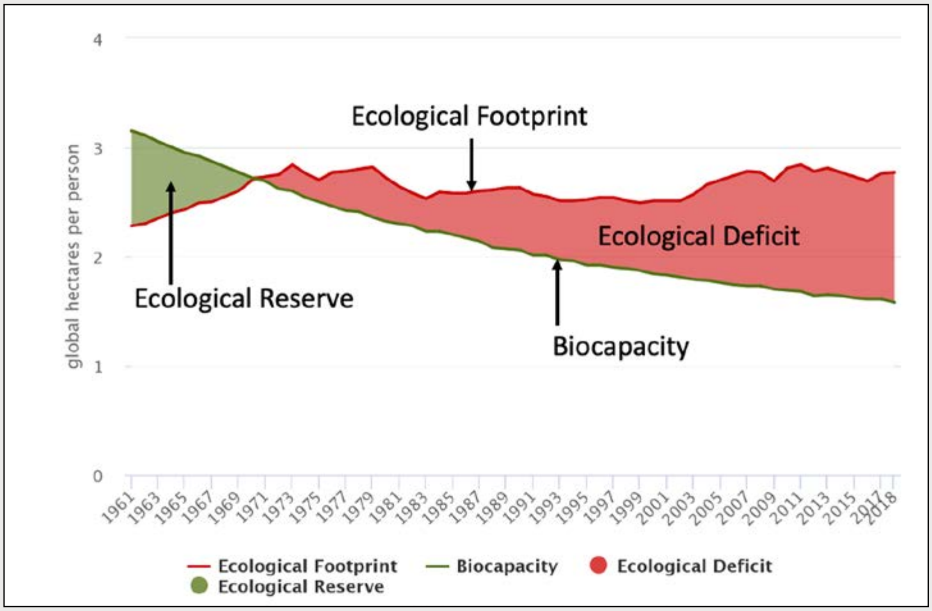


FIGURE 1.7. World ecological footprint and biocapacity per capita.

Credit: York University Ecological Footprint Initiative & Global Footprint Network. National Footprint and Biocapacity Accounts, 2022 edition.

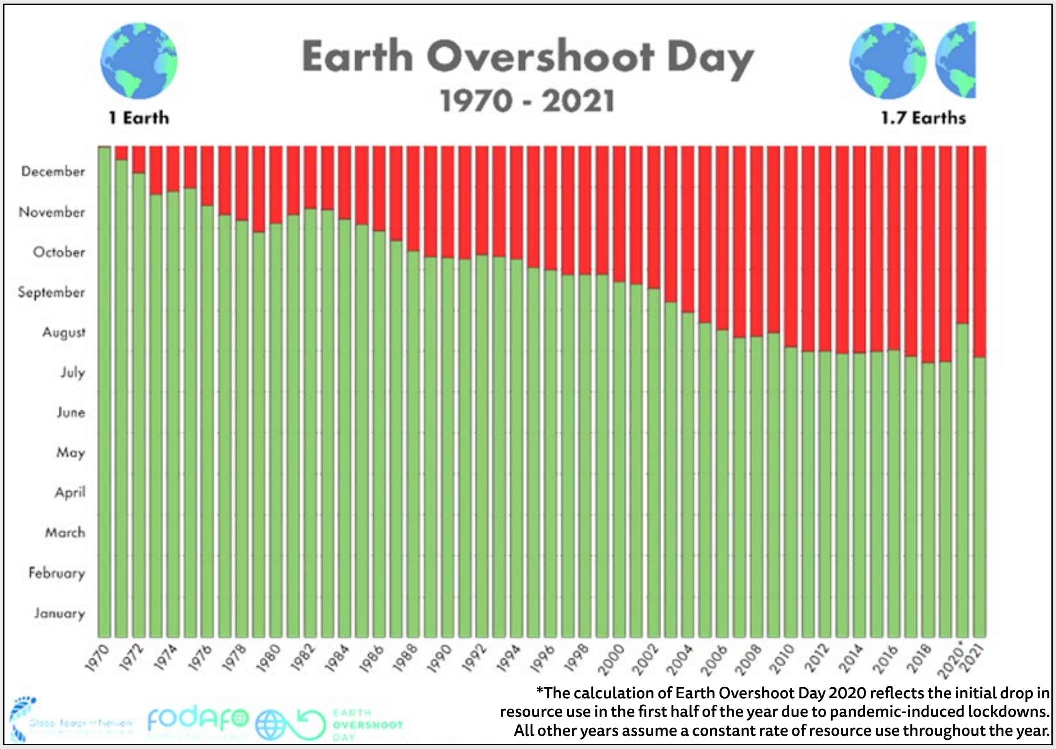
nations with an ecological footprint greater than their domestic biocapacity can make up the difference through imports, but this is not an option for the entire planet. Temporarily, an ecological deficit can be maintained by further depleting stocks of timber, fish, and soil nutrients but this reduces biocapacity and sooner or later the demands being placed on the biosphere can no longer be met. Biocapacity can also be increased through human actions such as irrigation and intensive management to increase agricultural output, or the more ambitious approach to food production of agroecology in which ecological concepts and principles are applied to farming.[8] Such increases as have happened in the past are reflected in the National Footprint and Biocapacity Accounts which records the ecological footprint and biocapacity of nations and the world for past years.

The data can also be displayed in terms of the average ecological footprint and biocapacity per capita, with the decline in biocapacity per capita being due largely to the increasing population.

Another way of thinking about overshoot is to recognize that each year global biocapacity—the regenerative capacity of the planet—is fully used before the year is over. The day on which this happens is Earth Overshoot Day. From 1970 to 2019 Earth Overshoot Day arrived earlier each year. In 2020 the downturn in economic activity caused by the COVID-19 pandemic postponed Earth Overshoot Day by about three weeks but it returned to its pre-Covid level in 2021 as the economy picked up. This connection between economic output and human impacts on the biosphere is a theme we will return to many times.

As noted, the ecological footprint and biocapacity are estimated for countries and for smaller regions as well. Some municipalities such as Athens, Cairo, and Barcelona have used estimates of their ecological footprints for planning purposes.[9] Many people have estimated their own individual ecological footprint using an online calculator.[10] There is a tremendous difference in individual ecological footprints at all levels. In 2018 the average ecological footprint worldwide was 2.8 gha per capita, found simply by dividing the global ecological footprint by the global population. This compares with the average ecological

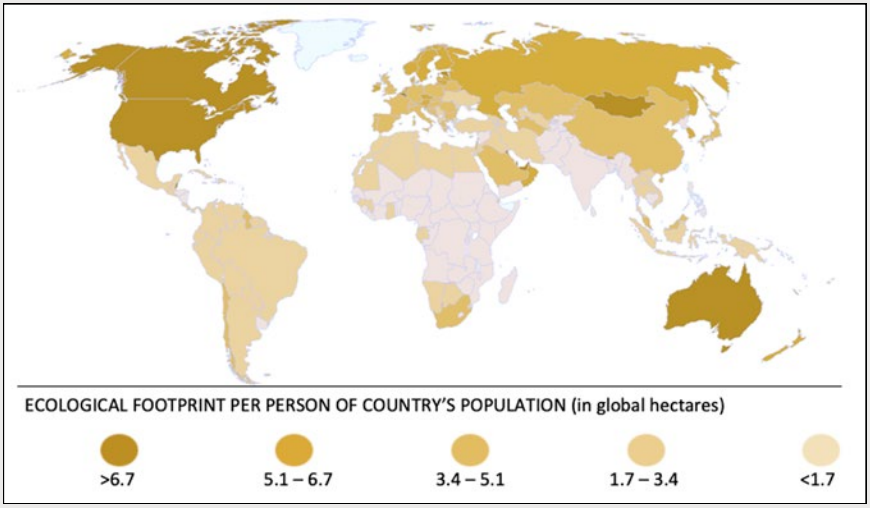
FIGURE 1.8. World Overshoot Day 1970–2021.



Credit: York University Ecological Footprint Initiative & Global Footprint Network. National Footprint and Biocapacity Accounts, 2022 edition.

footprint of someone living in the United States of 8.1 gha, in China 3.8 gha, 0.9 gha in Bangladesh, and a global average of per capita bio-capacity of 1.6 gha. There are also very substantial differences in the ecological footprints of people living within the same country, reflecting the large differences in incomes and consumption levels and in patterns of consumption. For example, a family living in an apartment, relying on walking, cycling and public transport, eating a vegetarian or vegan diet, and vacationing locally, has a much smaller ecological footprint than a family of similar size living in a large, detached house, with two or three cars, eating meat frequently, and enjoying trips to far-off places. This does not mean that a high living standard cannot be maintained with a much-reduced ecological footprint. For example, in 2018 the average German had an ecological footprint about 40 percent less than the average person in the USA while enjoying similar living standards. The ecological footprints of the average person in France and the UK were lower still.

These differences among the ecological footprints of people living in high-income countries pale in comparison to the differences in average ecological footprints of people in countries grouped by income levels. Using the World Bank's classification of countries—high-income, upper-middle income, lower-middle income, and low-income—in 2020 15 percent of the global population lived in high-income countries, yet because of their high levels of consumption, they accounted for 33 percent of the global ecological footprint. Meanwhile, with 35 percent of global population, upper middle-income countries accounted for 43 percent of the global ecological footprint. The 37 percent of global population living in lower middle-income countries accounted for only 19 percent of the global ecological footprint, and



Credit: York University Ecological Footprint Initiative & Global Footprint Network. National Ecological Footprint and Biocapacity Accounts, 2022 Edition. Produced for the Footprint Data Foundation.

FIGURE 1.9. Mapping the Ecological Footprint 2020.

the 12 percent of the global population living in low-income countries accounted for just five percent.

Changes in the ecological footprint of nations or regions over time can be attributed to a combination of changes in population and average per capita footprint. The ecological footprint of a country or

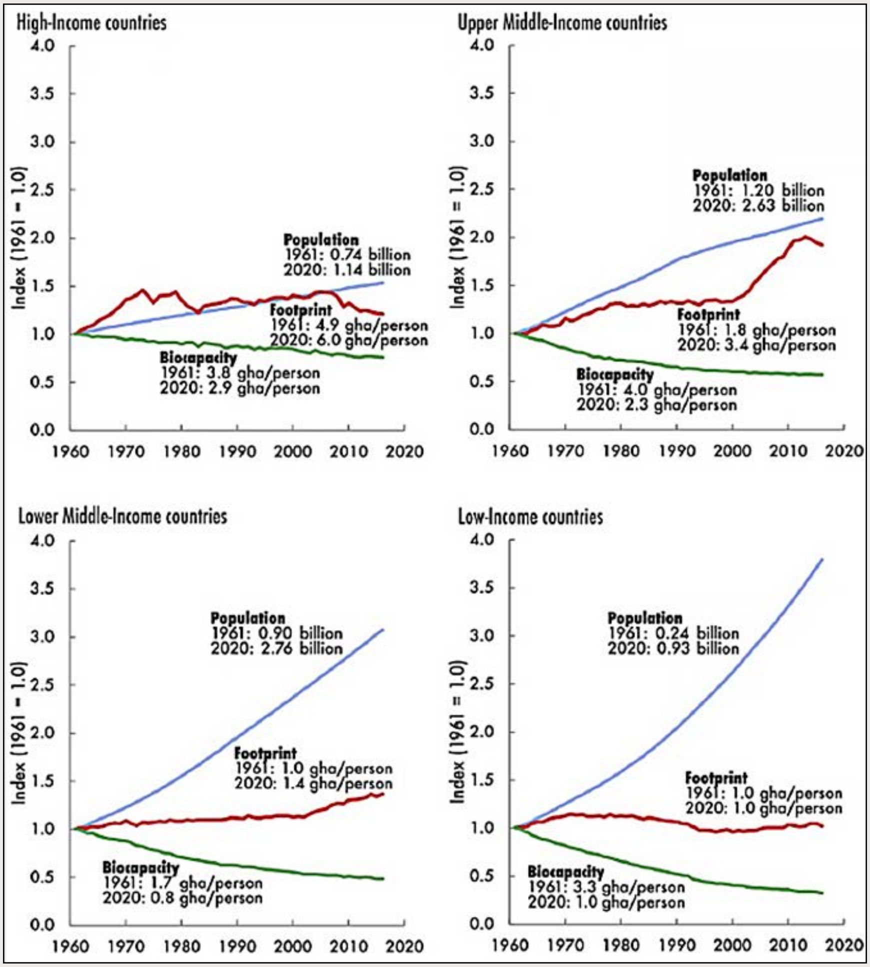


FIGURE 1.10.
Ecological footprint, biocapacity and population for high-income, upper-middle income, lower-middle income and low-income countries, 1961–2016.

Credit: M. Wackernagel (2021), "Shifting the Population Debate: Ending Overshoot, by Design & not Disaster," August 5, Global Footprint Network, https://www.overshootday.org/content/uploads/2021/08/Population-Perspective-M-Wackernagel-2021.pdf region equals the population of the country or region multiplied by its average per capita footprint. Over time this allows an assessment of the separate contributions of changes in population and changes in average per capita footprint. We see that from 1961 to 2016 the increase in population in each group of countries contributed more to the group's total ecological footprint than the increase in their average per capita ecological footprints. Population is a very sensitive issue and is often downplayed for that reason, yet it remains an important consideration in the context of overshoot.

The ecological footprint tells us that we are in planetary overshoot, but it does not say what the effects of overshoot are on the planetary systems that are affected. In 2009 Johan Rockström and twenty-eight other scientists introduced the concept of planetary boundaries.[11] They were concerned that human pressures on the fundamental physical, chemical and biological processes which make up the Earth's systems had reached a level where abrupt global environmental change had become a very real possibility. In their widely read work, they presented data covering nine interrelated issues that are global or continental in scope: climate change, ocean acidification, stratospheric ozone depletion, interference with the global phosphorous and nitrogen cycles, the rate of biodiversity loss, global freshwater use, land-system change, aerosol loading, and chemical pollution. Some of these issues, such as climate change and ocean acidification, have thresholds or tipping points that if transgressed are very likely to change the behavior of the climate and oceanic systems suddenly and irreversibly. Climate change is already bringing more frequent wildfires, longer periods of drought, and an increase in the number, duration, and intensity of tropical storms.[12] Ocean acidification affects many marine organisms, especially those that build their shells and skeletons from calcium carbonate, such as corals, oysters, clams, mussels, snails, and phytoplankton and zooplankton, the tiny plants and animals that form the base of the marine food web.[13]

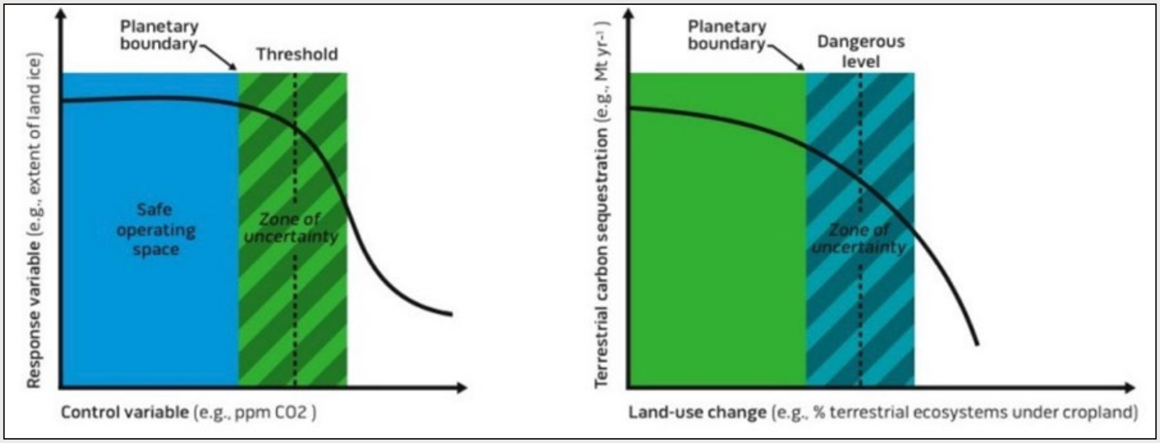
Other issues, such as a lack of fresh water and a high rate of biodiversity loss, have no identifiable thresholds but they can cause disproportionate impacts and, if severe enough, force masses of people to migrate. They can also be globally significant when they are widespread, as is increasingly the case.

Faced with considerable uncertainty about these thresholds and about the relationships between deteriorating conditions and their consequences, Rockström and his colleagues proposed a set of boundaries below which they deemed the risk of catastrophe to be low. This was a judgment call on their part, a precautionary approach in the face of uncertain, highly adverse consequences.

The combination of these boundaries give what the Rockström team called a "safe operating space for humanity." Where there were sufficient data, they proposed numerical values for these boundaries, such as 350 ppm for atmospheric carbon dioxide, and global freshwater use of 4,000 cubic kilometers per year. For others, such as atmospheric aerosol loading and chemical pollution they acknowledged that the data were too limited to set quantitative boundaries, though subsequent researchers have proposed boundaries for all but one of the original set of nine.

In 2015 an expanded research team published a follow-up study

FIGURE 1.11. Conceptual diagram of planetary boundary, threshold, and zone of uncertainty.



Credit: Designed by Azote for Stockholm Resilience Centre, based on analysis in Persson et al., 2022 and Steffen et al., 2015.

which further advanced the concept and quantification of planetary boundaries, for example by replacing "chemical pollution" with "novel entities" covering new substances, new forms of existing substances, and modified life forms that have the potential for unwanted geophysical and/or biological effects. Six years later Rockström and colleagues were featured in *Breaking Boundaries*, a deeply disturbing Netflix documentary on the planetary boundaries presented by David Attenborough who described the precarious state of the Earth systems.

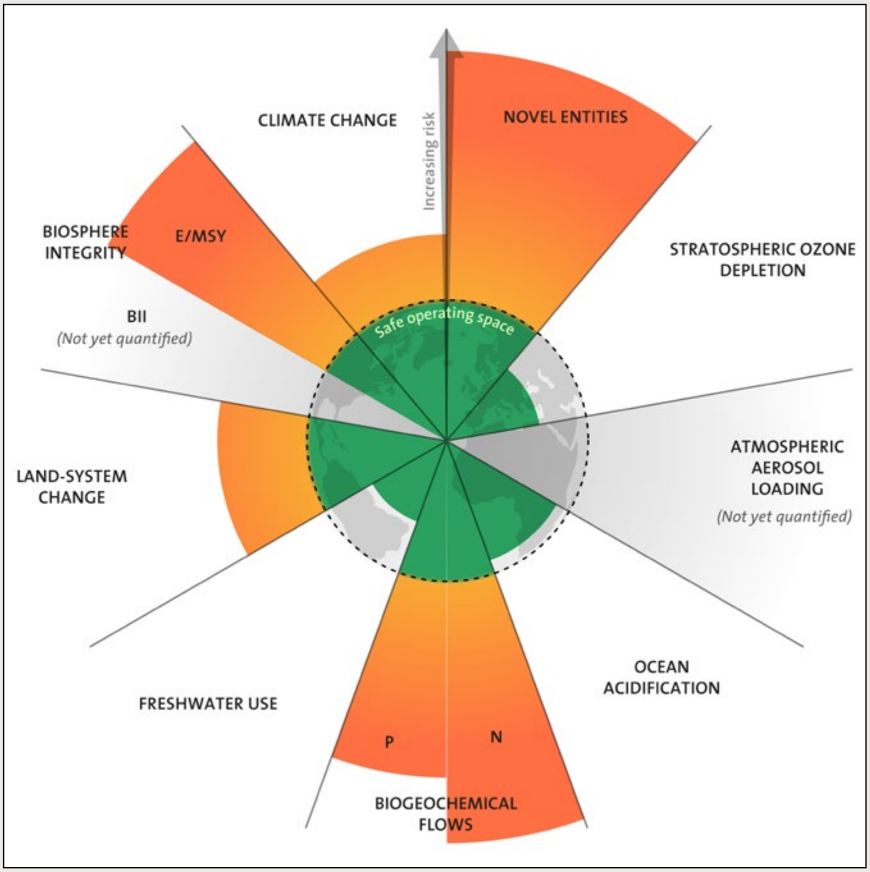


FIGURE 1.12. Planetary boundaries.

Credit: Designed by Azote for Stockholm Resilience Centre, based on analysis in Persson et al., 2022 and Steffen et al., 2015.[14] Note: E/MSY is extinctions per million species-years and BII is biodiversity intactness index.

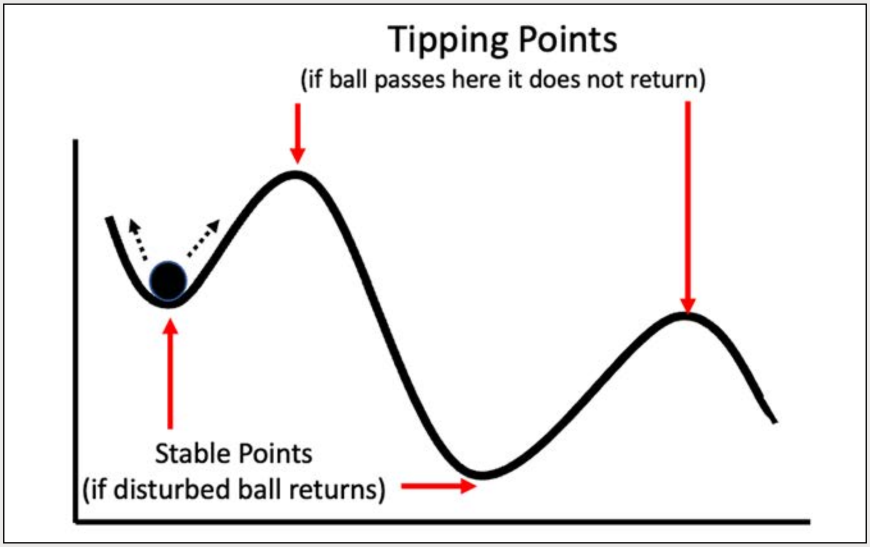


FIGURE 1.13.
Tipping points.

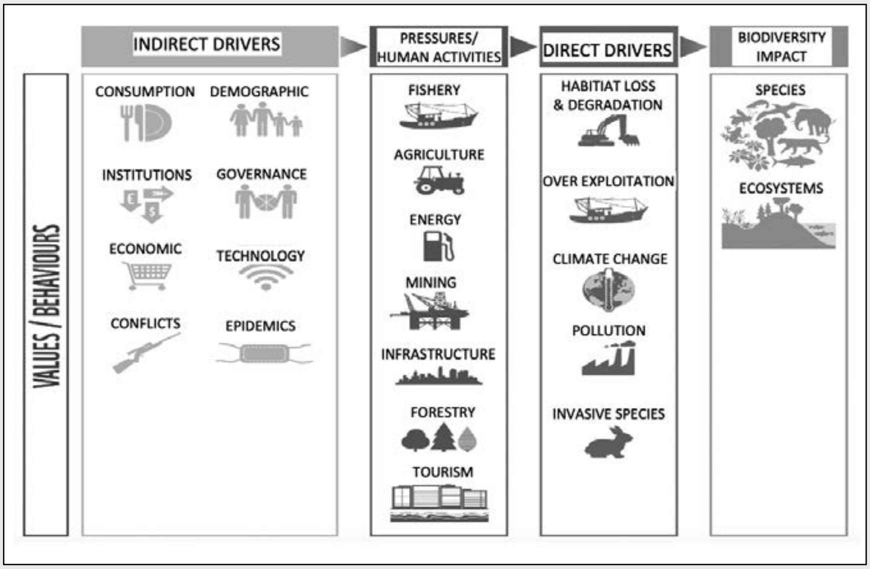


FIGURE 1.14.
Threats to nature and the pressures behind them.

Credit: WWF (2020), *Living Planet Report 2020—Bending the curve of biodiversity loss.* R. E. A. Almond, M. Grooten and T. Petersen, (eds). WWF, Gland, Switzerland.

Closely associated with the idea of boundaries is the concept of tipping points. Tipping points are most easily understood in relation to climate change but can apply to many natural, social, and economic systems. There is an increasing likelihood that the accumulation of greenhouse gases in the atmosphere will reach a tipping point, pushing the climate irreversibly out of the relatively stable 12,000-year Holocene epoch which made agriculture feasible and, for a while at least, capable of supporting the 8+ billion people alive today. The global consequences of such a shift from a stable climate, to which humans and other species have adapted, to another one far less suitable for humans at least, hardly bears thinking about, but think about them we must if we are to plan an escape. A good place to start is with the economy.

The Economy as a Sub-System of the Planet

The message from looking at the ecological footprint and planetary boundaries is clear. We are living in an unprecedented time of global overshoot. The causes and consequences of overshoot vary from place to place and between rich and poor, but even for the very rich there is no escape. We are not all in this together equally by any means, but we are in it together and should look for solutions that work well for us all. An element of that search is an improved understanding of the relationships between economies and the Earth systems on which they depend. This is essential since overshoot is fundamentally related to economic activity:

- to what is produced and how
- how it is transported and distributed
- the levels and patterns of consumption
- the materials and energy that are used
- the land that is transformed
- the waste products that are released back to the environment.

The economy is usually discussed as if it were independent of these Earth systems, a serious mistake that blinds some economists from appreciating the inescapable fact that the economy is a subsystem of the biosphere. Economies are open systems which means that their structure and functions depend on a continual "throughput" of materials and energy from and to the environment. They require resource inputs and produce waste outputs just like any other open system. All forms of life are open systems including you and me. We eat and excrete. Our lives depend upon it. Machines are open systems too. They require energy to operate, they are made of materials that must be replaced when they wear out, and depending on their purpose, they process materials and generate products and waste. Likewise, economies require ongoing inputs of materials and energy which eventually become wastes which must be removed. Reuse and recycling can extend the useful life of materials in an economy, but as they degrade they reach a point where they can be used no more and become waste.

The economy's fundamental dependency on the environment is all too often overlooked in discussions of the economy. The neglect of this dependency underlies the belief that economic growth can continue indefinitely. Take, for example, the simplest model of an economy,

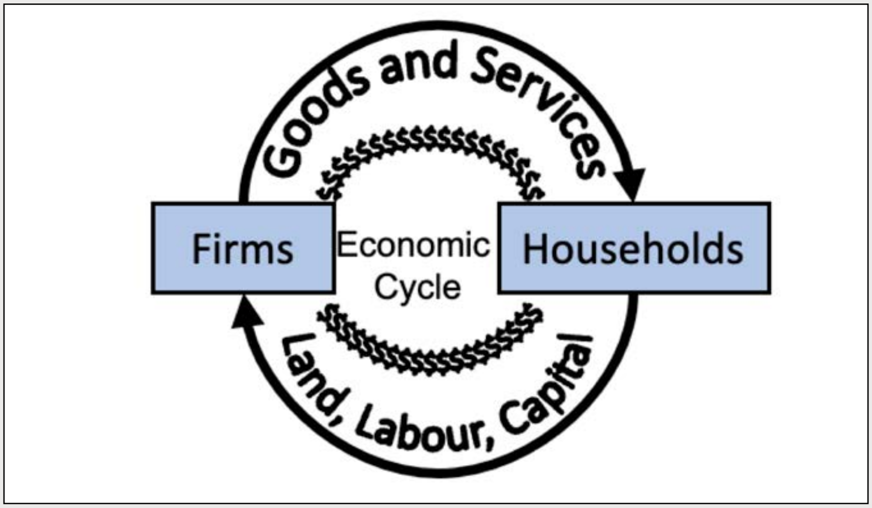


FIGURE 1.15.
The circular flow of income.

one that appears in most introductory economics textbooks. It consists only of households and firms. The households are the ultimate owners of the land, labor and capital, the so-called "factors of production." They make these available to firms in return for rent, wages, and profits. All households are assumed to own their labor; only some own land and capital. The firms make the goods and services which are sold to the households who pay for them from their incomes. The factors of production and goods and services flow in one direction, and money flows in the other. Once absorbed by students, an image of this sort, showing the circular flow of income, becomes their frame of reference with little or no appreciation of the environmental dependency of the economy and its consequences.

Much is missing from this image of the circular flow of income. Government is one, banks are another. More importantly for our purposes is the omission of the environment and the material and energy flows on which all economic activity depends. Without the life-giving energy from the sun, the Earth would be a desolate, cold, and dark place. Apart from a tiny amount of material from outer space that survives passage through the Earth's atmosphere, all that enters spaceship Earth is energy from the sun and virtually all that leaves is heat. Let's see what the economy looks like when we take these facts of economic life into account.

In terms of flows within the planet we can start with the natural resources extracted from the Earth's crust for use in the economy. These are shown with lines coming from an open pit mine and a forest. The resources go primarily to firms which process them into goods and services for sale to each other and to households. Included in these natural resources are fossil fuels which are used to supply energy to firms and households, as well as biomass, other minerals, and nonmetallic minerals. Some of the resources used in the economy remain there for considerable periods of time in infrastructure, buildings, and equipment. Other resources are disposed of back into the environment almost immediately upon use. This includes energy (as waste heat), food, and disposable consumer products. Reuse, recovery and

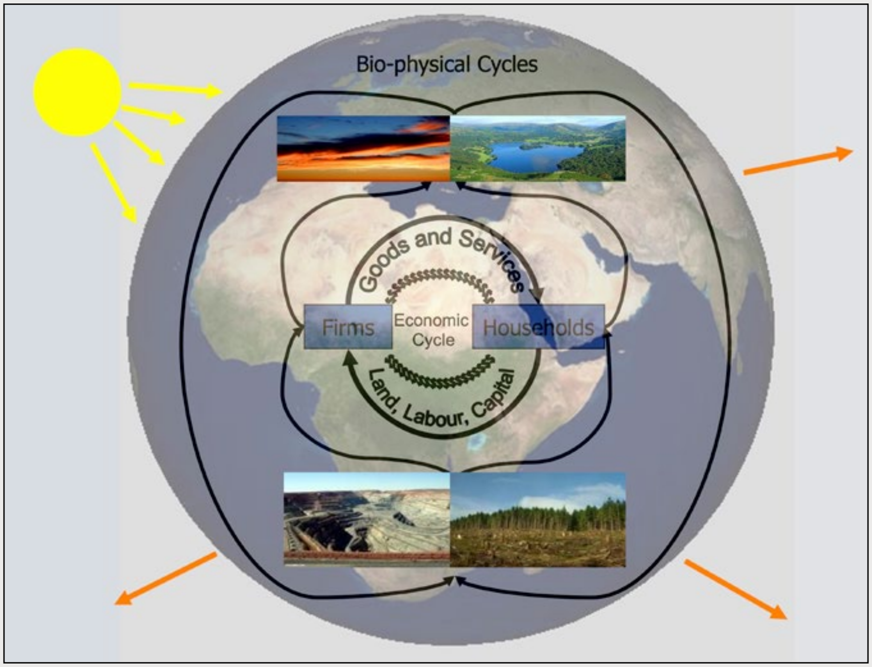


FIGURE 1.16.
Spaceship Earth.

recycling can reduce throughput, but as materials are degraded with repeated use they too are eventually returned to the environment as waste. The same is true of energy which can be used more efficiently but cannot be recycled since its capacity to do work is always diminished with use.

The lines linking firms and households to the images of the atmosphere and a lake represent the flows of waste materials and energy back to the environment. Overshoot occurs when these flows exceed the capacity of the environment to absorb them without causing significant damage. When the bio-physical-chemical cycles in the Earth system are disrupted, it can, through feedback, reduce the supply of natural resources. In conjunction with the transformation of land to suit human purposes, this disruption of biophysical cycles can be devastating to other species living on planet Earth.

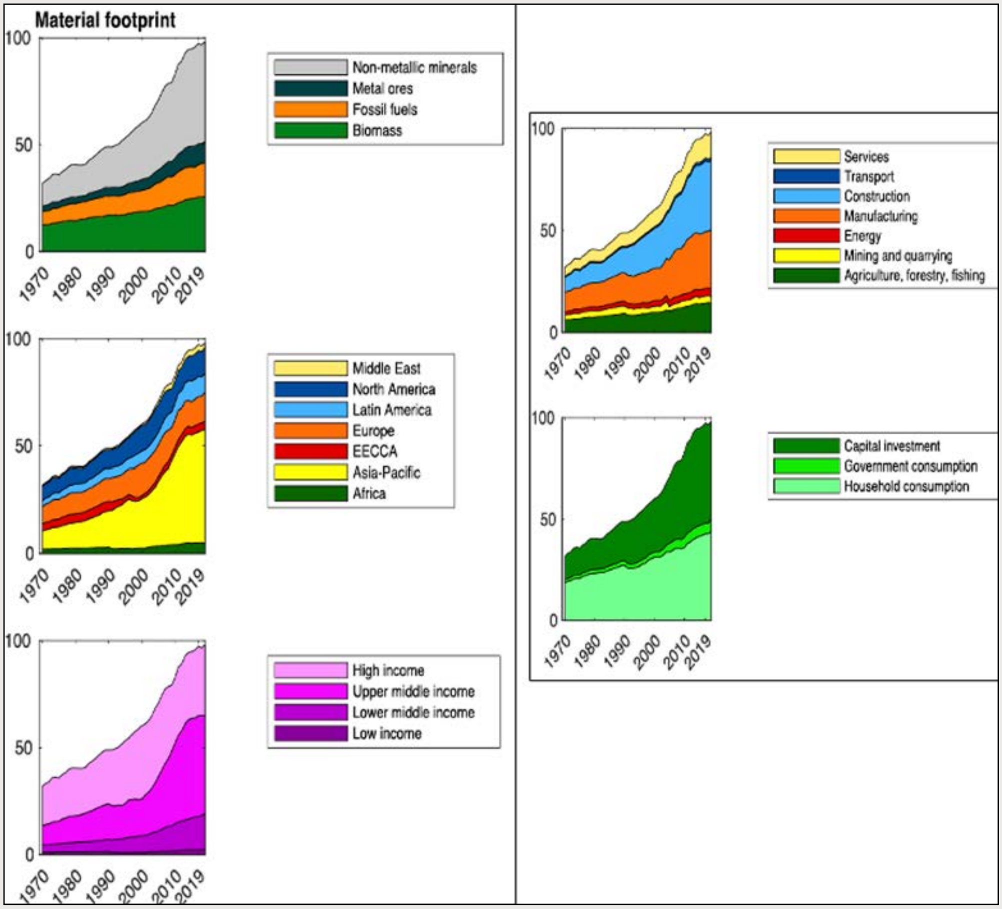
Material Flows

Now that we have in our minds an image of the economy embedded in the environment we can probe further into overshoot. Let's start with the increasingly rapid rise in global materials extraction from 1900 onwards. In the first fifty years of the twentieth century, the global extraction of materials increased exponentially so that by 1950 global materials extraction per year was more than double what it had been in 1900. Each of its four main components—biomass, fossil fuels, ores and industrial minerals, and construction materials—increased. This growth in materials extraction was due largely to economic growth in the United States, Western Europe, and the USSR. In the second half of the century global materials extraction accelerated so that by the year 2000 it approached four times its level in 1950. In this period, economic growth spread to more countries, most notably Japan, China and other Asian countries, all requiring increasing quantities of materials. During the first fifteen years of the twenty-first century, the rate of increase in global materials extraction accelerated again. By 2015 it was 60 percent higher than in the year 2000 with China being the dominant contributor followed at a distance by India and Brazil.[15]

This phenomenal increase in global materials extraction is a crucial factor in planetary overshoot. A large proportion of these materials is disposed of back into the environment very quickly, often exceeding its regenerative capacity. This may be because the dumped quantity of an otherwise unproblematic substance such as carbon dioxide is excessive, or because the extracted materials were used in the manufacture of non-biodegradable products. But even when the waste materials are not themselves particularly harmful, the massive mining and forestry operations to extract them at the outset can be extraordinarily damaging.

Recently, new light has been thrown on the question of what happens to the extracted materials after they have entered the global economy. We now talk about the "metabolism" of economies, borrowing from the biological sciences which use the term to describe the process by which living organisms obtain energy from food to sustain life and in doing so create degraded waste products that must be removed. The

FIGURE 1.17. Evolution of the world's material footprint between 1970 and 2019 (Gt).



Credit: M. Lenzen et al., (2020), "Implementing the material footprint to measure progress towards Sustainable Development Goals 8 and 12," *Nature Sustainability*, 5, 157–166, https://doi.org/10.10138/s41893-021-008111-6

material metabolism of the global economy is conveniently illustrated with a Sankey diagram, first devised by Irish Captain Henry Phineas Riall Sankey in 1898. In a Sankey diagram, the width of the arrows is proportional to the flow rate. When applied to the material metabolism of economies, a Sankey diagram traces the flow of materials from extraction through processing, where it is divided between those used as materials and those used for energy. Some of the extracted materials

FIGURE 1.18. Mining devastation.

Credit: Sebastian Pilcher on Unsplash.

are accumulated in stocks of infrastructure, buildings, equipment, and consumer durables which remain in the economy for years, decades, and centuries. From 1900 to 2010 global material stocks increased a remarkable 23-fold requiring further material inflows for maintenance, repair, and energy.[16]

Other components of extracted materials, including energy, are used as interim outputs (i.e., goods and services), and become final outputs returned to the environment as water vapor, emissions to air, and solid and liquid wastes. Recycling and downcycling (i.e., reuse) are also included for a complete accounting of material flows.

Sankey diagrams for global material flows for 1973 and 2015 show the phenomenal increase in these flows in just over four decades. Global materials extraction increased from 35 gigatons in 1973 to 88.9 gigatons in 2015. Recycling and downcycling more than tripled as a percentage of all processed materials between 1973 and 2015, reducing the requirement for virgin materials, but even in 2015 they were still only 6.4 percent of all processed materials.

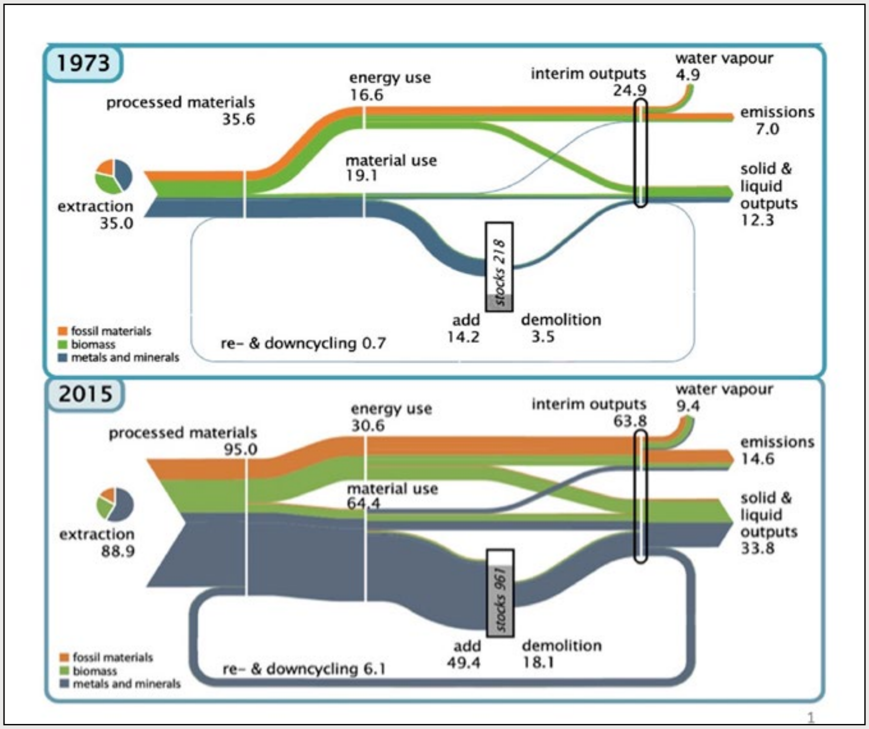


FIGURE 1.19. Material flows on planet Earth (Gt/yr) 1973 and 2015. Stocks are in Gt.

Credit: Haas, et al, (2020), "Spaceship earth's odyssey to a circular economy—a century long perspective", *Resources, Conservation & Recycling*, 163, 1–10.

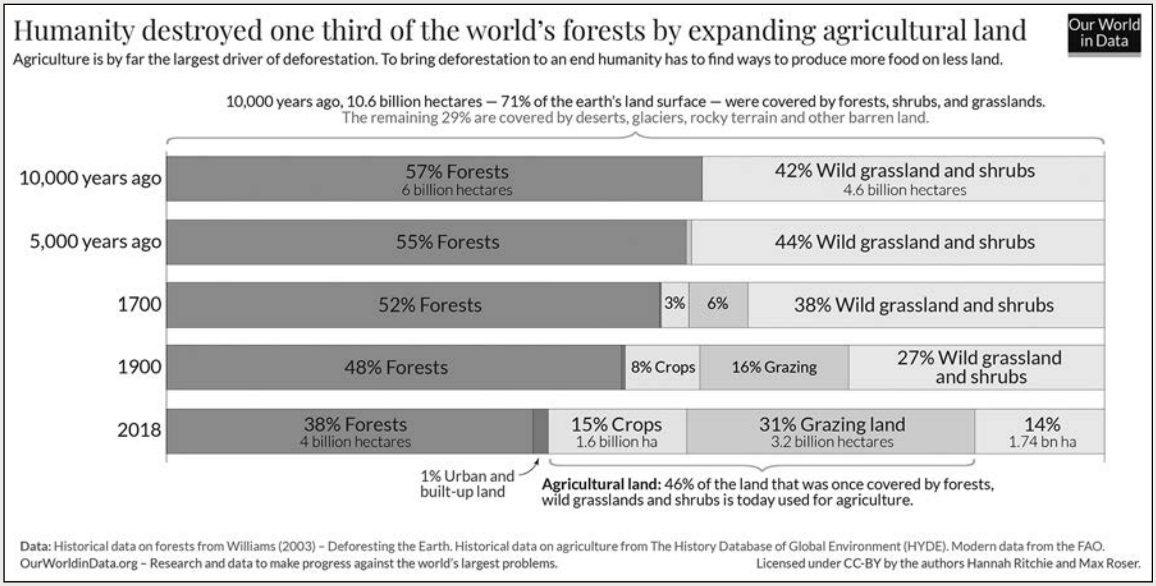
Forests

Increasing requirements for biomass have had very significant impacts on the forests of the world. After many decades of exploitation beyond the rate of regeneration, forests still cover almost one third of global land area and provide habitat for most of the Earth's terrestrial biodiversity. This includes 80 percent of amphibian species, 75 percent of bird species, 68 percent of mammal species, and more than 60 percent of all vascular plants, such as grass, coniferous trees, and flowering plants, that have special tissues that carry water and food throughout the plant. Global efforts to reduce the rates of deforestation and degradation have had some success but both continue at alarming rates and are significant contributors to the ongoing loss of biodiversity. An

Credit: Author, data from FAO, *The State of the World's Forests*, 2020.

FIGURE 1.20. Global forest expansion and deforestation 1990–2020 (million hectares per year).

FIGURE 1.21. Humanity's destruction of forests by expanding agricultural land.



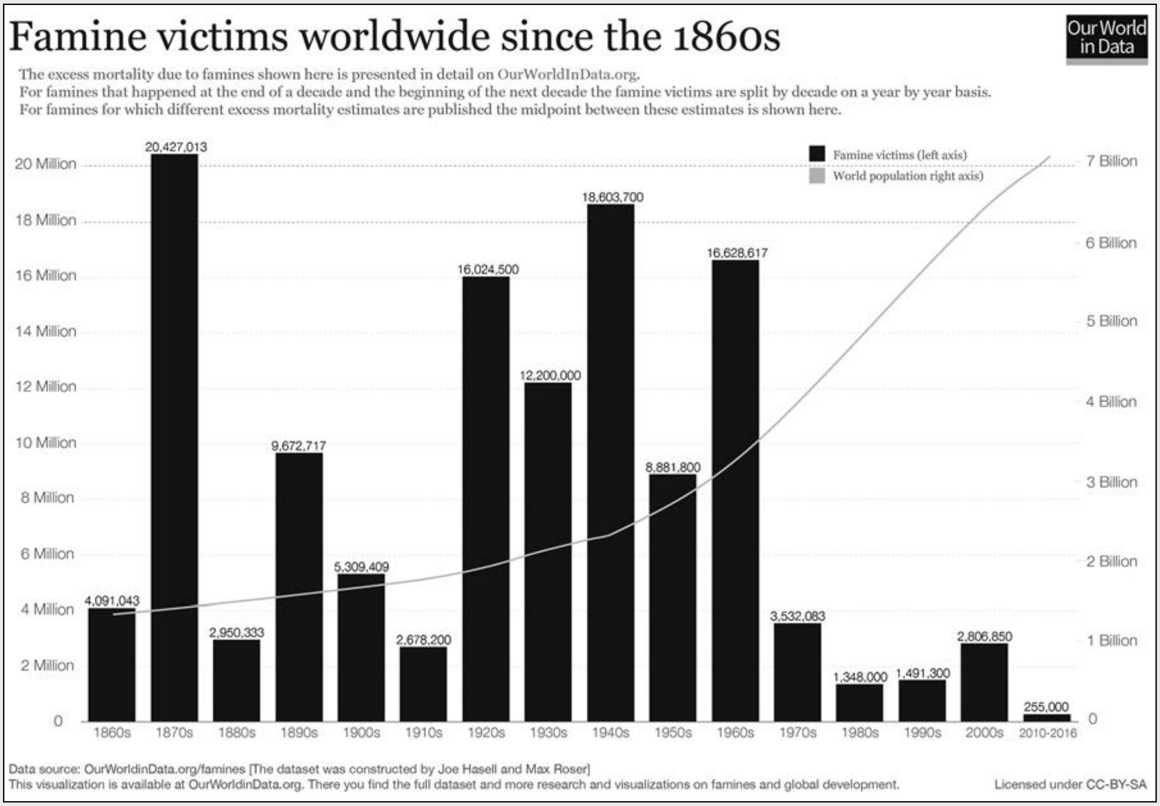
Credit: Hannah Ritchie and Max Roser (2021), "Forests and Deforestation." https://ourworldindata.org/forests-and-deforestation estimated 420 million hectares of forests were lost to deforestation between 1990 and 2020 although this was partially offset by natural expansion and the establishment of new forests. The net result was a reduction in global forest area of 178 million hectares, an area about the same as the combined area of Texas, California, Montana, and New Mexico.[17]

Agriculture

The main cause of deforestation is the expansion of agriculture to feed the growing global population and to accommodate changes in diet that have accompanied increases in income. Between 2000 and 2010, cattle ranching and soya bean and oil palm cultivation by large commercial operations accounted for 40 percent of tropical deforestation. The increase in local subsistence farming accounted for another 33 percent. When forests and grasslands are converted to farm fields and pastures, valuable topsoil can be lost. It is estimated that half of the planet's topsoil has disappeared through erosion in the past 150 years. Agriculture land suffers from other pressures too, such as compaction from heavy farm equipment, impaired soil structure, loss of nutrients, and increasing salinity. Runoff of phosphorous, nitrogen, and other chemicals added to agricultural soils to enhance their productivity contaminates rivers and lakes, which also suffer from increased sedimentation from eroded soils, harming aquatic life.[18]

For the past two centuries global food production has more than kept pace with population growth, allaying fears of widespread famine famously described by Thomas Malthus in the late eighteenth century. In fact, the incidence and severity of famines has declined considerably since the middle decades of the twentieth century, as have deaths from malnutrition. Many factors have contributed to this: food production increased faster than population largely due to increased yields from improved breeding, extensive use of synthetic fertilizers, genetic modification, more irrigation, mechanization powered by fossil fuels, and beneficial changes in other factors such as reduced conflict and poverty, greater access to markets and healthcare, and improved politi-

FIGURE 1.22. Famine victims worldwide since the 1860s.



Credit: Joe Hasell and Max Roser (2013), "Famines." https://ourworldindata.org/famines.

cal institutions.[19] Yet, in light of the ongoing degradation of agricultural land, the depletion of groundwater, and the climate-driven need to reduce the high dependence of farming on fossil fuels, the underlying situation of overshoot may well show itself in the years to come through disruption to and reductions in the food supply. David Beasley, head of the UN World Food Program, said its latest analysis shows that "a record 345 million acutely hungry people are marching to the brink of starvation"—a 25% increase from 276 million at the start of 2022 before Russia invaded Ukraine on February 24. The number stood at 135 million before the COVID-19 pandemic in early 2020.[20]

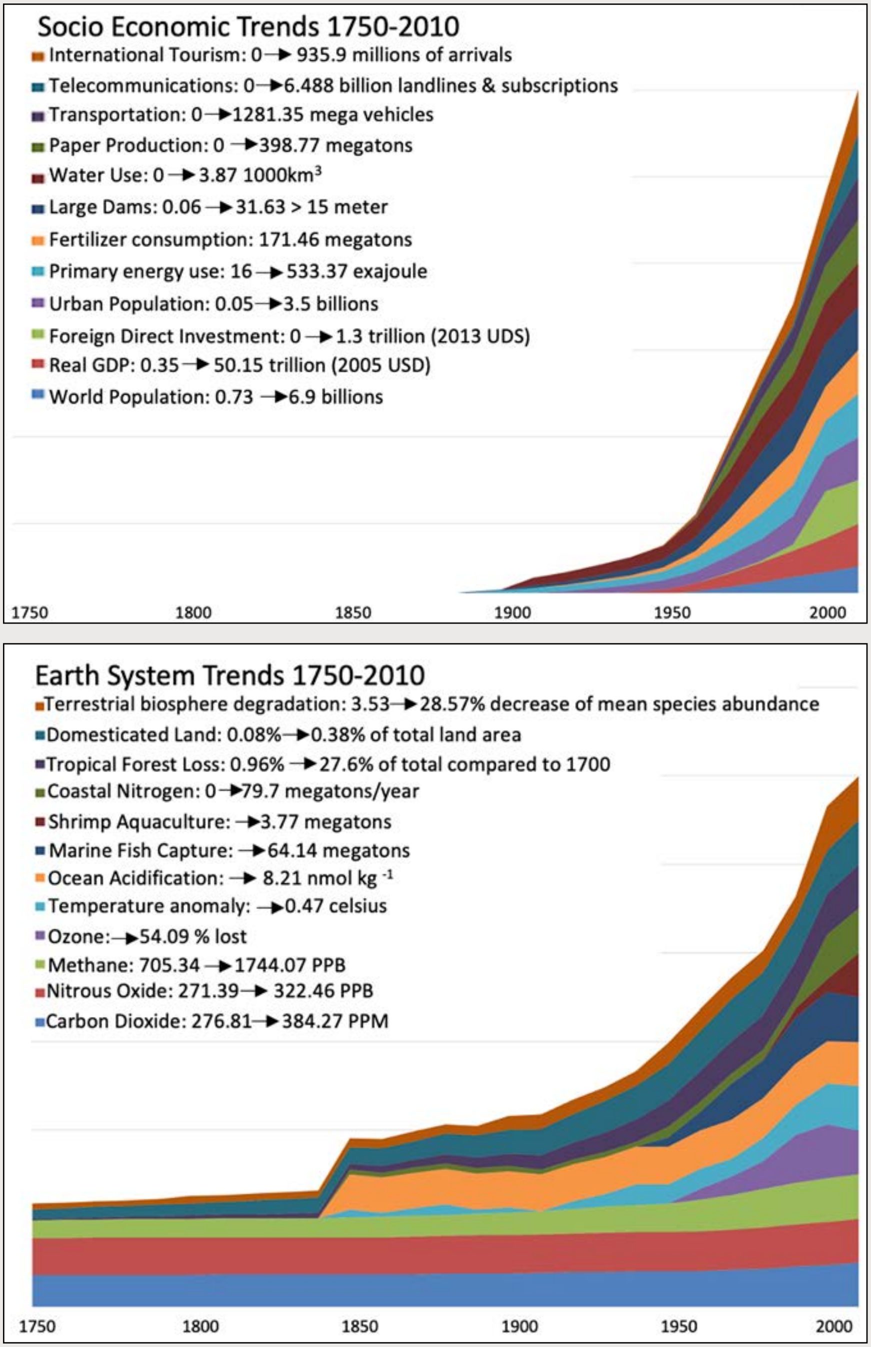


FIGURE 1.23. Global socio-economic and Earth system trends 1750 to 2010.

Credit: Source data is from the International Geosphere-Biosphere Programme www.igbp.net, Created by Bryan MacKinnon.

Forestry, fishing, and farming are the three main sectors of the economy that extract biomass from the Earth to feed, literally and figuratively, the world's economies. Non-living materials are extracted by the mining sector. Because minerals are non-living and do not regenerate naturally, or exceedingly slowly like oil, the concept of overshoot does not apply in the same way. The extraction of minerals depletes deposits in the Earth's crust. This becomes problematic if the rate of extraction is high relative to known reserves and readily accessible deposits. New extraction technologies, combined with more efficient use, recovery, and recycling induced by higher prices, regulation, and better management, can alleviate these problems, at least temporarily. However, mining puts pressure on the Earth's biological systems through erosion, sinkholes, and the chemical contamination of soil, groundwater, and surface water, so excessive exploitation of mineral deposits can reduce biological regeneration, exacerbating overshoot.

The Great Acceleration

Earlier we saw the very rapid increase in the human population and global economic output since 1750. This period is sometimes referred to as the Great Acceleration in recognition of the rapid increase in a wide variety of interrelated socio-economic and Earth-systems. Extensive research and many reports and scientific papers have been written about each of these accelerating changes in the systems. They are indicative of the Anthropocene—the unofficial name given to the current era in the Earth's geological history—signifying the extraordinary impact of human activity on the planet's climate and ecosystems.

Biodiversity

One of most devastating impacts of these trends is the dramatic decline in the populations of numerous non-human species and the reduction in biodiversity on planet Earth. We have reached the point where humans and their livestock together account for 96 percent of the mass of all mammals on the planet. Wild animals account for the remaining four percent and their populations are declining as they lose habitat.[21]

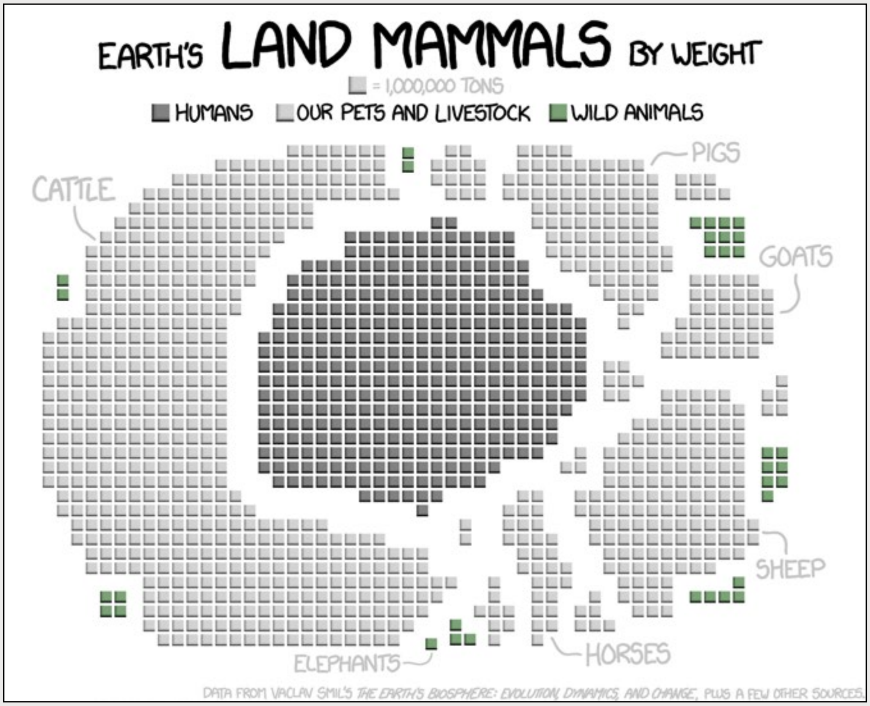


FIGURE 1.24. Earth's land mammals by weight.

Credit: Randall Munroe, https://xkcd.com/1338/

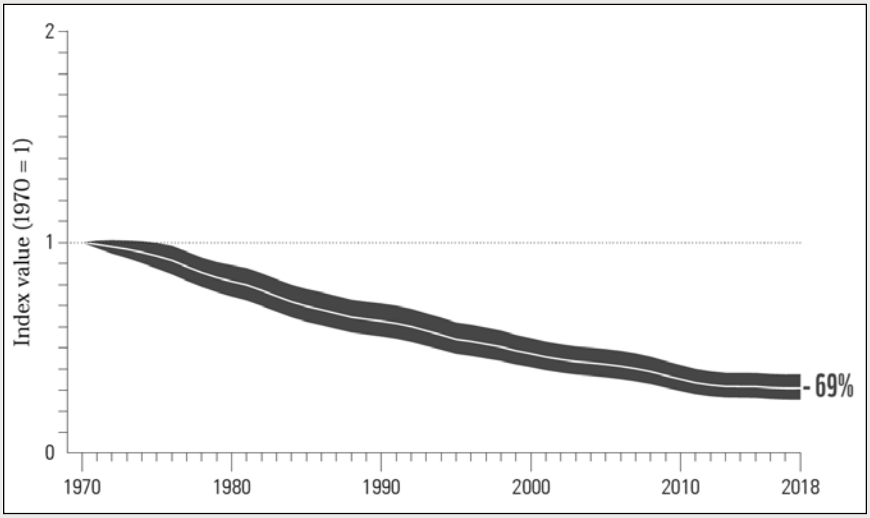


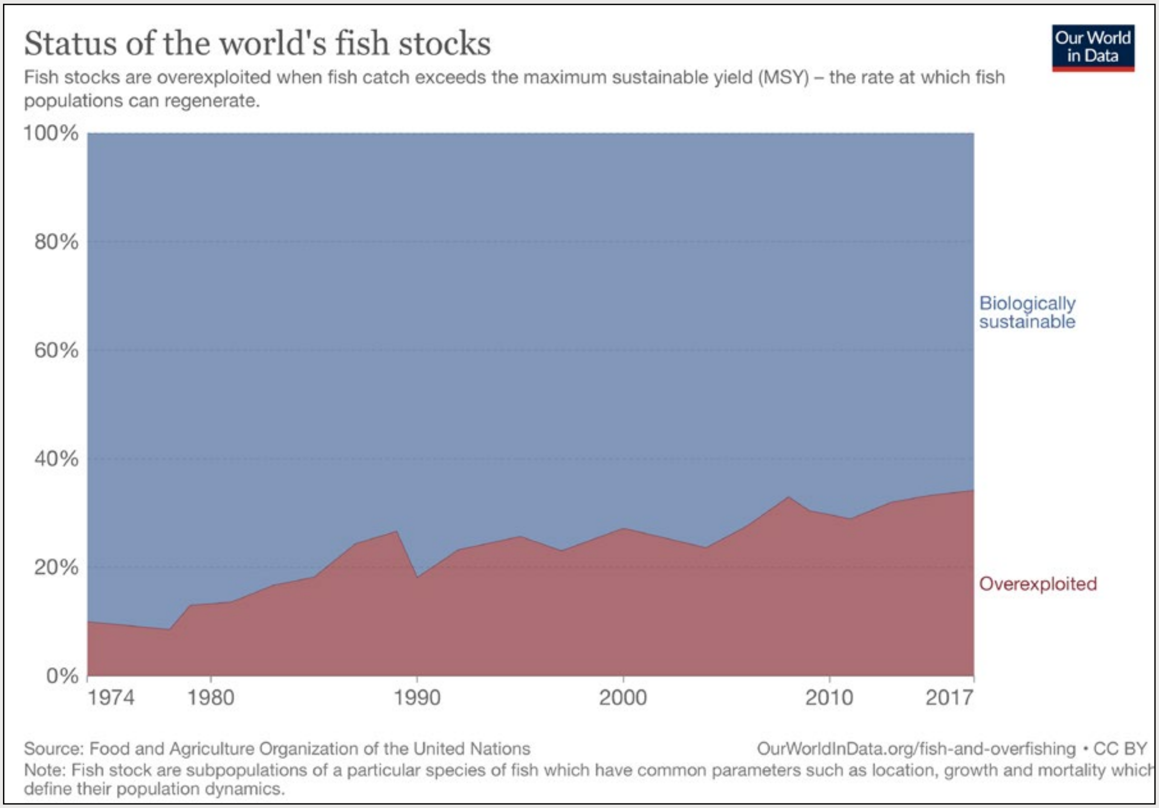
FIGURE 1.25. The global Living Planet Index.

Credit: WWF/ZSL, *Living Planet Report* 2022, http://www.livingplanetindex.org/

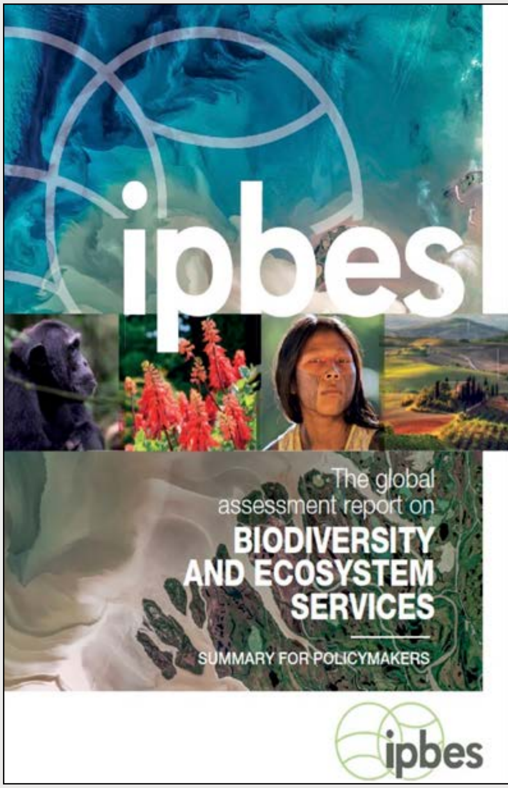
The Living Planet Index, published annually by the World Wildlife Fund, shows a steady reduction of 69 percent between 1970 and 2018 in the average percent change in the populations of mammals, birds, fish, reptiles, and amphibians. 'This estimate is based on monitoring data for nearly 32,000 populations around the world covering more than 5,200 different species, and is a measure of the state of the world's biodiversity. An even greater reduction averaging 84 percent occurred in the more than 900 species that make up the Freshwater Living Planet Index of freshwater populations.

Marine fisheries are also in decline largely because of overfishing. In 1974 90 percent of fish stocks were within biologically sustainable levels, falling to 65.8 percent in 2017.

FIGURE 1.26. Status of the world's fish stocks.



Credit: Hannah Ritchie and Max Roser, 2021, "Biodiversity." https://ourworldindata.org/biodiversity



'Human actions threaten more species with global extinction now than ever before. An average of around 25% of species in assessed animal and plant groups are threatened, suggesting that around 1million species already face extinction, many within decades, unless action is taken to reduce the intensity of drivers of biodiversity loss. Without such action, there will be a further acceleration in the global rate of species extinction, which is already at least 10s to hundreds of times higher than it has averaged over the past 10 million years. the Intergovernmental.

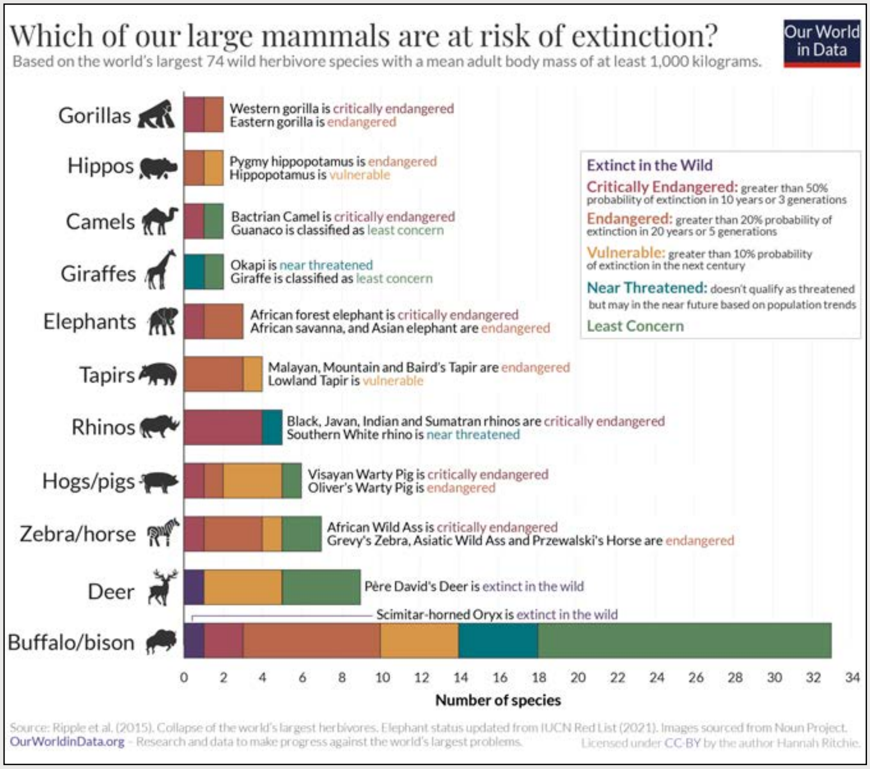
Globally, local varieties and breeds of domesticated plants and animals are disappearing. This loss of diversity, including genetic diversity, poses a serious risk to food security by undermining the resilience of many agricultural systems to threats such as pests, pathogens and climate change.' (IPBES 2019)

FIGURE 1.27.
Scientists warn of threatened species.

Credit: S. Díaz et al., (2019), "Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services," IPBES secretariat, Bonn, Germany

These reductions in populations on land and sea have been accompanied by an acceleration in the rate of species extinction. The warnings to policy makers of the 2019 Global Assessment Report on Biodiversity and Ecosystem Services are chilling.

This anticipated increase in the already high rate of extinction is only to be expected as wild animals are forced to survive in disappearing and degraded habitat. It is making some scientists think that we are on the verge of—or already in—the Sixth Great Extinction, the last one being 65 million years ago when all dinosaurs unable to fly became extinct. About half of the Earth's population was killed when a meteor



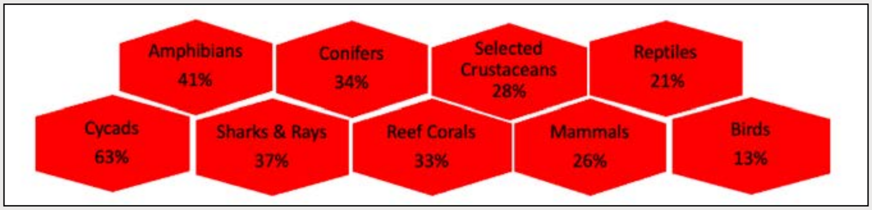
Credit: Hannah Ritchie and Max Roser, 2021, "Biodiversity." https://ourworldindata.org/biodiversity

FIGURE 1.28. Large mammals at risk of extinction.

fell into the Gulf of Mexico. Combined with high volcanic activity, it released vast quantities of carbon dioxide, dramatically changing the conditions under which so many species, dinosaurs among them, had evolved and thrived. The Sixth Extinction has a totally different set of causes, all traceable to overshoot.[22]

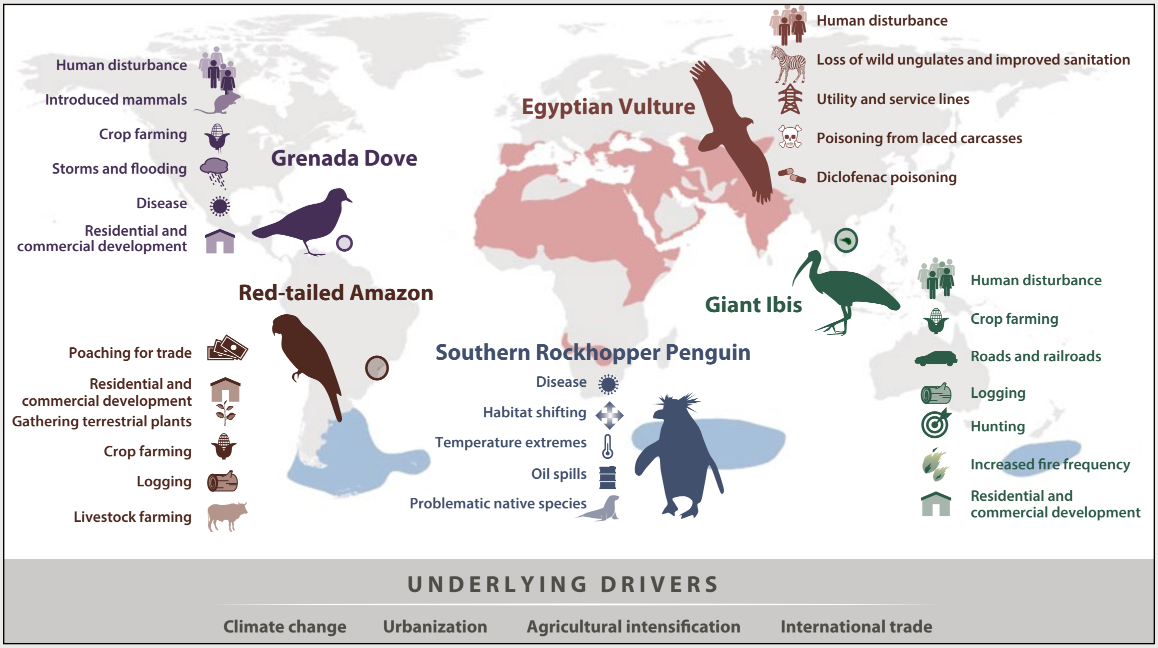
The International Union for Conservation introduced Nature's Red List of Threatened Species in 1964. It is a critical indicator of the health of the world's biodiversity. As of 2022, 142,500 species have been assessed for the Red List. More than 40,000 species are threatened with extinction ranging from 13 percent of birds to 63 percent of cycads (tropical palm-like evergreen plants). The increasing risk of extinction

FIGURE 1.29. More than 40,000 species threatened with extinction.

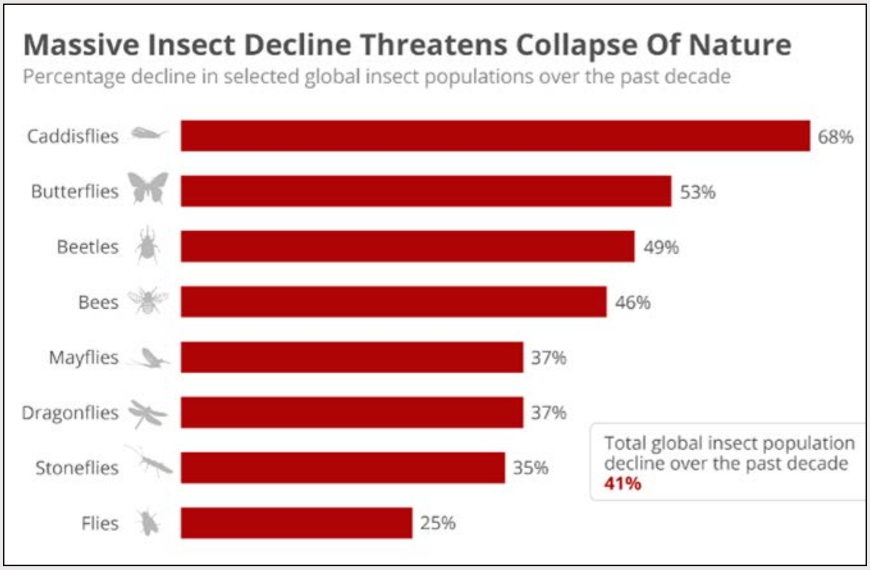


Credit: Data from IUCN Red List https://www.iucnredlist.org/

FIGURE 1.30. Five globally threatened bird species and underlying drivers.



Credit: A.C. Lees et al., 2022, "State of the World's Birds," *Annual Review of Environment and Resources*, 47.

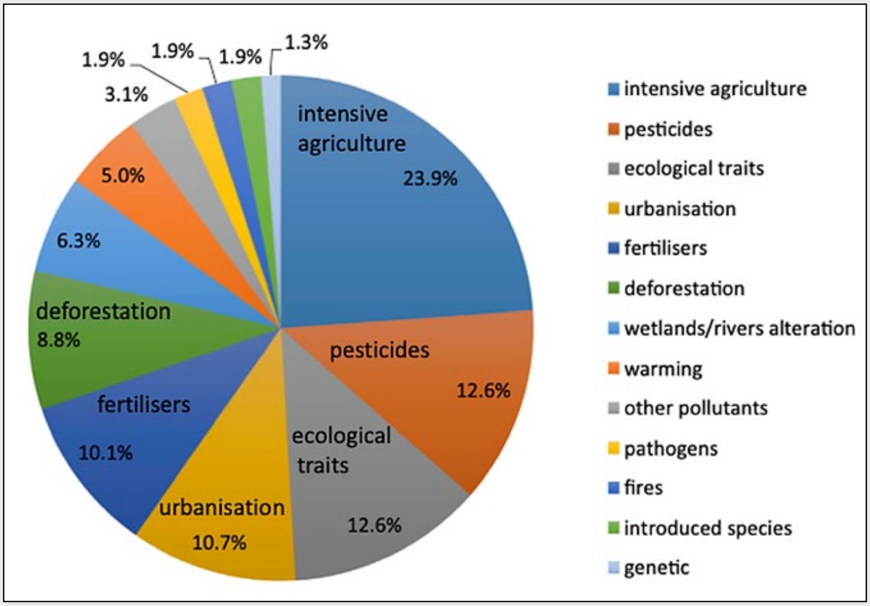


Credit: Data from F. Sánchez-Bayo and K. A. G. Wyckhuys, 2019, *Biological Conservation*, 232, 8–27.

FIGURE 1.31. Massive insect decline threatens collapse of nature. (Percentage decline in selected global insect populations 2010–2019.)

to birds is typical of the situation faced by all categories of species on the Red List.

It is not only mammals, birds, fish, reptiles, and amphibians that are in decline but also insects on which many of these populations further up the food chain depend, including humans who rely on pollination for about a third of global crop production.[23] The causes of the decline in insect populations are many and varied, with human demands on the biosphere the common denominator, as with all the other examples of overshoot given in this chapter. Ultimately, it is these demands that will have to be reduced if we are to escape from overshoot. Whether and how this can be done equitably and effectively, is the theme that runs through all the chapters that follow.



Credit: Data from F. Sánchez-Bayo and K.A.G. Wyckhuys, 2019, *Biological Conservation*, 232, 8–27.

FIGURE 1.32. Main factors associated with insect declines.