Chapter 9
Human Impacts


WORLD POPULATION HITS 7 BILLION!! LET'S CELEBRATE!
POP!
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UM... THERE MAY NOT BE ENOUGH FOR EVERYONE...
Earth's Resources

Overview

Our species, *Homo sapiens*, has been around for only 200,000 years, a tiny blip in the 4.5 billion years of our planet's history. Yet we have had a greater impact on the Earth than any other species. All over the world, we are cutting down forests, using too much water from rivers, choking our oceans with plastic and pushing many animals to extinction.

For both people and wildlife to thrive, now and in the future, we need a healthy planet, with a rich variety of plants and animals and vibrant ecosystems.

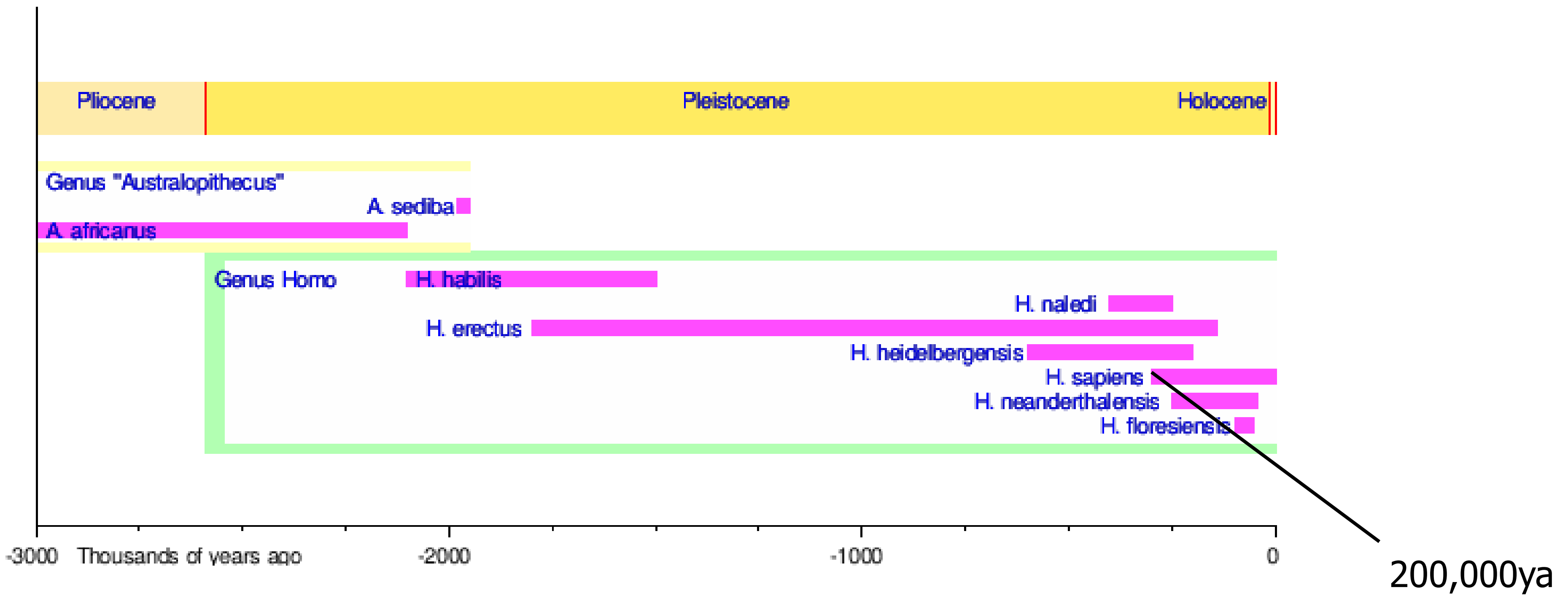
Contents

9.1

Human impacts in the Pleistocene

The Pleistocene

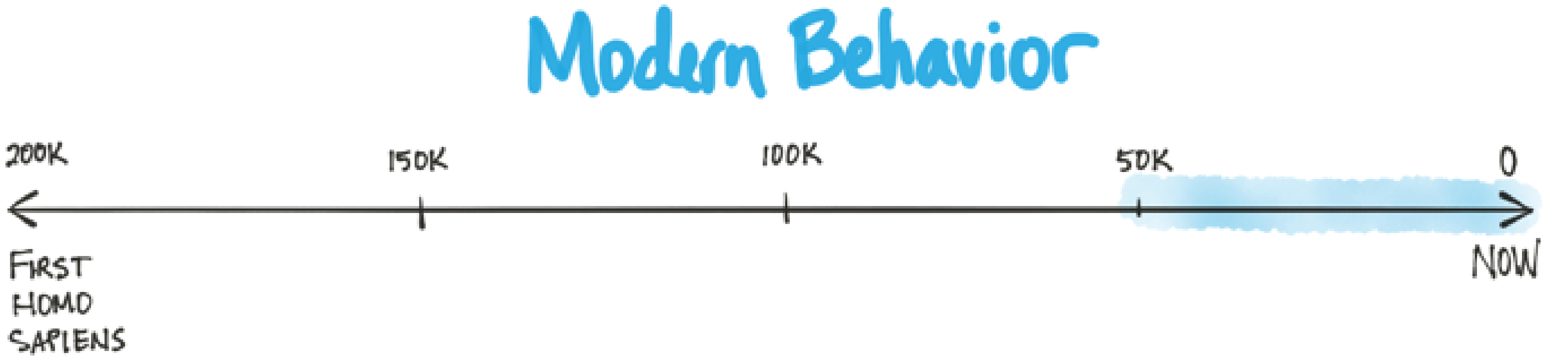
The Pleistocene epoch lasted from about 2.6 million to 11,700 years ago, spanning the world's most recent period of repeated glaciations. Our genus, *Homo*, appeared during the transition between the end of the Pliocene and the start of the Pleistocene. Our species, *Homo sapiens,* appeared around 200,000 ya. The end of the Pleistocene corresponds with the end of the last glacial period.



Modern *Homo sapiens*

Although the first *Homo sapiens* arrived around 200,000 years ago, they were not like us. However, a shift occurred around 50,000 years ago, when humans started to rapidly change their behaviour, adopting behaviours that people today would recognise as ‘modern’. The archaeological record shows, from about 50,000 years onwards, evidence of increased creativity and innovation, use of language, art, religion, the development of advanced technologies, abstract thinking and burial.

Coincidentally, this is also about the time we start detecting the first environmental impacts of humans on our planet.



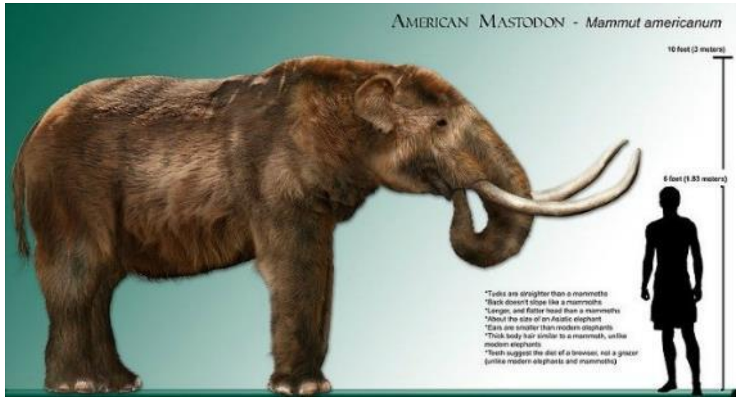
Pleistocene megafauna

100,000 years ago, the earth was filled with large **megafauna**- many more than there are today. Over 90 genera of megafauna were found in almost all landscapes and seascapes. They had survived on Earth for hundreds of millions of years and persisted through multiple periods of climate change.

Homotherium- a genera of sabre-toothed cats that lived in Eurasia and North America

Calicotherium- an odd-toed ungulate, related to tapirs and rhinos. Lived in Europe and Asia.

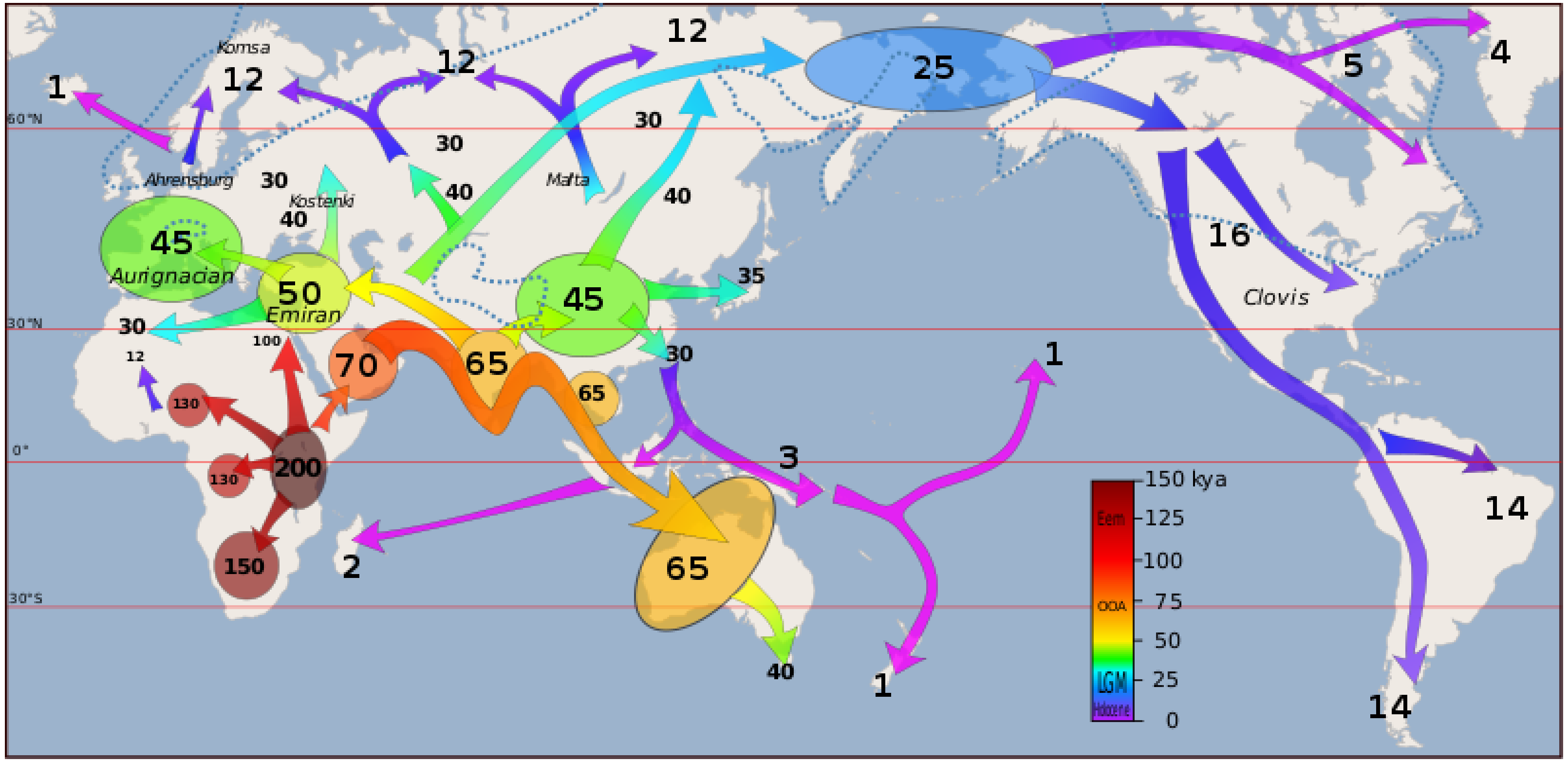
Glyptodon- a giant armadillo-like creature weighing 1 ton. Lived in South and North America.



Mastodon- a primitive mammoth that lived in North America.

Human migrations

Then, around 70,000 years ago, modern *Homo sapiens* began to migrate out of Africa. They progressively spread across the Earth, reaching South Asia and Australia 65,000 years ago, Europe and Eastern Asia 45,000 year ago, and the Americas more recently, around 15,000 years ago.



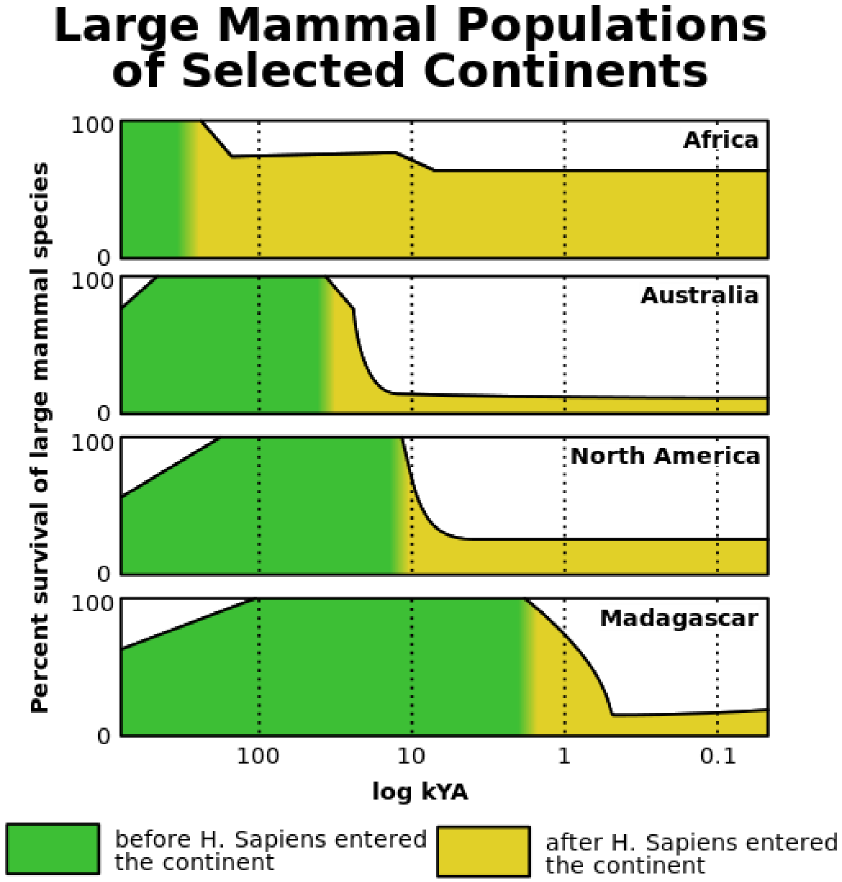
Map source: https://commons.wikimedia.org/wiki/File:Early_migrations_mercator.svg

Pleistocene extinctions

Very rapidly, from about 50kya, large mammal species start to rapidly disappear from the fossil record- this occurred in every continent. It is estimated that >1 billion animals were lost during this period.

The timing of megafaunal loss coincides with the global expansion of *H. sapiens.* Climatic changes were also occurring around this time – the earth was getting warmer, which also facilitated the expansion of *H.sapiens* across the globe.

There is ongoing debate over the relative contribution of climate change and hunting to these extinctions : but humans were essentially super-predators, armed with dogs, fire and tools. It is easy to imagine how these innovations made them super-effective hunters against naïve herbivores they encountered in new lands.



Martin P. S. (1989). Prehistoric overkill: A global model. In Quaternary extinctions: A prehistoric revolution (ed. P.S. Martin and R.G. Klein). Tucson, AZ: Univ. Arizona Press. pp. 354–404

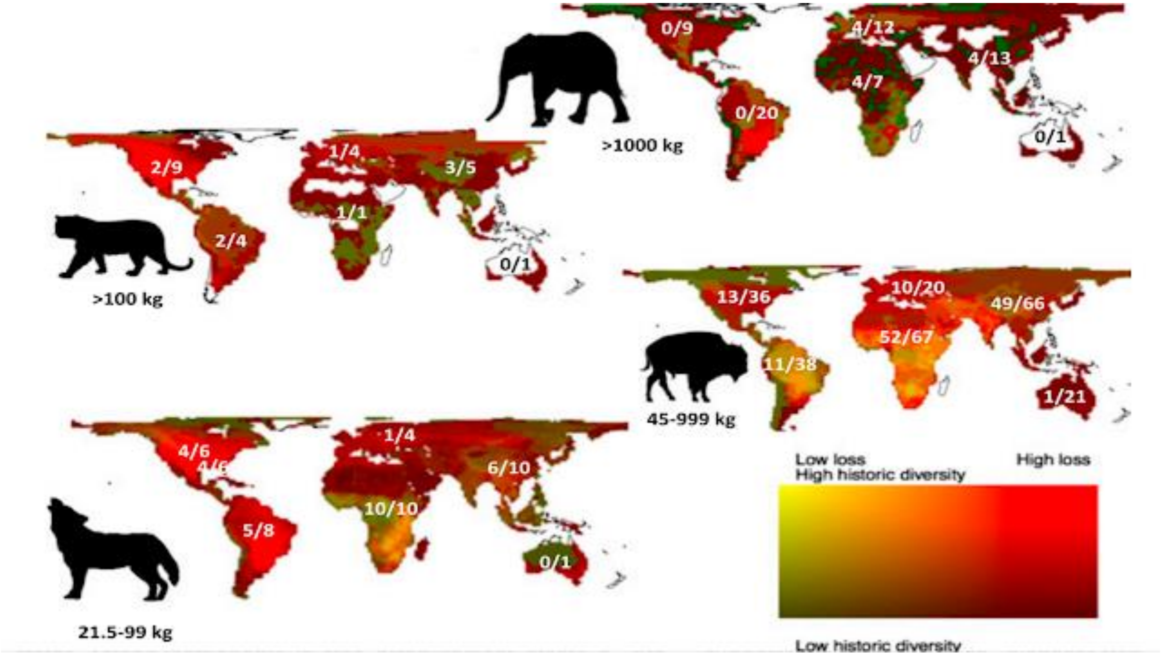
 https://commons.wikimedia.org/wiki/File:Extinctions_Africa_Austrailia_NAmerica_Madagascar.gif

Pleistocene extinctions

Further evidence to support the theory that humans played a more important role than climate comes from the patterns of extinction observed in each continent.

The places that were colonised by modern humans more recently in history lost the highest proportion of megafauna. Australia lost 19 of 27 genera (71%); South America 58 of 71 genera (82%), North America 45 of 61 genera (74%) and Europe 23 of 59 genera (59%).

Only Africa and southern Asia, which both have a longer human prehistory, maintained a substantial proportion of their remaining megafauna. Sub-saharan Africa only lost 16% of its megafauna during this period.
It is thought that because hominids and mammals co-evolved here, species had plenty of time to adapt to human hunting behaviour. However, in other continents where *H. Sapiens* had never been seen before, species were ill-equipped to deal with the arrival of these advanced super-predators.



Source: Malhi et al. 2016. Megafauna and ecosystem function. Proceedings of the National Academy of Sciences Jan 2016, 113 (4) 838-846.

Living in the shadow of giants

We know that megafauna play an important functional role in ecosystems, so their loss in the (evolutionary) recent past must have had a significant impact on natural systems. So what happens when you "suddenly" remove most of the largest animals from global ecosystems that have co-evolved with those large animals for millions of years? Scientists have only just begun to consider this question, but it will help to understand the long-term impacts of megafaunal loss today.

For example, when you remove mega-herbivores, more woody vegetation grows, shifting grassland and open woodland to dense forests. This has been seen in Australia, where the decline in megafauna 40,000 years ago coincides with an increase in fire, and a shift from mixed open woodland to dense forest. In Europe, the loss of mega-herbivores (such as the straight-tusked elephant) coincides with an expansion of tree cover.

Many tree species depend on megaherbivores for seed dispersal, and their loss will affect the patterns of distribution and abundance of these plants. There are many examples of modern-day plants with tough fruits, big seeds, and harsh defenses, that are thought to have previously been food for megaherbivores – ghosts of our megafaunal past.

Osage Orange, thought to have been eaten and dispersed by Gomphotheres and giant ground sloths

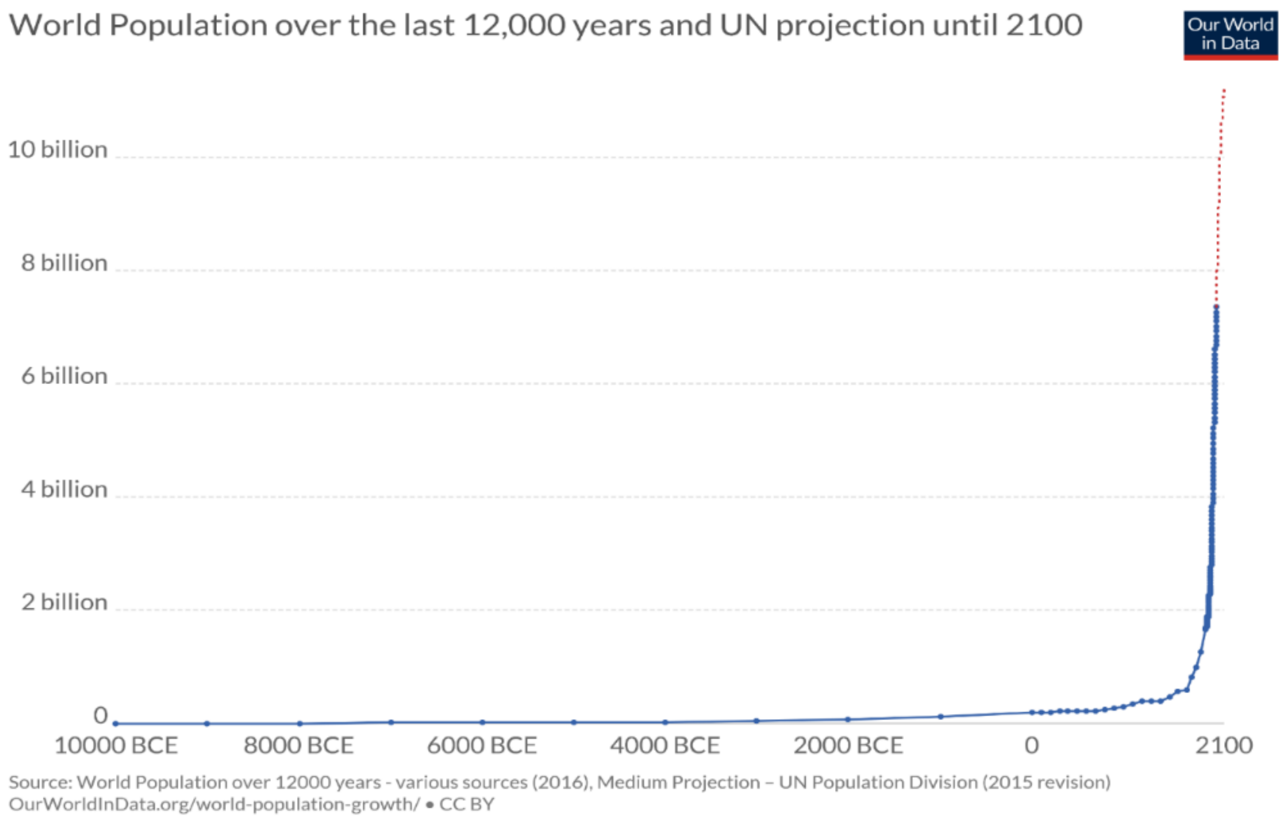
Honey locust, native to north America- whose thorns are thought to have evolved as protection against browsing Pleistocene megafauna

9.2

The Anthropocene

Human population

The world's human population at the end of the ice age (11,700 years ago) was estimated at 2.43 million. Since then it has increased by 3,300 fold : however, nearly all of this expansion has occurred since the industrial revolution, and more specifically in the last 70 years. The world's population doubled between 1950 and 1987 and as of 2019, it stood at 7.6 billion. By 2088 it is predicted to reach 11 billion.



The Anthropocene

Recent global environmental changes suggest that the Earth may have entered a new human-dominated geological epoch known as "**The Anthropocene**". Analyses of environmental signatures in the geological record shows that two key dates emerge as possible indicators of the start of the Anthropocene : 1610 and 1964.

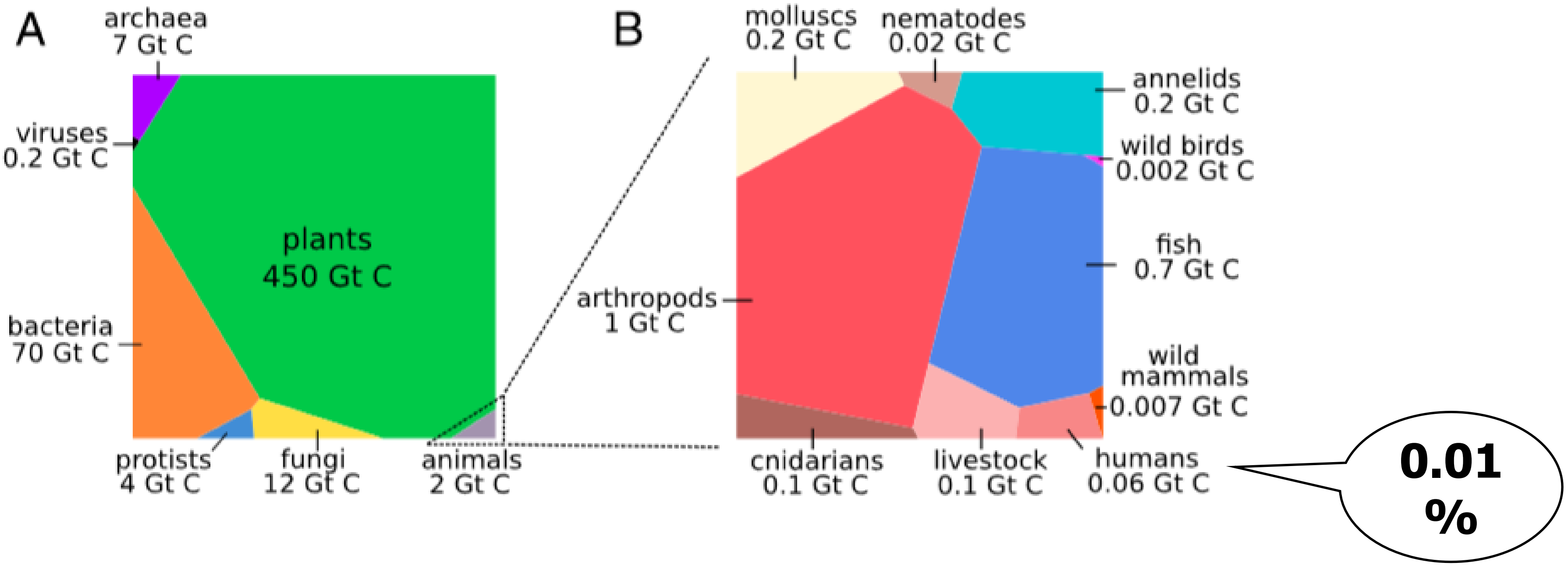
Firstly, a sharp **decrease** in global CO_2 levels have been dated in the record to around 1610: this date coincides with the arrival of Europeans in the Americas, which precipitated the deaths of about 50 million people due to disease. It is thought that approximately 65 million hectares of agricultural land were subsequently abandoned: as forests reclaimed the land, carbon sequestration increased, lowering global CO_2 levels.

The second indicator is dated to 1964: here a sharp **increase** in atmospheric C_{14} has been detected, which is due to the nuclear bomb tests that were conducted at the time. This indicator coincides with the "Great Acceleration" which describes the period since the 1950s that has seen a major expansion in human population, large changes in natural processes and widespread use of plastics and organic pollutants.

Source: Lewis and Maslin, 2015. Defining the Anthropocene, Nature, 519, 171-180

Human impact

We live in a world of plants. Despite our massive population size, humans only make up 0.01% of the earth's biomass, of which 80% is plants. All animal life on the planet represent 0.4% biomass- and wild mammals just 0.001%. However, our impact is disproportionately significant.



Source: Bar-On et al., 2018. The Biomass Distribution on Earth. PNAS, 115, 6505-6511.

Human impact

Humans affect almost every biophysical environment and ecosystem on earth, including the atmosphere, the climate, marine and terrestrial environments. We affect ecosystem structure and processes, species distribution, diversity and abundance, ecological connectivity, we are disrupting nutrient cycles in the soil, rivers and oceans, and we are depleting almost all the earth's natural resources including forests, minerals, wildlife populations, fossil fuels, and groundwater.

Some of the most widely reported anthropogenic impacts we are having on the natural world include climate change, deforestation, acid rain, desertification and pollution.

We are achieving this through overexploiting and overconsuming natural resources, through the degradation and destruction of habitats, by polluting natural systems, and by artificially transporting species and pathogens across the globe.

Human impact

In the following sections we will look in more detail at the different ways humans are impacting the environment today, the extent of environmental damage that is being seen across the globe and what lies in store for our planet in the coming century.

9.3

Human consumption

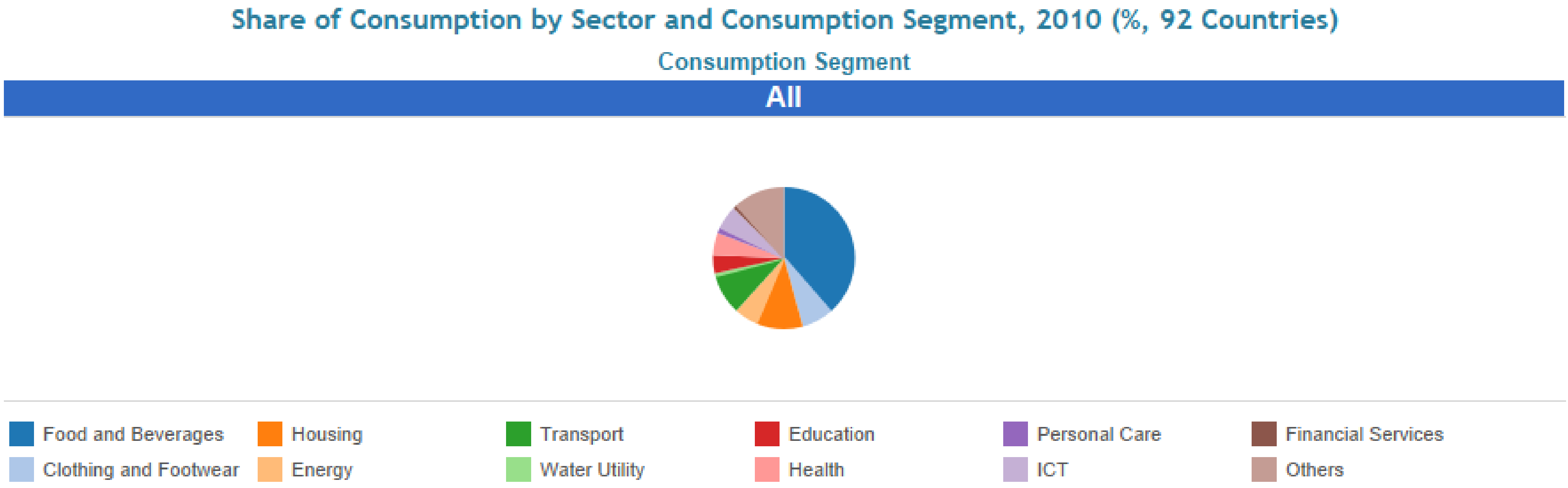
Human consumption

No, we're not talking about **anthropophagy** here (the act of eating human flesh), so Zombie Apocalypse can wait for another day. What we are referring to, of course, is the consumption by humans of the earth's natural resources.

Modern humans are reliant on a wide range of goods and services to both survive and enjoy a decent standard of living. These goods and services include food and beverages, clothing and footwear, housing, energy, technology, transportation, education, health and personal care, financial services and other utilities.

Consumption patterns

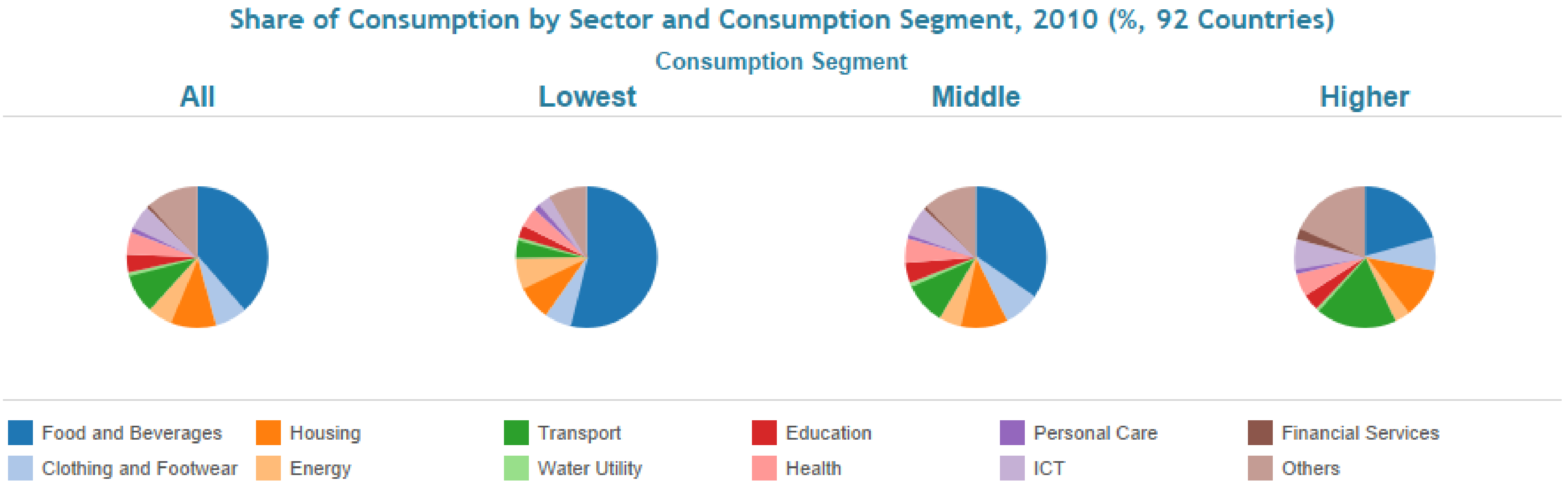
According to the World Bank, the highest shares of consumption lie in food and beverage and clothing and footwear, which make up 46% of all consumption.



 http://datatopics.worldbank.org/consumption/

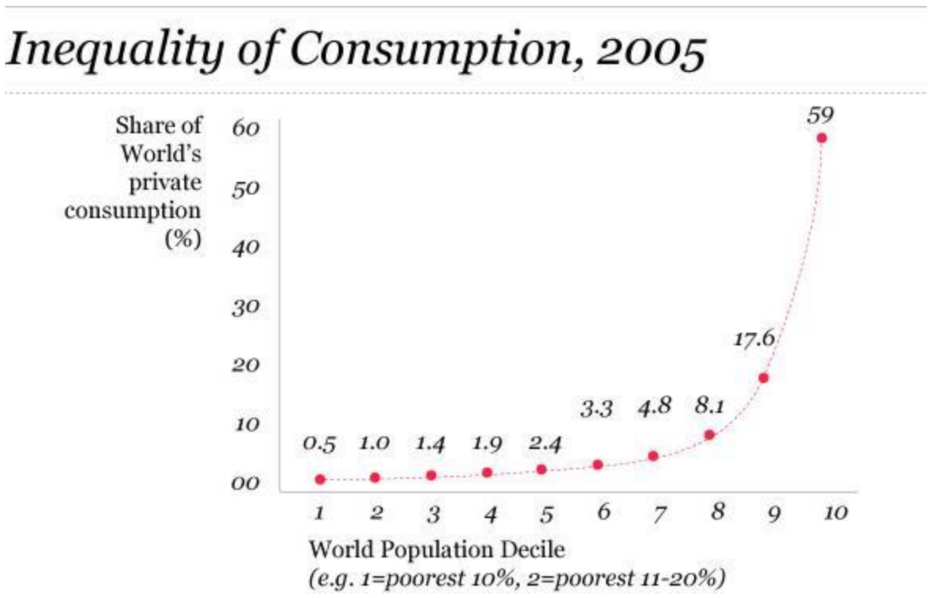
Consumption patterns

As you might expect, consumption is not equal. The richest and the poorest sectors of society have different consumption patterns: those in the highest income brackets spend more on transport (they can afford it), compared to those with a lower income, who spend most of their available resources on food and drink.



Consumption patterns

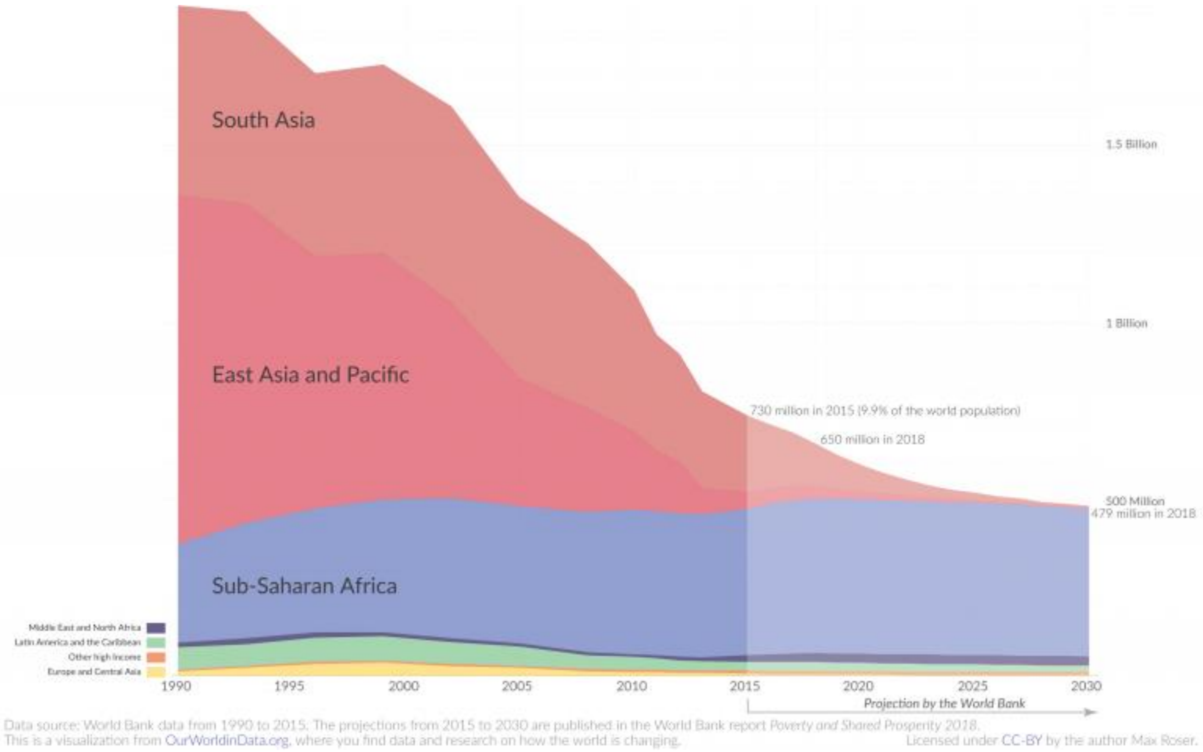
It is no surprise that the richest people in society also consume more than those living in poverty. World Bank data show that in 2005 the wealthiest 20% of the world accounted for 77% of all private consumption, and the poorest 5th just 1.5%. Or to put it another way, the poorest 10% accounted for just 0.5% of all that was consumed, whereas the wealthiest 10% consumed a whopping 59%!



Source: World Bank Development Indicators, 2008.

Consumption patterns

Furthermore, advances in technology and rising productivity means that the share of people living in extreme poverty has decreased considerably over the last 2 centuries. This is a remarkable achievement of humankind: quality of life has improved for billions of people. In 1990 an estimated 1.9 billion people were living in extreme poverty – today that stands at 650 million. However, as more countries become developed and more people move into a higher income bracket, this is inevitably putting even more strain on the earth's natural resources.



Consumption patterns

Compounding all of these problems even further is a modern shift towards products that are intentionally designed to be discarded after a short amount of time. Never before have human societies had access to so much, and discarded so much.

For example, in 2012, it was shown that only 1% of purchased goods were still in use after 6 months.

We truly live in a throwaway society.

Overconsumption

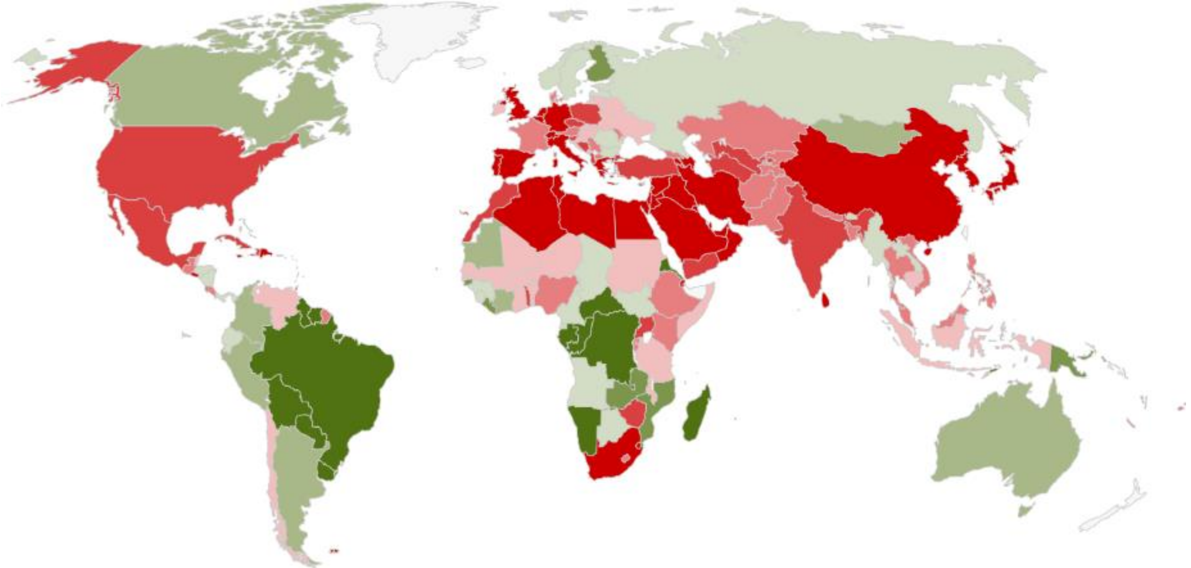
The goods and services humans consume all require a different resource and once that resource is exploited to a certain point, that qualifies as **overconsumption**. The idea of overconsumption is closely tied with **overpopulation**. Putting aside our throwaway habits, more humans on Earth simply require more resources.

A fundamental effect of overconsumption is a reduction in the planet's **carrying capacity**. Excessive unsustainable consumption will exceed the long term carrying capacity of its environment : this is known as **ecological overshoot** and results in subsequent resource depletion, environmental degradation and reduced ecosystem health.

Ecological Footprint

This leads us to the concept of **ecological footprint** which compares human demands on ecosystems with the amount of natural resources ecosystems can renew (**biocapacity**).

Currently, more than 80% of the world's population lives in countries that are running "ecological deficits". The USA for example, has only 4.6% of the world's population, but consumes 40% of the earth's natural resources. It has been said that if everyone consumed resources at the level of the USA, you will need another four or five Earths.



You can explore these data at www.footprintnetwork.org/ and calculate your own ecological footprint here: https://www.footprintcalculator.org/

Earth Overshoot Day

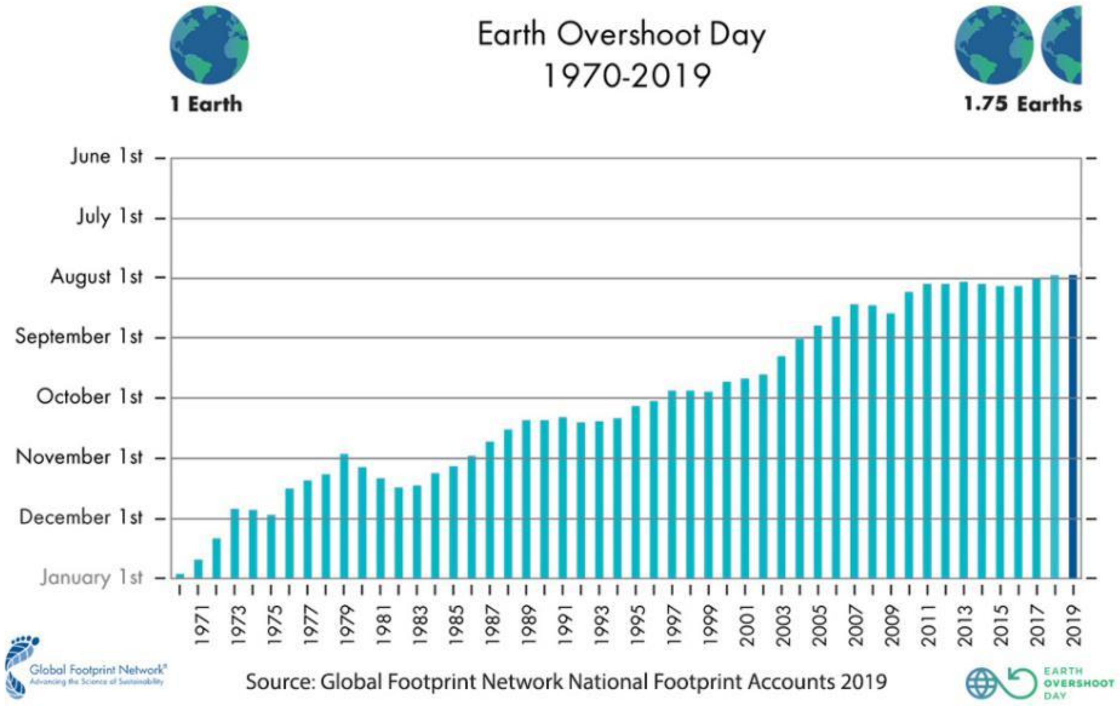
Earth Overshoot Day marks the date when humanity has officially consumed more ecological resources and services in a given year that the Earth can replenish in that year.

Earth Overshoot Day is computed by dividing the planet's **biocapacity** (the amount of ecological resources Earth is able to generate that year), by humanity's **Ecological Footprint** (humanity's demand for that year), and multiplying by 365, the number of days in a year.

The results are worrying:

- In1970, Earth Overshoot Day was 29th December
- In 1990, it was 11th October
- In 2000, it was 23rd September
- In 2019, it was 29th July

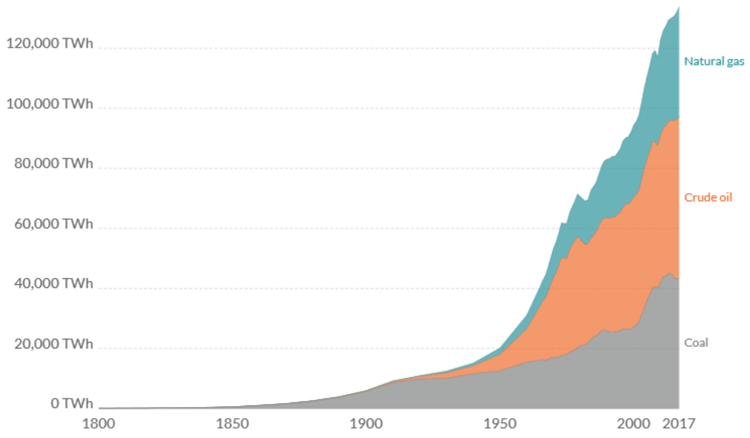
In just 50 short years, we have gone from living within our planet's means to requiring 1.75 Earths to sustain our way of life.



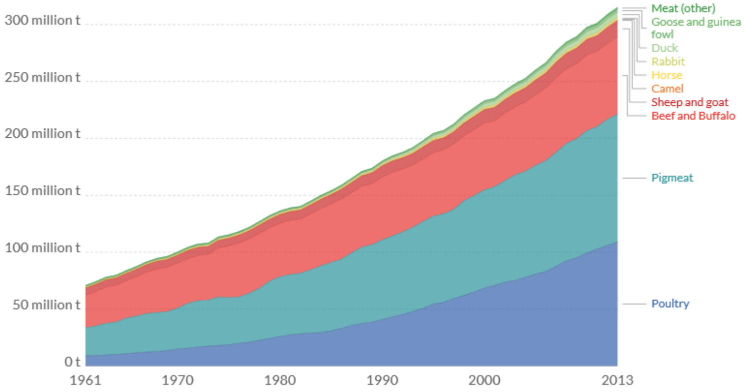
Consumption trends

We are devouring the earth's natural resources at unprecedented, and ever-increasing rates.

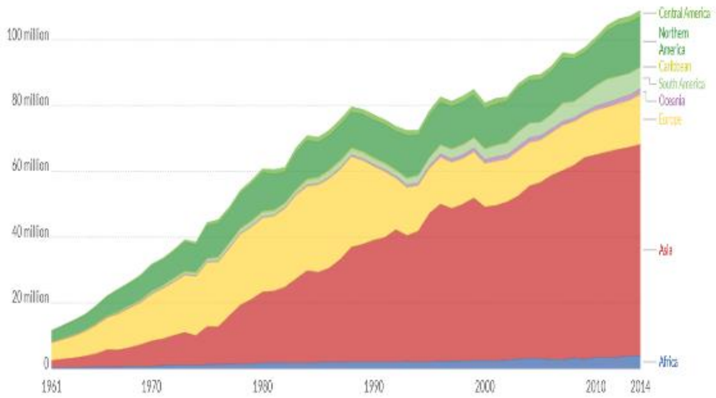
To give some examples, since 1960 global fossil fuel consumption has quadrupled, global meat (livestock) production and consumption has more than quadrupled, nitrogen fertilizer consumption has increased almost 9-fold, and global demand for timber has also increased ninefold.



Fossil fuel consumption



Global livestock production



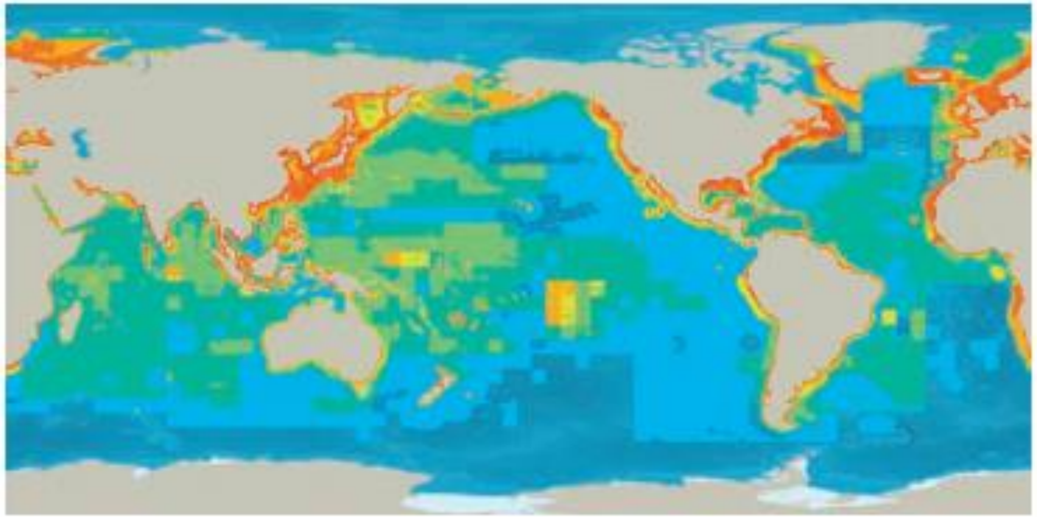
Nitrogen fertiliser consumption

Consumption trends

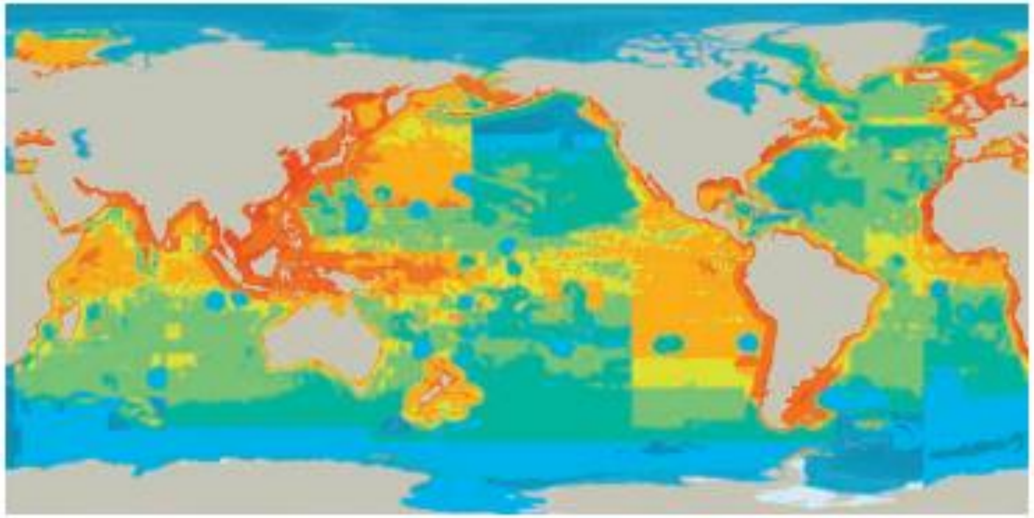
The oceans are also increasingly depleted of wildlife stocks. It is thought that almost 6 billion tonnes of fish and seafood have been extracted from the world's oceans since 1950.

This has increased from 28 million tons in 1950 to more than 110 million tons in 2014.

1950s



2000s



Average annual catches (blue = very little/none: red = intensive)

 https://c402277.ssl.cf1.rackcdn.com/publications/1187/files/original/LPR2018_Full_Report_Spreads.pdf

Over-hunting and bushmeat

Bushmeat has long been a traditional source of food for many rural people in developing countries, but the unregulated, illegal harvesting of wild meat has become a global crisis, accelerating in response to growing human populations and an increasing trend for wild meat to be traded commercially.

Bushmeat is not just an economic necessity for the rural poor, but also a cultural preference for many and a luxury good for the urban rich. In Africa alone, tens of millions of people eat bushmeat : urban populations in Gabon, DRC and CAR consume on average 4.7 kg/person/year[1]. Bushmeat can be found in markets and on dinner plates in Paris, LA and London: an estimated 40 tons of bushmeat is flown into Geneva and Zurich airports every year[2].

1. https://www.cifor.org/publications/pdf_files/articles/ANasi1101.pdf
2. https://news.mongabay.com/2017/03/endangered-species-to-declare-europes-understudied-bushmeat-trade/

 https://www.conservation.org/blog/eating-wild-animals-commonplace-cultural-complicated

Over-hunting and bushmeat

The scale of the global bushmeat trade is difficult to measure but the Center for International Forestry Research (CIFOR) has estimated that more than 6 million tonnes of animals are taken from the Amazon and Congo Basins each year[1].

As logging roads have opened up previously inaccessible areas of rainforest, hunting access has become easier and large-scale commercial hunting is leaving tropical forests and other habitats devoid of wildlife. The widespread use of firearms and motorized transport has also made hunting a lot more efficient.

1. https://www.cifor.org/publications/pdf_files/articles/ANasi1101.pdf

Overhunting and body parts

In addition to hunting for food, many animals are killed for their body parts, whether it be for hunting trophies, medicinal use, spiritual purposes or for ornaments and jewelry.

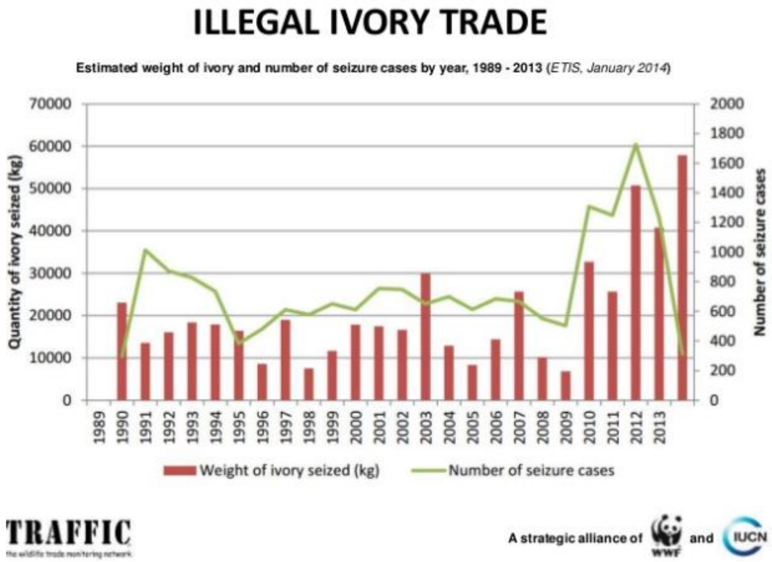
Some examples:

- a lucrative business in ape body parts is devastating dwindling gorilla populations in Nigeria, where they are considered vital items for worship and ritual in traditional religions that are practiced and followed by millions of people[1].
- Lions have already gone extinct in 38% of their former range states in Africa, yet body parts such as skin, claws, teeth and bones are still in high demand across the continent for use in traditional medicine and witchcraft[2].

1. https://www.projetogap.org.br/en/noticia/what-is-magic-without-ape-parts-inside-the-illicit-trade-devastating-nigerias-apes/
2. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0187060

Overhunting and body parts

- The most trafficked animal in the world is the beleaguered pangolin, of which there are 8 species, all threatened with extinction. Despite their elusive, nocturnal nature, they are heavily hunted: their meat is a delicacy in Asia and their scales are used in Chinese medicine and in traditional medicine across Africa. According to IUCN, more than a million pangolins were poached between 2004 and 2014.
- The international ivory market is thought to be worth around 19M € globally, and is decimating elephant populations in many countries. Some 16,000 elephants are illegally poached in Central Africa each year: this has led to a loss of more than 60% of forest elephants since 2002.



Over-hunting and mass extinction

A recent major global assessment[1] revealed that over 300 mammal species in Asia, Africa and Latin America are being literally eaten into extinction. Orders with the most species threatened by hunting include primates (168 species), even-toed ungulates (73 species), bats (27 species) and carnivores (12 species). 100% pangolin species, 50% odd-toed ungulates and 31% all primates are at risk of over-hunting.

Many beloved and flagship species, such as the western lowland gorilla, chimpanzee, tiger, hippopotamus, pangolin, mandrill, ring-tailed lemur, wild yak, bactrian camel, black rhinoceros, and clouded leopard are under serious threat from hunting.

This is part of a larger trend known as a "mass extinction event," only the sixth time in half a billion years that Earth's species are dying out at more than 1,000 times the usual rate.

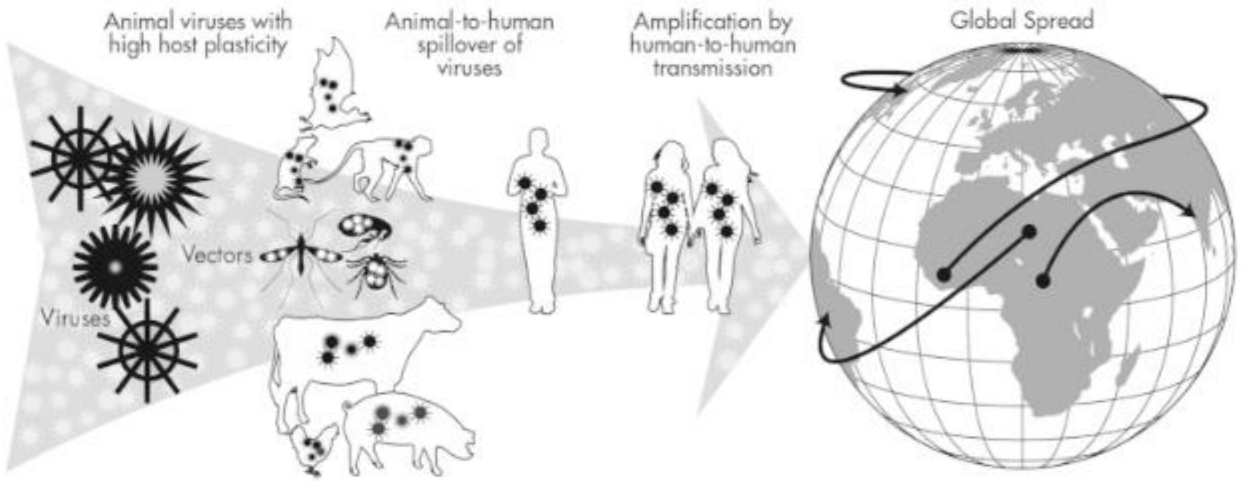
Mass extinction events are discussed a bit more in the next section.

1. Ripple et al., (2016). Bushmeat hunting and extinction risk to the world's mammals. R.Soc.opensci. 3: 160498

Over-hunting and emergent disease

Aside from irretrievable biodiversity loss, poaching and wildlife trafficking also pose serious threats to public health.

When humans are exposed to wildlife, particularly through hunting, butchering carcasses or preparing fresh meat, they are also exposed to the live viruses and other pathogens that the animal may be carrying. In many cases, because the pathogen has not evolved to infect humans, it has little effect. However, sometimes it mutates, acquiring characteristics that allow it to infect its new host. This is known as **cross-species pathogen transmission**, and once transmitted within human populations it can have devastating consequences.



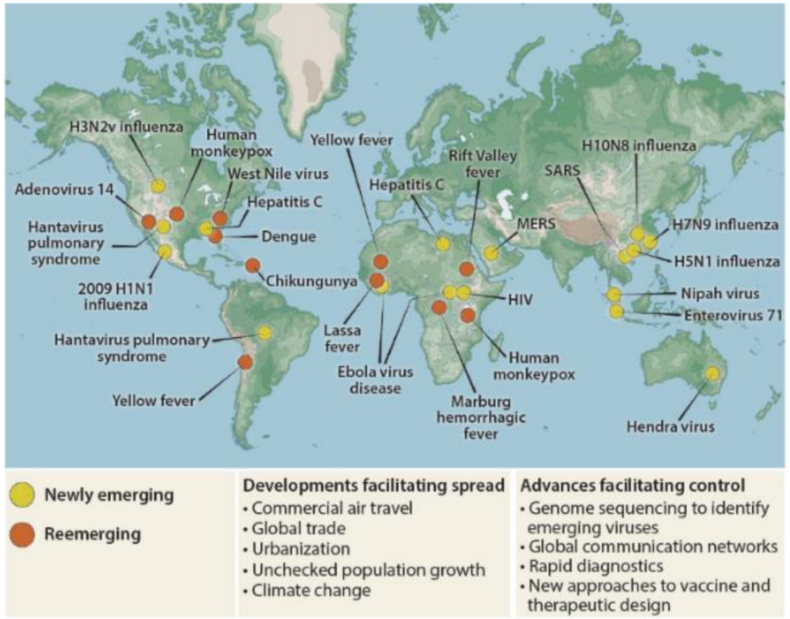
Kreuder Johnson C et al. Spillover and pandemic properties of zoonotic viruses with high host plasticity. *Sci Rep*. 2015;5:14830.

Over-hunting and emergent disease

Such new diseases are known as **emergent disease,** and can cause epidemics or **pandemics** (epidemics of worldwide proportions). Many diseases that have infected and killed thousands or millions of people are of zoonotic origin: these include smallpox (primates), "Spanish" influenza (water birds), HIV (chimpanzees), SARS (bats), Ebola (bats), bubonic plague (rats and fleas), and more recently Coronavirus (thought to be from horseshoe bats).

Pathogens are more likely to shift between closely related species, which is why humans are more likely to get diseases from bats than crickets, and why it is particularly dangerous for humans to eat primate meat[1]. Sometimes the pathogen passes through an intermediate host to infect humans- for example Ebola is thought to originate in bats, but is fatal to gorillas and chimpanzees. Humans can become infected either directly from bats, or when they eat infected ape meat.

You can explore a real-time map to track the global spread of Coronavirus here: https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6



1. https://www.globalmeatnews.com/Article/2016/05/11/Monkey-consumption-a-threat-to-mankind

 Map Source: Marsten et al., 2014. Emerging Viral Diseases: Confronting Threats with New Technologies. *Science Translational Medicine*, 6: 253ps10

9.4

Habitat and biodiversity loss

Habitat loss and landuse conversion

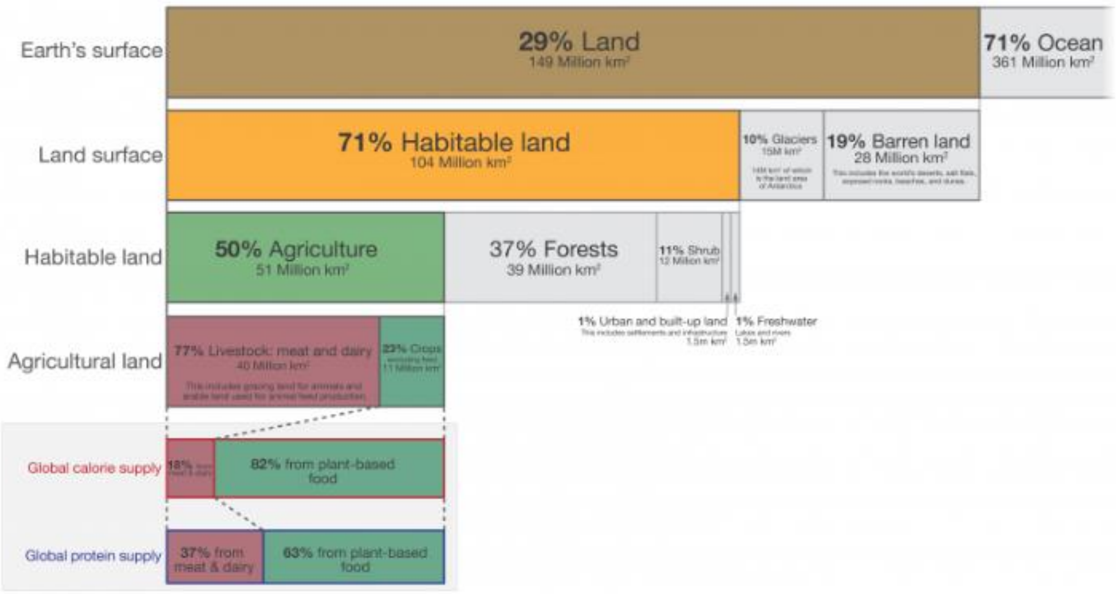
The clearance and destruction of natural habitat by humans is mainly done for the purposes of industrial production and urbanization. When natural habitats are lost, they are often converted to another landuse type. For example, habitat conversion could refer to a patch of forest or grassland that is converted to an oil palm plantation. The integrity of the original ecosytem is lost.

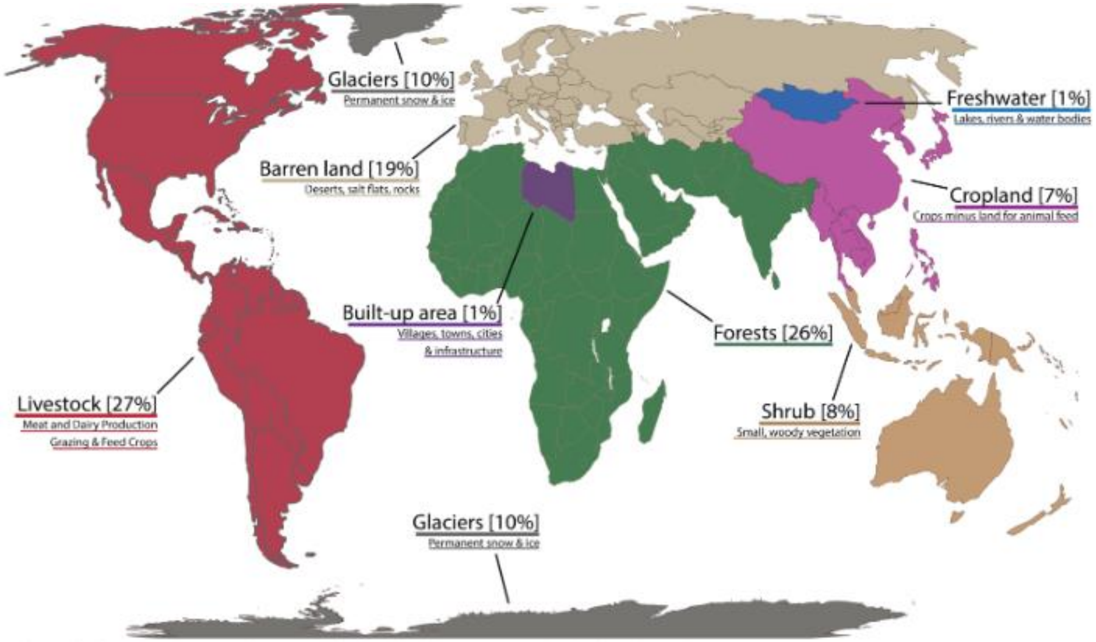
Vast areas of the earth's terrestrial surface are now used for agriculture, with mining, logging, trawling, and urban sprawl also important drivers of natural habitat loss.

Habitat loss and landuse conversion

A thousand years ago only 4% of the world's habitable land was used for agriculture. Today this stands at 50%: agricultural expansion and the conversion of wild lands to cropland and pasture has been one of humanity's biggest impacts on the earth. You may be surprised to learn that only 1% of our habitable land is covered by urban areas including cities, towns, villages and roads. This leaves just 37% for forests and11% for shrubs and grasslands.

What is striking is that livestock accounts for 77% of the agricultural land we use: this is equivalent to the whole of North and South America combined! However livestock only produces 18% of the world's calories and 37% of total protein.

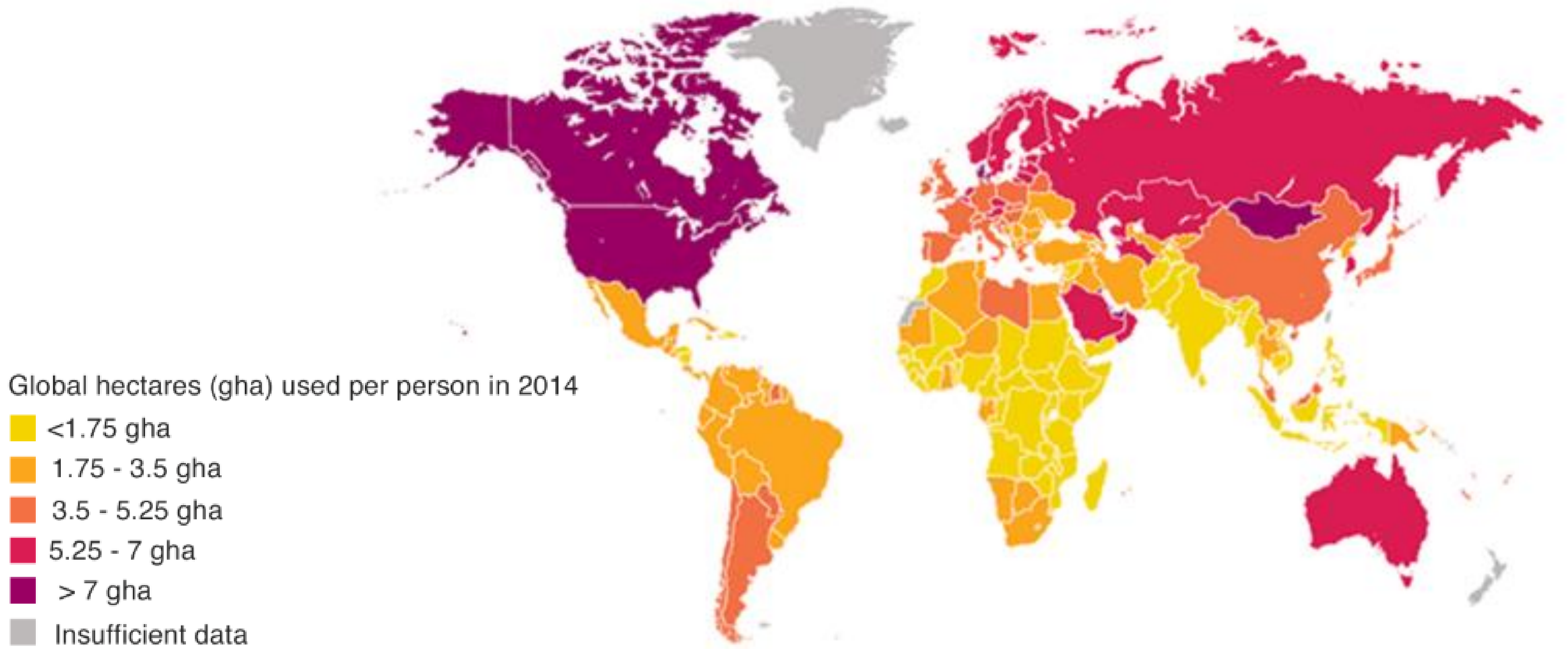




Source: https://ourworldindata.org/land-use

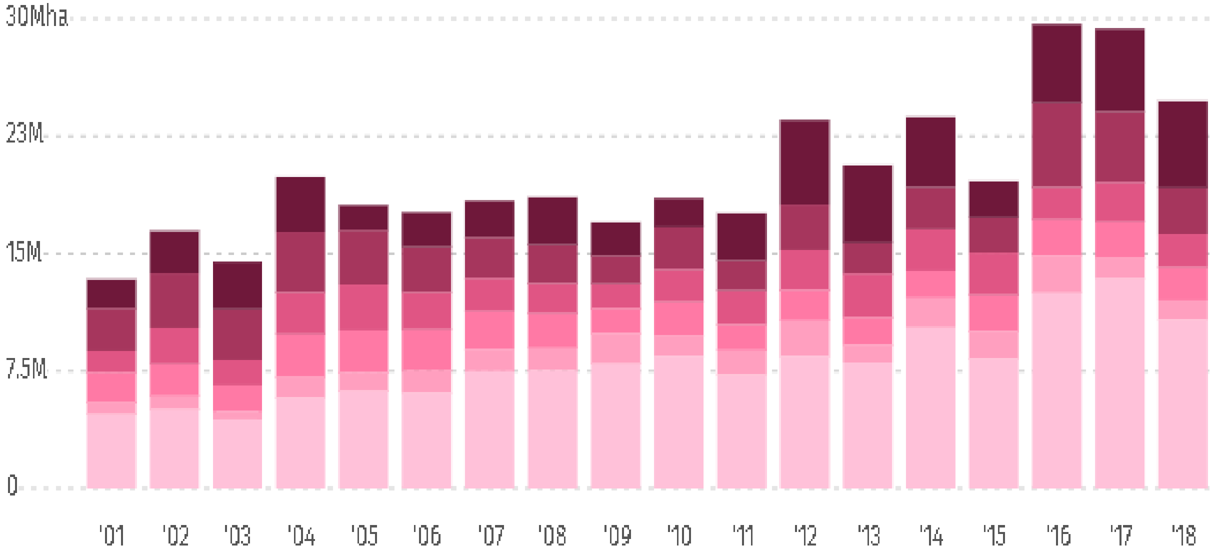
Habitat loss and landuse conversion

Overall, it is estimated that only a quarter of the world's land area is now free from the impact of human activity.



Forest loss

Advances in remote sensing technology allow the earth's forest cover change to be continuously monitored, and many free online tools exist, such as Global Forest Watch. Data show us that between 2000 and 2018 the earth lost a total of 361 million ha forest, or about 20 million ha every year, with deforestation rates increasing over time. This is equivalent to a 9% decrease in tree cover since 2000.



1. https://earthenginepartners.appspot.com/science-2013-global-forest 2. https://www.globalforestwatch.org/dashboards/global

Habitat loss and degradation

Habitat loss- or destruction- can be considered different to degradation. Habitat destruction occurs when a natural habitat can no longer support its native species. For example, deforestation refers to areas of forested habitat that are completely lost, thus they no longer remain forest.

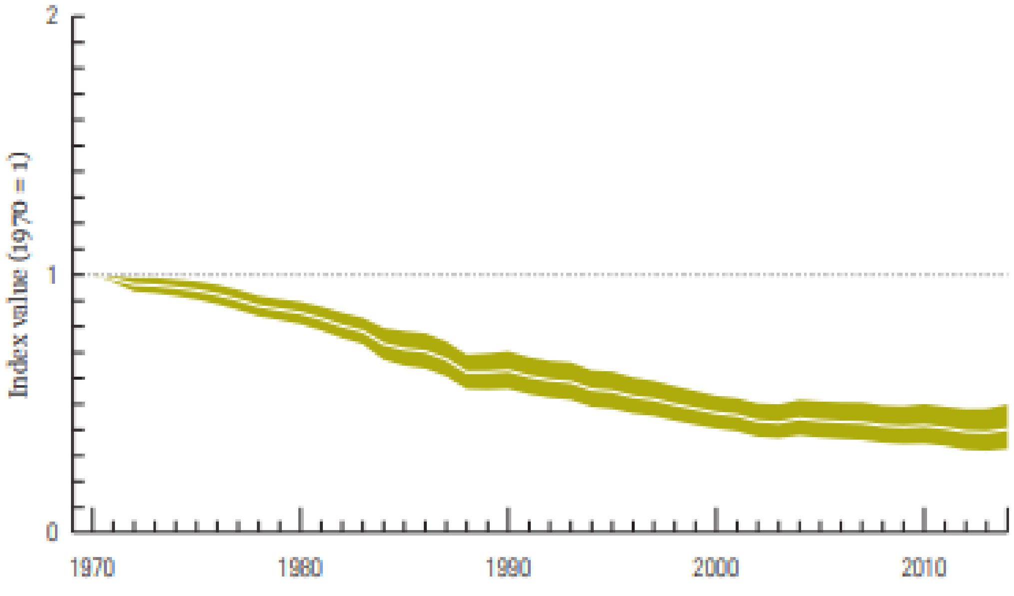
Degradation is when damage to a habitat occurs but it remains intact. Selective logging practices cause degradation to forests, but the forest remains forest, albeit with some damage to its structure and composition and maybe some biodiveristy loss. Of course, micro-habitats can be lost within a degraded habitat, but on a global scale, habitat loss usually means the wide-scale clearance and conversion of entire habitats.

The loss and degradation of habitat is not only a major source of CO_2 emissions, but also of biodiversity and indigenous ways of life.

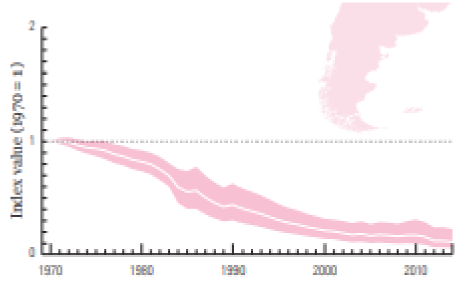
Biodiversity loss

Hand in hand with habitat loss, the earth is suffering increasing rates of biodiversity loss. The Global Living Planet Index compiled existing data on wildlife populations from 1970 to 2014. They found that the average abundance of 16,704 populations, equivalent to 4,005 species, declined by 60% during that time.

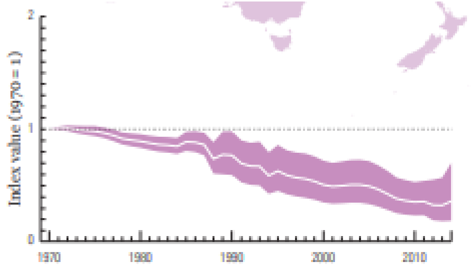
All regions suffered losses, but the most dramatic declines were seen in the tropics, which suffered a loss of 89% in the abundance of wildlife populations.



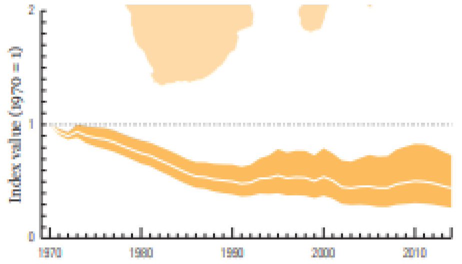
Globally: 60% decline



89% Neotropics: 89% decline



Indo-pacific: 64% decline

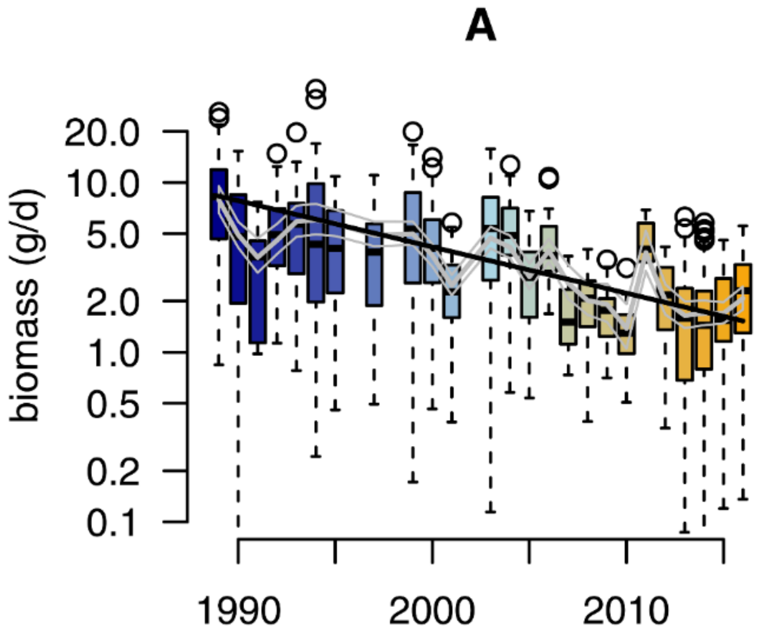


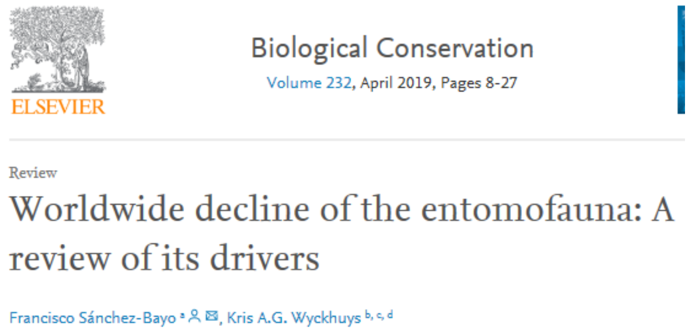
Afro-tropics: 56% decline

https://c402277.ssl.cf1.rackcdn.com/publications/1187/files/original/LPR2018_Full_Report_Spreads.pdf

Biodiversity loss

Other studies have shown similar, shocking trends. The biomass of flying insects has dropped by 75% in protected areas in Europe since 1990, and globally, insect biomass is decreasing by 2.5% / year. It has been estimated that more than 40% insect species could go extinct within the next three decades.





ELSEVIER

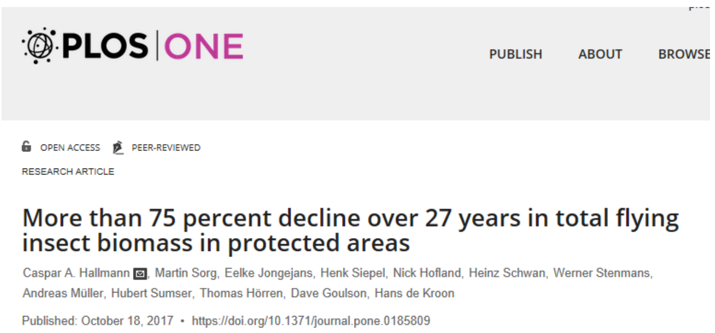
Biological Conservation

Volume 232, April 2019, Pages 8-27

Review

Worldwide decline of the entomofauna: A review of its drivers

Francisco Sánchez-Bayo [a], Kris A.G. Wyckhuys [b, c, d]



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RESEARCH ARTICLE

More than 75 percent decline over 27 years in total flying insect biomass in protected areas

Caspar A. Hallmann, Martin Sorg, Eelke Jongejans, Henk Siepel, Nick Hofland, Heinz Schwan, Werner Stenmans, Andreas Müller, Hubert Sumser, Thomas Hörren, Dave Goulson, Hans de Kroon

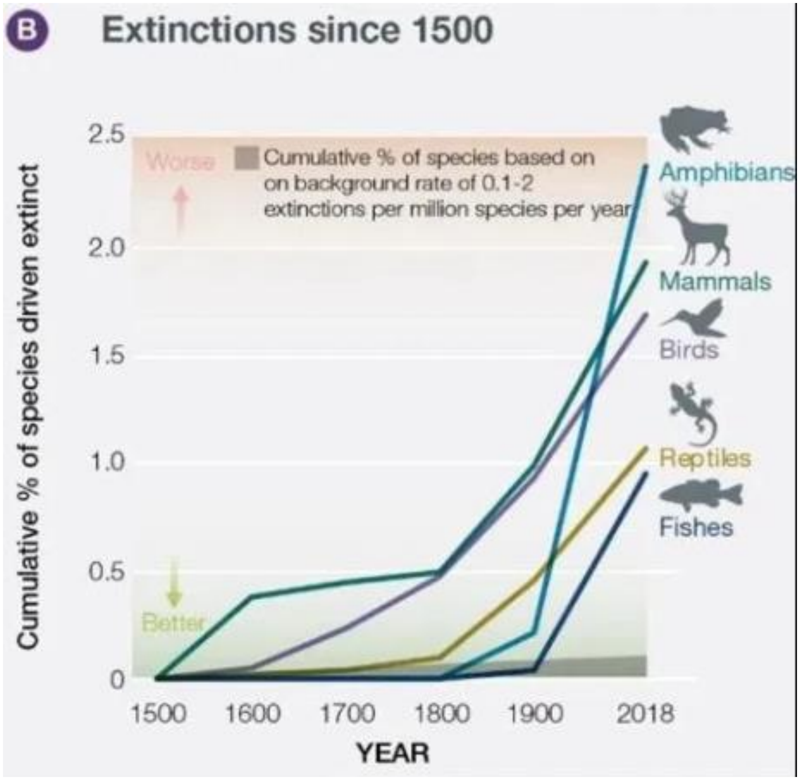
Published: October 18, 2017 • https://doi.org/10.1371/journal.pone.0185809

Mass Extinction

Species extinction is a natural consequence of the evolutionary process, and 'background extinction rates' are often used to compare mass extinction events. Because we don't know how many species exist today, or in the past, it is notoriously difficult to measure.

However, research shows that at least five major mass extinctions have occurred in the last 540 million years[1], and that we are currently experiencing a sixth mass extinction caused by human activity. This is resulting in extinction rates over 1000 times the background rate since 1900[2].

A recent study by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has predicted that **one million species** will become **extinct in the next few decades**, unless action is taken to reduce the intensity of the drivers of biodiversity loss[3].



https://ipbes.net/global-assessment

1. Gould, S.J. (March 1, 2004). "The Evolution of Life on Earth". *Scientific American*. **271**(4): 84–91
2. Malcolm L. McCallum (27 May 2015). "Vertebrate biodiversity losses point to a sixth mass extinction". *Biodiversity and Conservation*. **24** (10): 2497–519
3. https://ipbes.net/global-assessment

9.5

Pollution

Pollution

Pollution is the introduction of contaminants into the natural environment, that cause adverse change. Environmental pollution is considered one of the most serious problems facing humanity and life on earth.

There are many types of pollution including chemical pollution into the air, bodies of water and soil, noise and light pollution created by cities and urbanization as a result of population growth.

Air pollution

Air pollution occurs when harmful or excessive quantities of substances including gases, particles and biological molecules are introduced into the earth's atmosphere. There are two types of air pollutant: primary and secondary. **Primary pollutants** are emitted directly from their source, while **secondary pollutants** are formed when primary pollutants react in the atmosphere.

While most sources of air pollution are anthropogenic in origin (e.g. transport, industry, agriculture, urban areas) some are natural (wildfire, volcanoes, wind-blown dust).

The burning of **fossil fuels** for transportation and electricity produces both primary and secondary pollutants and is one of the biggest sources of air pollution. The heavy use of fertilizer for agriculture is also a major contributor of fine-particulate air pollution. Agricultural air pollutants include ammonia, pesticides, herbicides, and fungicides.

Air pollution generates major environmental problems including acid rain, depletion of the ozone layer, global warming and the greenhouse effect.
It is also one of the leading risk factors for death across the world[3]: a well-known risk factor for cardiovascular and bronchial disease, lung cancer and respiratory infections, particulate air pollution is thought to kill between 5 -7 million people a year[1,2].

1. GBD 2017 Risk Factor Collaborators. "Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017." (2018).
2. UN Environment (2019). Global Environment Outlook- GEO-6: Healthy Planet, Healthy People. Nairobi.
3. https://ourworldindata.org/air-pollution

Air pollution

Major primary air pollutants include: Carbon dioxide, Sulphur oxides, Nitrogen oxides, Carbon monoxide, Methane, Ozone, CFCs, ammonia, particulate matter and radioactive pollutants.

- **Carbon dioxide** is considered the leading pollutant due to its role as a greenhouse gas, it is the main contributor to climate change, especially through the burning of fossil fuels.
- **Sulphur dioxide** is produced by volcanoes, fossil fuel combustion and industrial processes. SO_2 reacts in the atmosphere with water vapour to form sulphuric acid which comes down as acid rain.
- **Nitrous oxide** is released by chemical fertilizers and burning fossil fuels, and has a global warming potential 310 times that of carbon dioxide. Agriculture is a major source of nitrous oxide.
- **Methane** is produced naturally when vegetation is burned, digested or rotted without the presence of oxygen. Large amounts of methane are released by cattle farming, waste dumps, rice farming and the production of oil and gas. Oil and gas drilling and hydraulic fracturing ("fracking") operations are also major sources of methane pollution, via leaks from damaged or improperly fitted equipment.
- **Ammonia** is the primary air pollutant that comes from agricultural activities: it enters the air as a gas from concentrated livestock waste and fields that are over fertilized. This then combines with other pollutants such as nitrogen oxides and sulphates created by vehicles and industrial processes, to create aerosols.

Water pollution

Water pollution results when contaminants —often chemicals or microorganisms— are introduced into water bodies, degrading water quality and rendering it toxic to humans or the environment.

A major cause of water pollution is sewage, garbage and liquid waste water, which is discharged from households, agricultural lands and factories into lakes and rivers. Other causes of water pollution include mining activities, the dumping of household and industrial waste into rivers, lakes or the sea, oils spills, acid rain caused by fossil fuel burning, use of chemical fertilisers and pesticides that mix with rain, and landfill leakage.

Agriculture is the leading cause of water degradation around the world[1] and it is estimated that around 80% of the world's wastewater is dumped back into the environment, largely untreated[2].

One of the main consequences of water pollution is that it causes loss of aquatic life and biodiversity, either through poisoning, disease, disruption of food chains or ecosystem degradation. Water pollution is also a major global health problem, thought to kill1.5 million people a year[3].

1. Mateo-Sagasta et al., (2017). Water pollution from agriculture: a global review. FAO, Italy.
2. WWAP (2017).The United Nations world water development report 2017: wastewater: the untapped resource; facts and figures
3. UN Environment (2019). Global Environment Outlook- GEO-6: Healthy Planet, Healthy People. Nairobi.

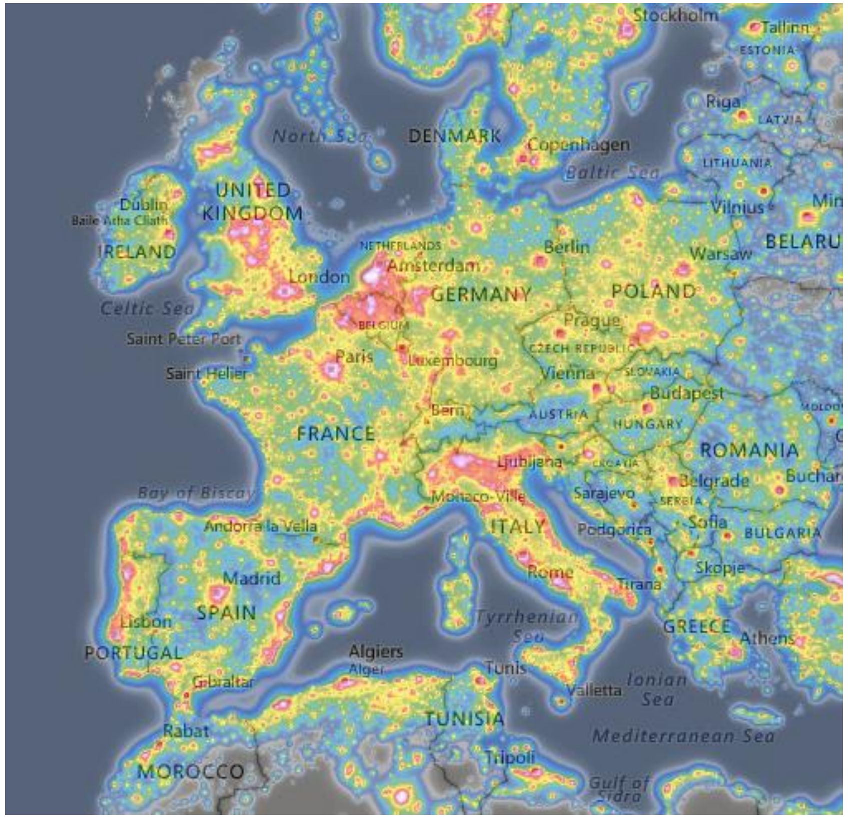
Light pollution

Light pollution is the excessive or inappropriate use of artificial light in the night environment. It is side-effect of our industrialised society. However, life has evolved on earth to the natural rhythms of light and dark created by the sun, moon and stars. The disruption of these cycles affects life-sustaining behaviours such as reproduction, predator-prey relationships and sleep, having negative and even fatal effects on wildlife.

Nocturnal animals are the most affected: light pollution radically alters the environment by turning night into day, making it more difficult for prey to avoid predators.

Glare from artificial lights can impact wetland habitats that are home to amphibians such as frogs and toads, whose night-time croaking is part of the breeding ritual.

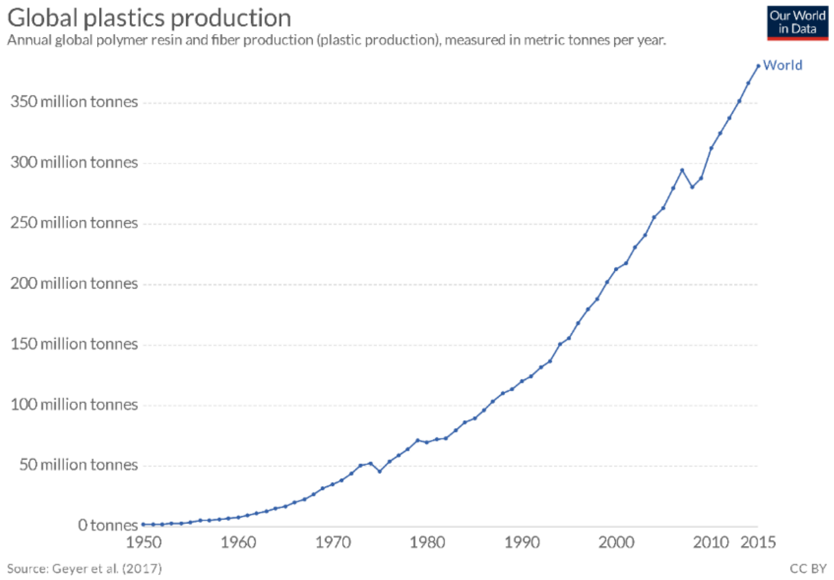
In coastal towns and cities near turtle nesting grounds, lights disorientate hatchling turtles who follow the light of the ocean’s horizon, leading them away from the ocean. Millions of hatchlings die this way every year.

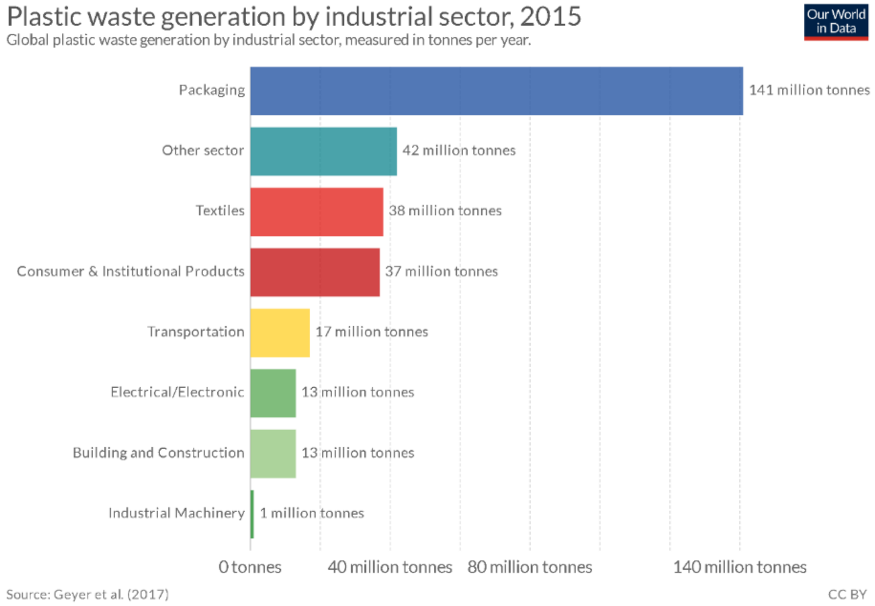


https://www.lightpollutionmap.info/

Plastics

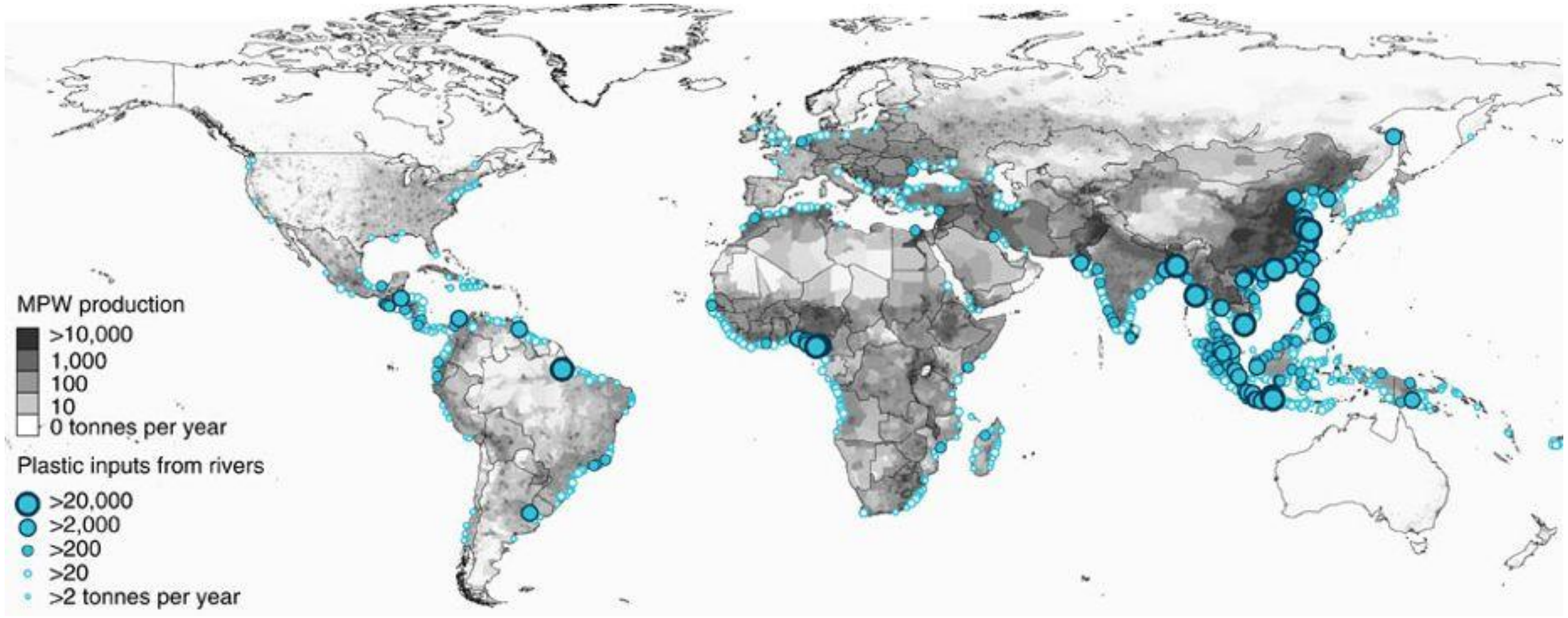
Because plastics have become such an integral, yet unsustainable part of our lives, they merit particular attention. The first plastic – Bakelite- was invented in the early 20th century but plastics did not see a rapid growth until the 1950s. Since then, plastic production has increased by about 200 fold, to about 381 million tons in 2015. Cumulatively, this amounts to 7.8 billion tonnes of plastic ever produced- more than 1 tonne for every person alive today. The vast majority of plastic waste is attributed to packaging, which represents almost half the world's plastic waste. This is partly because packaging has a very short user lifetime- usually 6 months or less before it is discarded.





Plastics

Only about 20% of plastic waste is recycled- 25% is incinerated and 55% discarded. Discarded plastic that has a user life of minutes ends up in landfills where it may take up to 500 years to decompose. More than 8 million tons of plastic waste is estimated to reach the oceans every year. Here, rivers play an important role in transporting mismanaged plastic waste from land into the ocean. Just 20 rivers are responsible for two-thirds of the global plastic input to the oceans. These are mainly in Asia, with the top polluting river- the River Yangtze in China - contributing about 4% of annual ocean plastic pollution (333,000 tonnes in 2015).



LeBreton et al., 2017. River plastic emissions to the world’s oceans. Nature Communications, 8, 15611

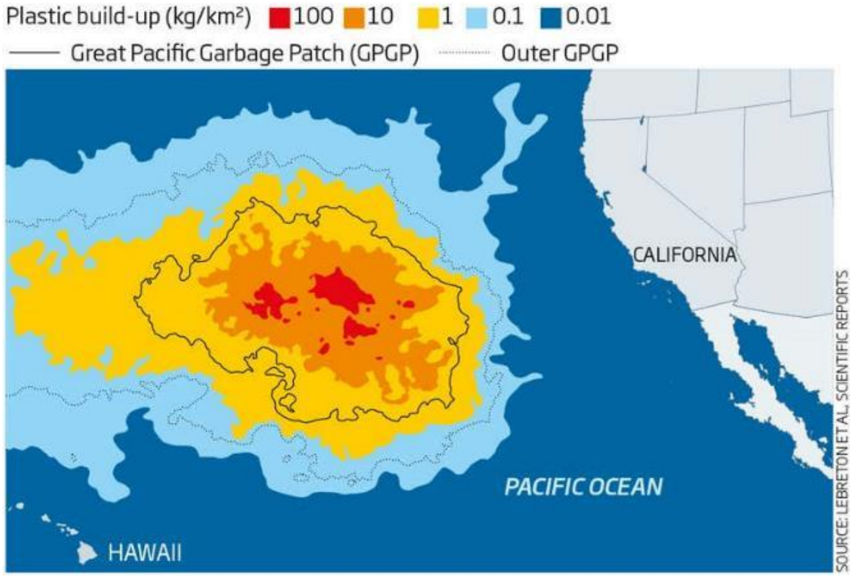
Plastics

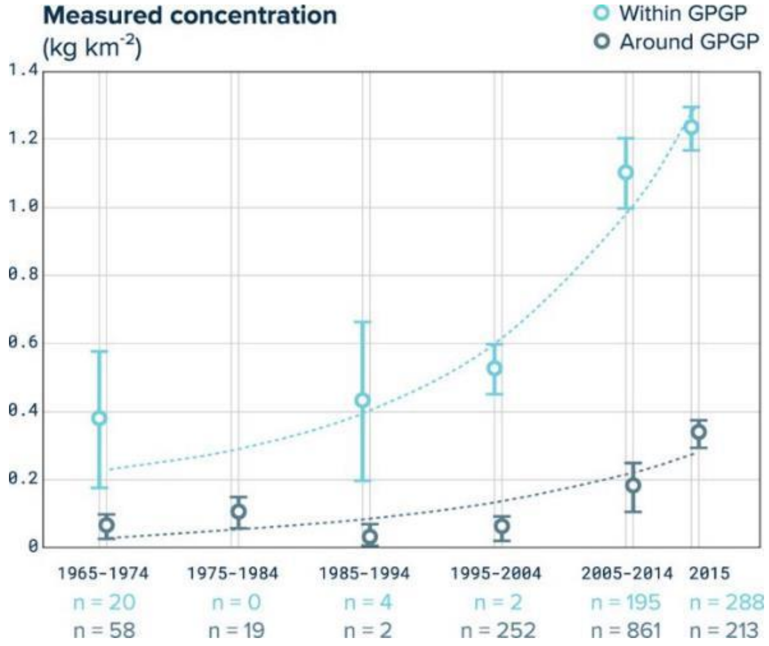
The distribution and accumulation of ocean plastics is strongly influenced by oceanic surface currents and wind patterns. As plastics are buoyant and float, they tend to accumulate in oceanic gyres, which are large systems of circulating ocean currents. There are five gyres —the North Atlantic Gyre, the South Atlantic Gyre, the North Pacific Gyre, the South Pacific Gyre, and the Indian Ocean Gyre. All contain high concentrations of plastics.

Le Breton et al., 2018. Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports. 8, 4666

Plastics

The most well-known example of large plastic accumulations in ocean waters is the 'Great Pacific Garbage Patch' (GPGP) located in the North Pacific gyre off the coast of California. It spans 1.6 million km^2- an area 3 times the size of France. 1.8 trillion pieces of plastic, weighing 79,000 tonnes are estimated to be floating within its perimeter, and it is accumulating ocean plastic pollution at an exponential rate.





Le Breton et al., 2018. Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports. 8, 4666

Plastics

Plastic pollution has a deadly effect on wildlife: thousands of marine animals are killed each year by ingestion or entanglement. Sea turtles mistake floating plastic such as plastic bags for food, such as jellyfish; it is estimated that half of all sea turtles worldwide have ingested plastic. Fish, seabirds and marine mammals are all increasingly found with large quantities of plastic waste in their stomachs, including micro-plastics[1,2].

More alarmingly, new research indicates that micro-plastics are found everywhere on earth, even in the remotest places such as mountain-tops and deepest ocean[3].

The consequences of this global accumulation of plastic waste is expected to be great. Not only is it catastrophic for marine biodiversity and ecosystem health, microplastics move up the food chain and end up being ingested by humans, with unknown consequences for health.

Further, a 2018 survey by the Global Oceanic Environmental Survey (GOES) Foundation predicted that – due plastic, ocean acidification and ocean pollution - marine ecosystems may collapse in the next 25 years, potentially causing failure of terrestrial ecosystem and "very possibly the end of life on Earth as we know it"[4].

Despite this, the fossil fuel industry plans to **increase plastic production** by 40% over the next decade[5].

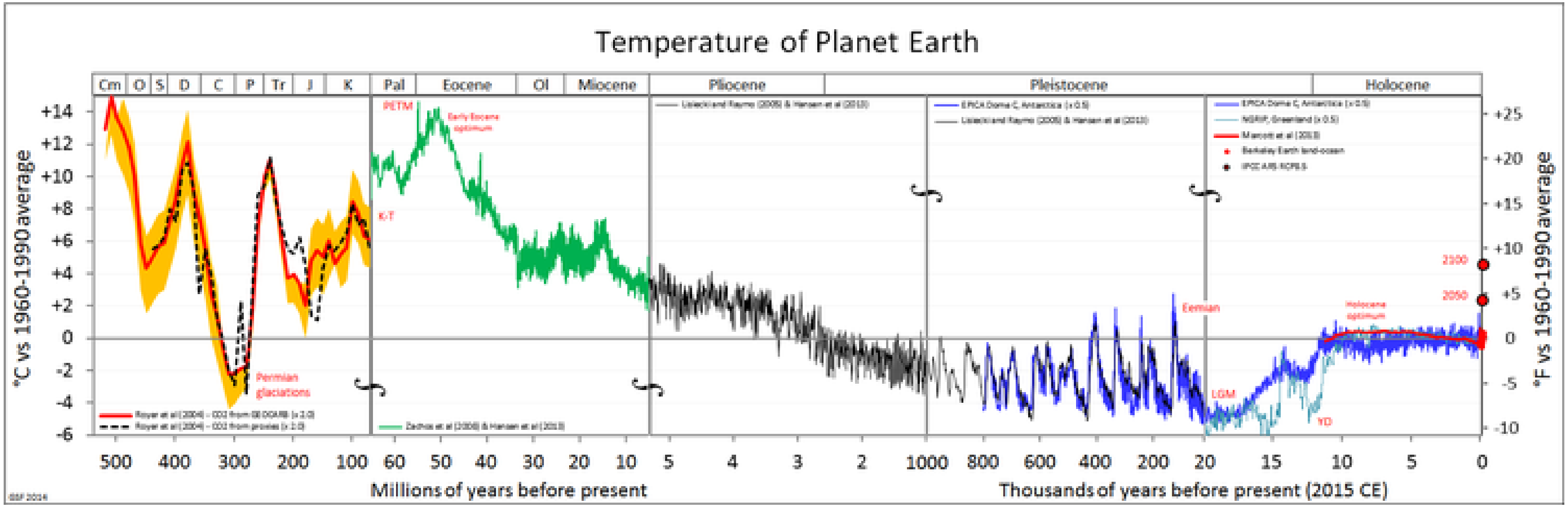
1. https://www.vox.com/2019/5/24/18635543/plastic-pollution-bags-whale-stomach-beached
2. Moore et al., 2019. Microplastics in beluga whales (*Delphinapterus leucas*) from the Eastern Beaufort Sea. Marine Pollution Bulletin, v150: 110723
3. https://www.theguardian.com/environment/2019/mar/07/microplastic-pollution-revealed-absolutely-everywhere-by-new-research
4. https://www.goesfoundation.com/
5. https://www.theguardian.com/environment/2017/dec/26/180bn-investment-in-plastic-factories-feeds-global-packaging-binge

9.6

Climate change

Past climate change

Climate change is nothing new for the planet: throughout Earth's history, climatic changes have occurred on regional and global scales. For at least the last million years, our world has experienced cycles of glacial and interglacial periods that take approximately 100,000 years to complete. Currently, the Earth is in an interglacial period, beginning about 20,000 years ago. The Paleozoic era, from 542- 252 million years ago was marked by massive temperature fluctuations as continental masses shifted around the Earth's surface.



https://commons.wikimedia.org/wiki/File:All_palaeotemps.png

Past climate change

Mostly climatic changes have happened gradually, slowly enough that the long-term feedbacks of Earth's climate system have had time to process them. For example, during the glacial-interglacial cycles of the ice ages, changes in temperature and CO_2 levels occurred over tens to hundreds of thousands of years, enough for deep oceans and ice sheets to keep pace.

During the Cretaceous thermal maximum about 90 million years ago, the earth was several degrees warmer than it is today. Temperate forests grew in the poles and tropical conditions were found in Northern Europe. Although CO_2 levels rose to over 1000ppm (almost four times higher than pre-industrial levels of 280ppm) they did so over a 20 million year period, when massive undersea volcanoes belched out vast quantities of CO_2. Life flourished during this, and other times of high atmospheric CO_2 because the greenhouse gases were in balance with the carbon in the oceans and the weathering of rocks. Life, ocean chemistry, and atmospheric gasses had millions of years to adjust to those levels.

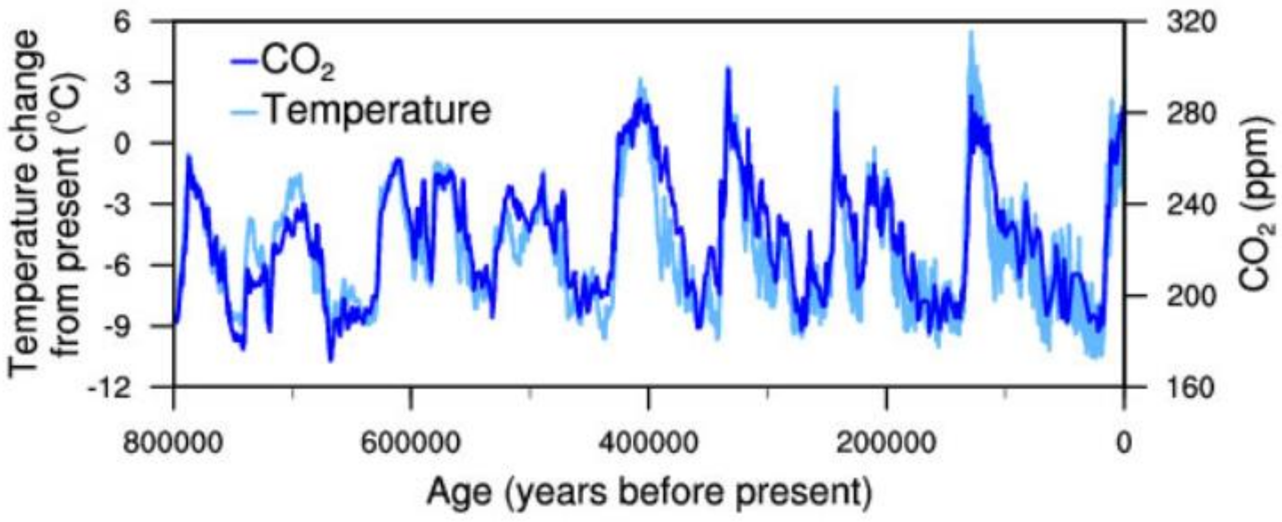
However, at other times, past climatic changes have been abrupt, and this is when mass extinctions have occurred.

The most severe in Earth's history is the Permian mass extinction which occurred around 252 million years ago wiping out almost all life on earth. Here, 96% marine and 70% terrestrial species were killed off. It is thought the Permian mass extinction was caused by massive volcanic eruptions that released huge amounts of sulphur dioxide and carbon dioxide into the air, heating the atmosphere and acidifying the oceans. The key difference here is that research indicates it occurred almost instantaneously in geological terms: while the extinctions took around 60,000 years to happen, the initial carbon emissions that triggered them only took between 2,100 and 18,800 years **(ref)**

Past climate change

Important points to note are:

- During the glacial cycles of the past several hundred thousand years, CO_2 levels and temperature have been very closely correlated : this is consistent with a feedback between carbon dioxide and climate
- Rapid global warming events have almost always been highly destructive for life, causing mass extinctions
- While the Earth has already experienced global temperatures and CO_2 levels higher than the increases predicted for the coming century, the impacts of current climate change are going to be felt by societies, species and ecosystems that are adapted for Holocene climates – not climates 100 million years ago.



Temperature change (light blue) and carbon dioxide change (dark blue) measured from the EPICA Dome C ice core in Antarctica (Jouzel et al. 2007; Lüthi et al. 2008).

Climate v weather

Although there is much talk of weather and climate there is often confusion between the two.

Just so it’s clear, weather refers to short term atmospheric conditions: the way the atmosphere is behaving now, and short-term (minutes to months) changes in the atmosphere. Most people think of weather in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure.

Climate, however, refers to long-term changes and trends in weather in a particular region for an extended period of time- usually at least 30 years.

When scientists talk about climate, they're looking at averages of precipitation, temperature, humidity, solar radiation, wind speed and other measures of the weather that occur over a long period in a particular place.

Climatic changes today

While global climate has been relatively stable over the last 10,000 years—the span of human civilization- it is now undergoing a period of rapid change.

The overwhelming scientific consensus is that human activities are the cause of this change, largely through the burning of fossil fuels and deforestation of large areas of land.

These activities have primarily led to the increase in three key greenhouse gases in the atmosphere: carbon dioxide, methane, and nitrous oxide.

What are greenhouse gases?

Before we look at greenhouse gas concentrations and emissions in a bit more detail, it is a good place to revisit what greenhouse gases (GHGs) actually are.

Very simply put, they are gases in Earth's atmosphere that trap heat. They let sunlight pass through the atmosphere, but they prevent the heat that the sunlight brings from leaving the atmosphere. More technically, they are gases that absorb and emit infrared radiation in the wavelength range emitted by Earth.

The primary **GHGs** in Earth's atmosphere are water vapor and clouds (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).

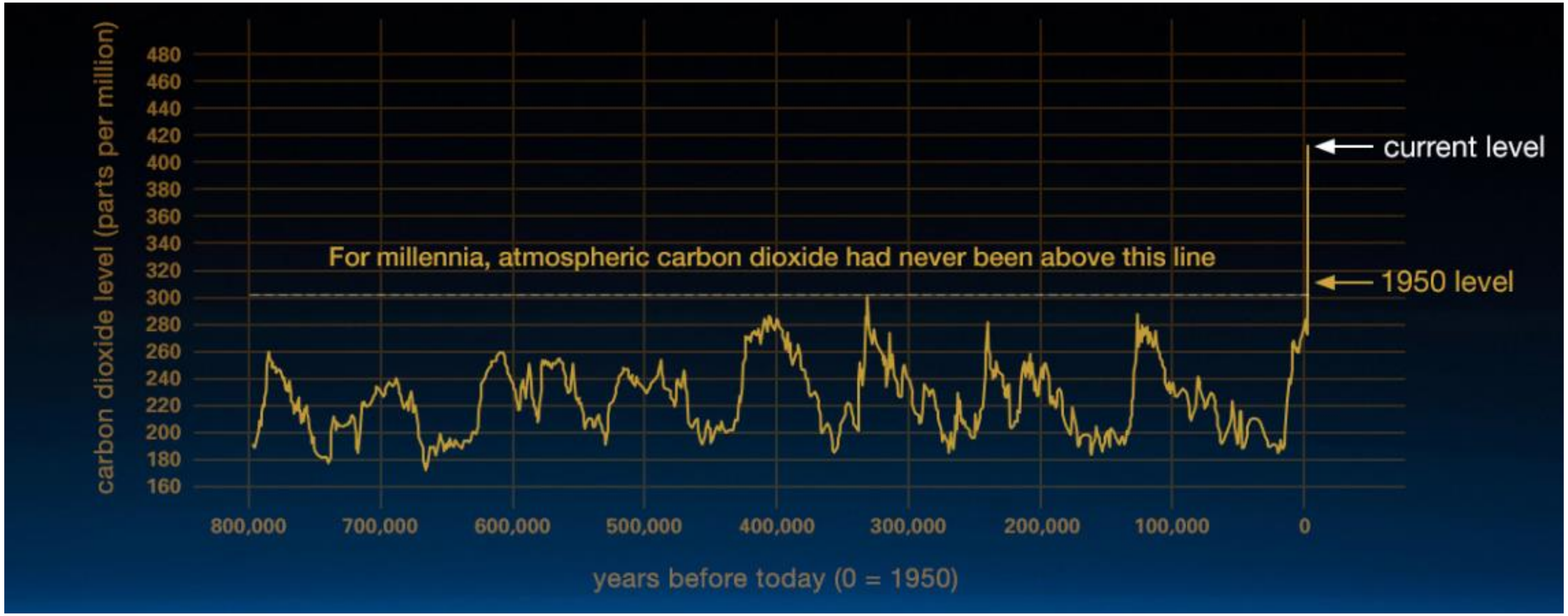
Atmospheric GHG concentrations are determined by the balance between sources (emissions of the gas from human activities and natural systems) and sinks (the removal of the gas from the atmosphere by conversion to a different chemical compound or absorption by bodies of water). The proportion of an emission remaining in the atmosphere after a specified time is the "airborne fraction‟.

The contribution of each gas to the greenhouse effect is determined by its concentration in the atmosphere, how long it stays in the atmosphere and how strongly it impacts the atmosphere. This is measured with a metric known as the Global Warming Potential. CO2 is the reference and has a GWP of 1, and remains in the atmosphere for thousands of years. Methane lasts for only a few years but absorbs much more energy and has a GWP of 28-36 over 100 years[1].

1. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

Global CO_2 concentrations

Over the past 800,000 years atmospheric CO_2 has fluctuated consistently – these fluctuations coincide with glacial and interglacial cycles, and were caused by changes in the Earth's orbit around the sun. Since the end of the 18th Century- the onset of the industrial revolution- atmospheric CO_2 concentrations have increased by about 48% and now stand around 412 ppm, higher than they have been for the last 3 million years[1]. They are increasing by about 2ppm per year.

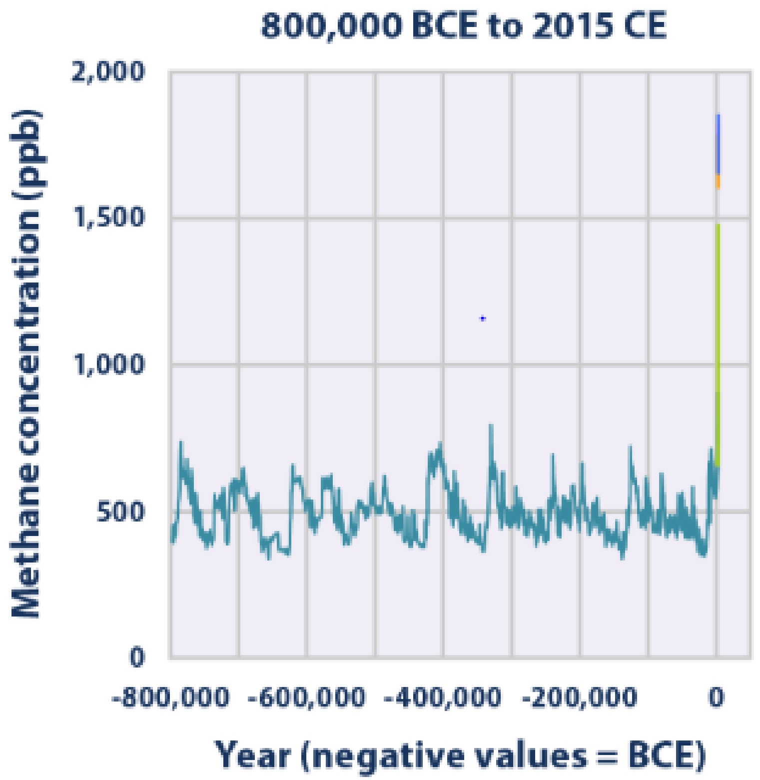


1. https://e360.yale.edu/digest/co2-concentrations-hit-highest-levels-in-3-million-years

Chart source: https://climate.nasa.gov/evidence//

Global methane concentrations

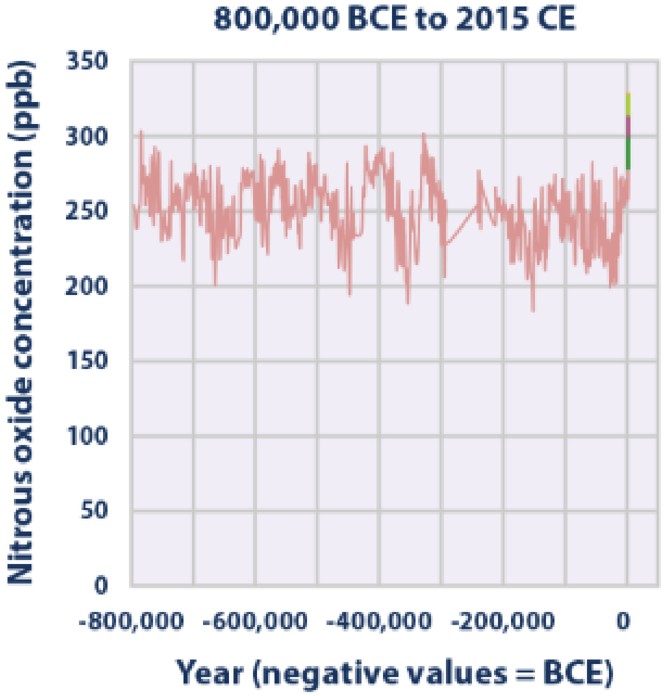
The concentration of methane in the atmosphere has more than doubled since pre-industrial times, reaching approximately 1,800 parts per billion (ppb) in recent years. This increase is predominantly due to agriculture and fossil fuel use.



Map source: https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases

Global nitrous oxide concentrations

Over the past 800,000 years, concentrations of nitrous oxide in the atmosphere rarely exceeded 280 ppb. Levels have risen since the 1920s, however, reaching a new high of 328 ppb in 2015. This increase is primarily due to agriculture.

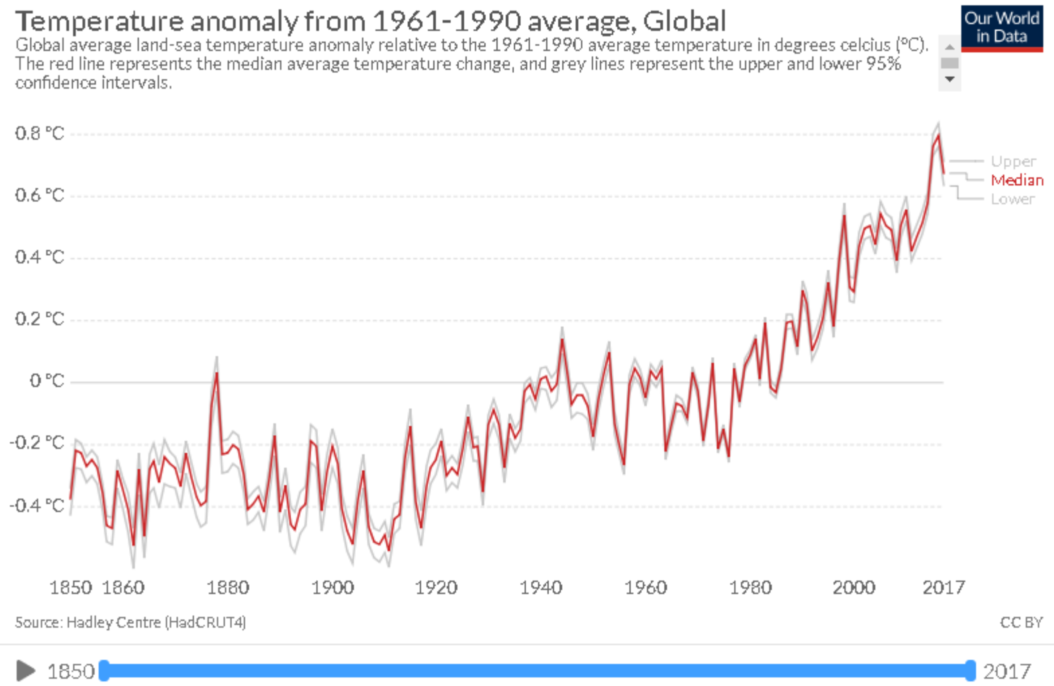


Map source: https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases

Global temperatures

While water vapour and clouds are the major contributors to Earth's greenhouse effect, research shows the planet's temperature ultimately depends on the atmospheric level of carbon dioxide[1].

Global temperatures have increased by 1.2° C since pre-industrial times. The rise in global average temperature is attributed to an increase in greenhouse gas emissions.



1.Lacis et al., 2010. Atmospheric CO_2: Principal Control Knob Governing Earth’s Temperature. Science v 330:356-359

Data source: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

How are global GHG emissions measured?

Measuring and monitoring atmospheric climate variables is a purely scientific endeavor, but measuring CO_2 emissions is much more tricky. This is because it involves many different stakeholders from industry to farmers to local and national goverments, all of whom have different interests, science not necessarily a priority. Getting all the countries of the world to measure their CO_2 emissions in a consistent, transparent and robust way is a huge challenge. The Intergovernmentall Panel for Climate Change (IPCC) is there to assist with this. IPCC is an intergovernmental body of the United Nations that evaluates climate change science, produces regular reports and issues guidance for countries on how to measure and report on their greenhouse gas emissions. In 2006, the IPCC issued a set of standardised guidelines (revised in 2019) which are the 'gold standard' for countries to use when measuring and reporting their greenhouse gas emissions[1]. In it, they identify 5 sectors which are used to break down and compare emissions. These are:

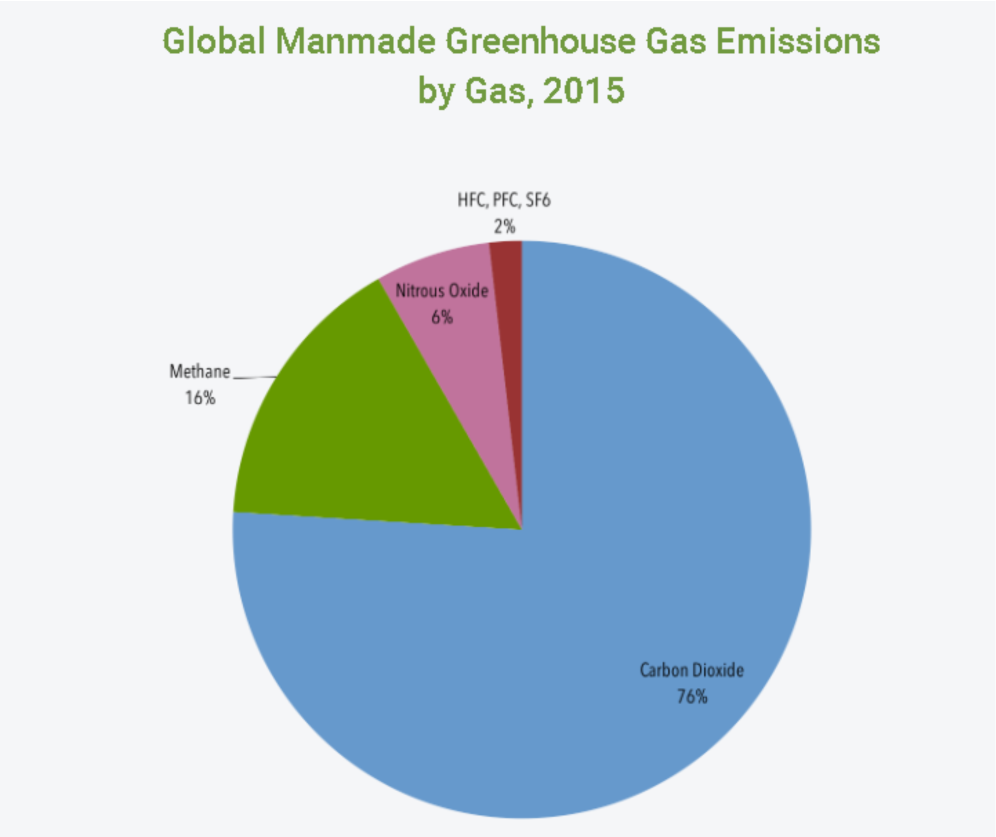
- Energy
- Industrial Processes and Product Use
- Agriculture, Forestry and Other Land Use
- Waste
- Other (e.g. fossil fuel fires, non-agricultural nitrous oxide emissions)

National governments work with scientists to follow these guidelines, using the best available data, and submit their greenhouse gas inventories periodically to the United Nations Framework Convention on Climate Change (UNFCCCC). Here, they are evaluated by independent experts.

1. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

What gases are emitted?

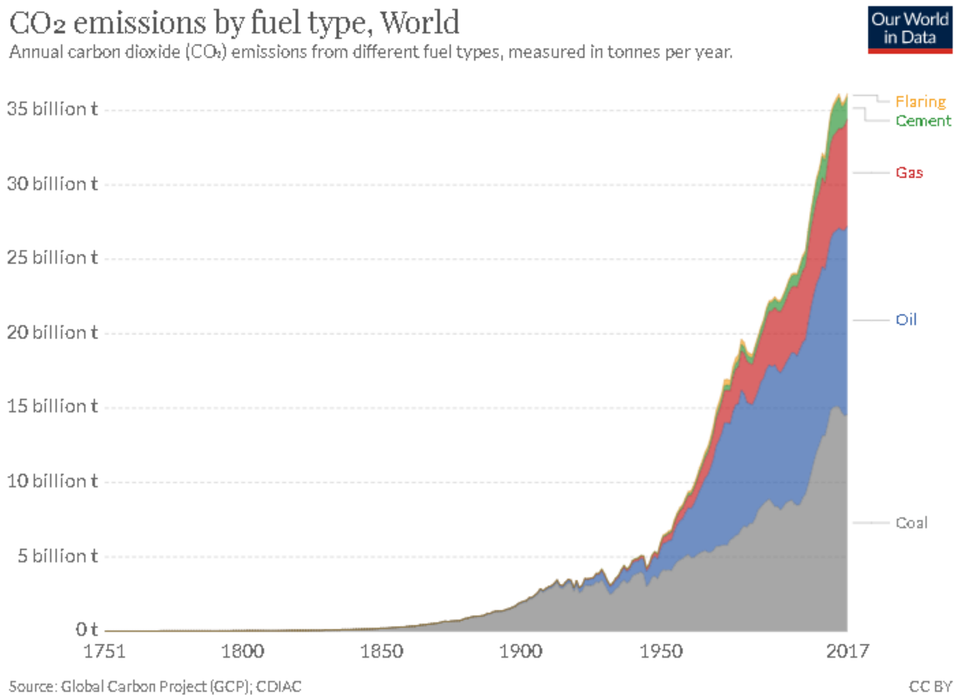
Carbon dioxide is the most important GHG emitted, accounting for 76% of manmade greenhouse gas emissions. Methane contributes 16% GHG emissions and nitrous oxide contributes 6% to global emissions. Due to the large contribution of CO_2 to overall emissions, we will focus on CO_2 in the following slides.



 https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

$C0_2$ emissions

The link between atmospheric CO_2 concentrations and human-induced CO_2 emissions is unequivocal. While the industrial revolution saw incredible technological advances it also heralded the era of humanity's reliance on fossil fuels that we have yet to shake. Since 1950, within living memory of a single generation - global CO_2 emissions from fossil fuel consumption- that includes gas, coal, oil, cement production and flaring - increased from about 6 billion tonnes/ year to 36 billion tonnes: a 500% increase.



https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

Which sectors emit the most CO_2?

The best data available indicate that by far the biggest source of global CO_2 emissions is the energy sector, making up 72% all emissions. Globally, the primary sources of CO_2 emissions are electricity and heat (31%), agriculture (11%), transportation (15%), manufacturing (12%) and forestry (6%).

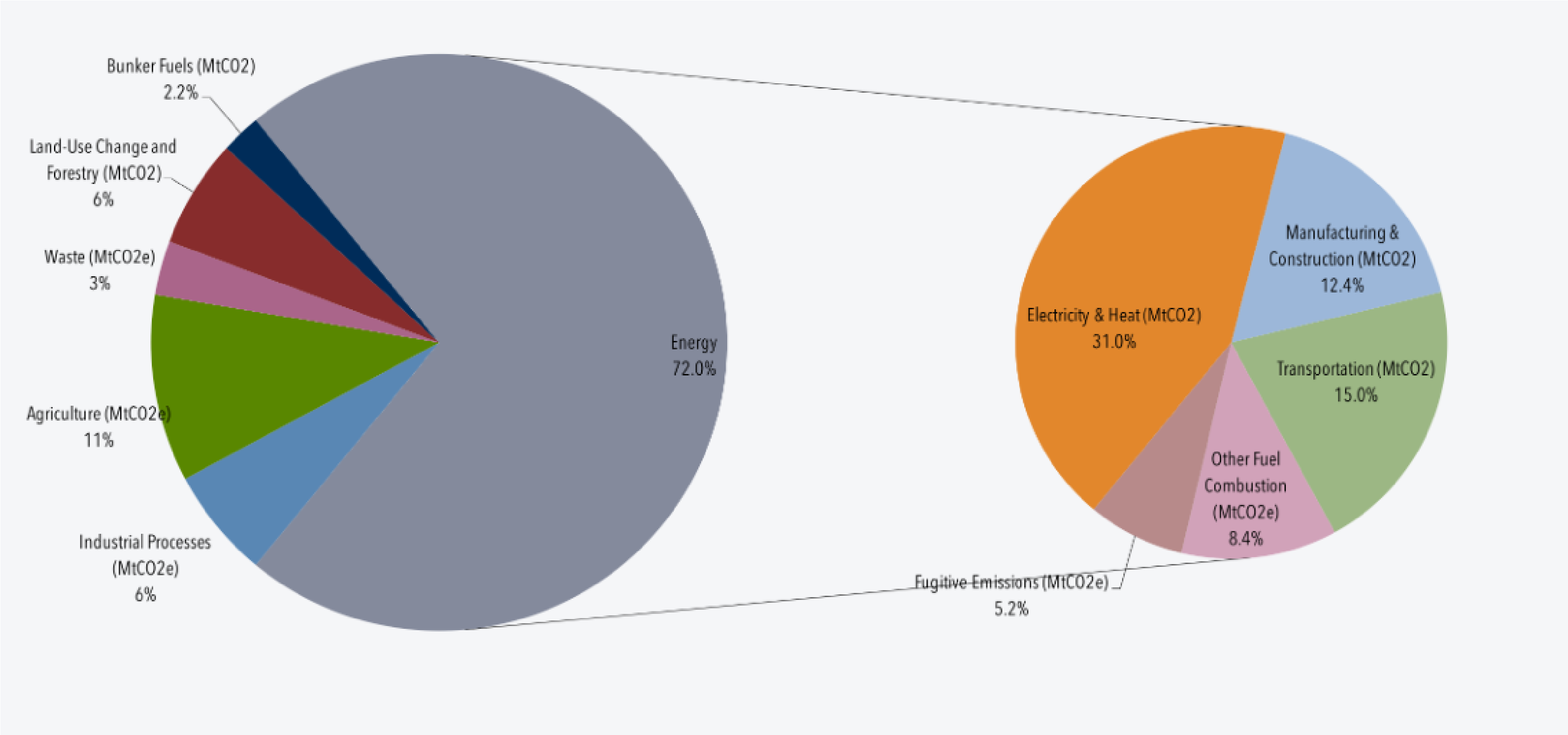
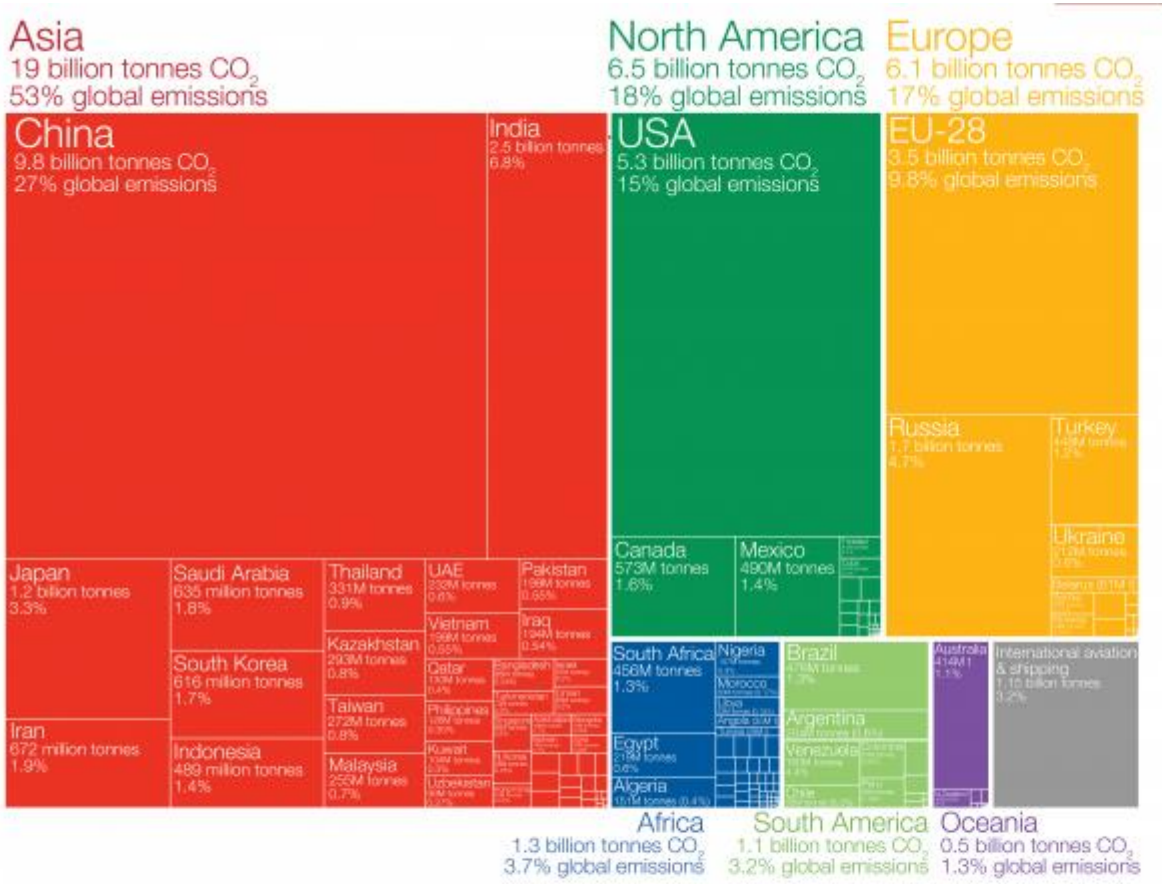


Chart source: https://www.c2es.org/content/international-emissions/

Who emits the most CO_2?

Asia is the biggest emitter, contributing 53% of global emissions: 27% of these are from China. North America is the second biggest emitter with the USA contributing 15% global emissions, followed by the EU at 9.8%.



2017 CO2 emissions by country

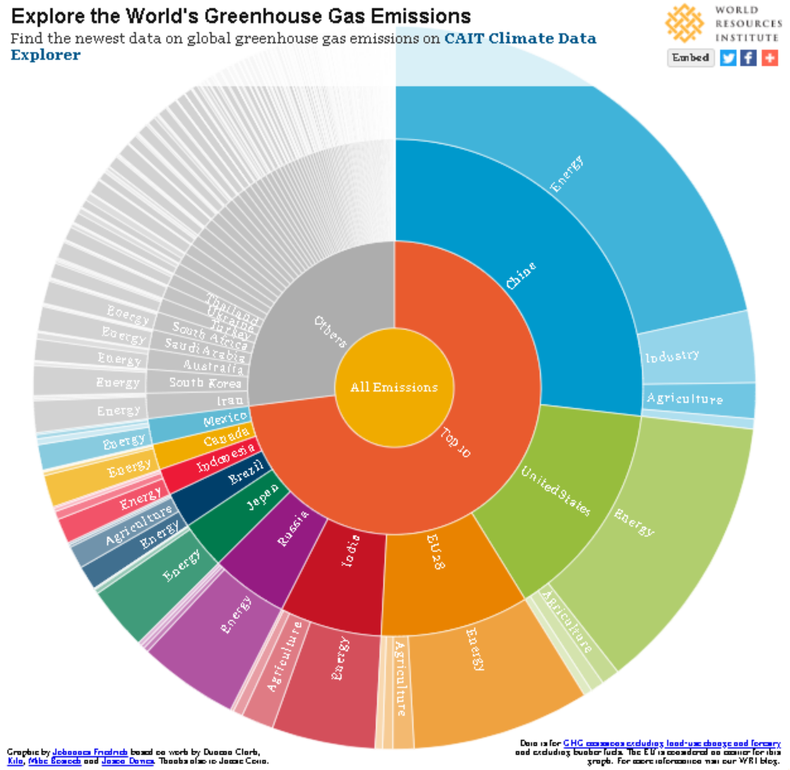
https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions#how-have-global-co2-emissions-changed-over-time

Emissions by country and sector

Overall the top three greenhouse gas emitters are China, the European Union and the United States, who contribute more than half of total global emissions, while the bottom 100 countries only account for 3.5 percent.[1] Collectively, the top 10 emitters account for nearly three-quarters of global emissions. These are: China, USA, EU-28, India, Russia, Japan, Brazil, Indonesia, Canada and Mexico. The world can't successfully tackle the climate change challenge without significant action from these countries.

Explore this interactive chart here:
https://www.wri.org/blog/2017/04/interactive-chart-explains-worlds-top-10-emitters-and-how-theyve-changed

You can also explore the world's climate and emissions data here:
https://cait.wri.org/

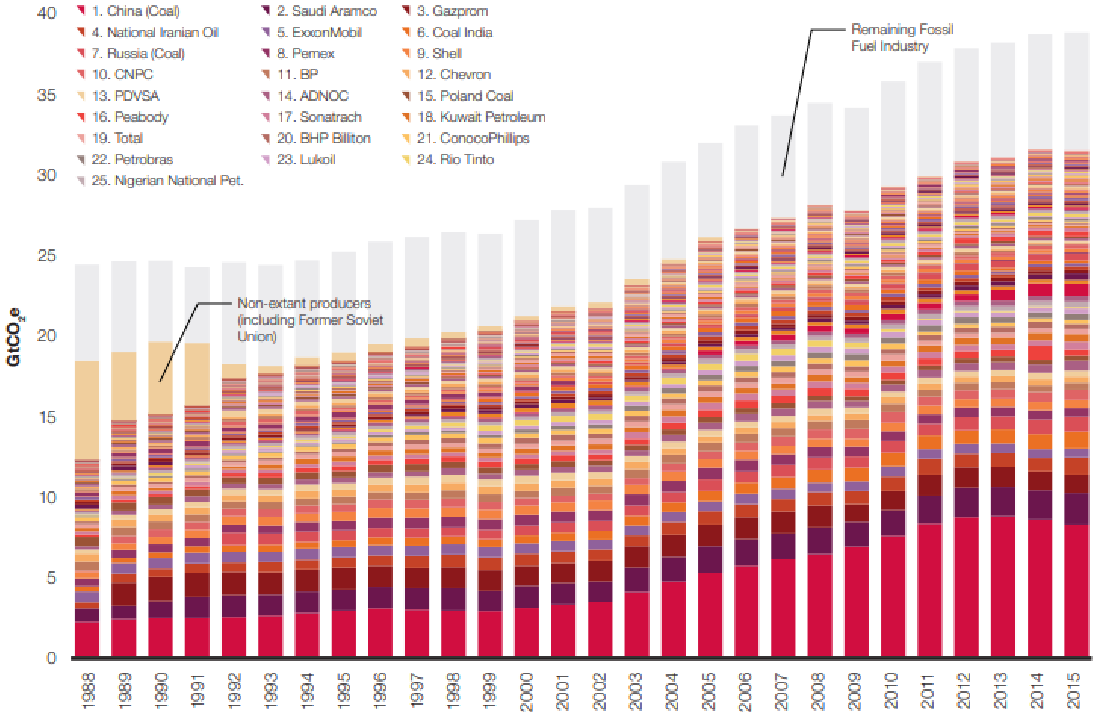


Which companies emit the most CO_2?

While individual countries are responsible for managing and reducing their emissions, we know that the fossil fuel industry in particular is the biggest culprit. The Carbon Majors Database[1], a study by the Carbon Disclosure Project (CDP), found that between 1988 and 2015, just 100 companies were responsible for 71% of global GHG emissions. Incredibly, **over half of the world's industrial emissions since the dawn of the industrial revolution can be traced back to just 25 companies.**

The top 10 emitting companies in the world are:

- China Coal 14.3 %
- Saudi Aramco 4.5 %
- Gazprom OAO 3.9 %
- National Iranian Oil Co 2.3 %
- ExxonMobil Corp 2.0 %
- Coal India 1.9 %
- Petróleos Mexicanos 1.9 %
- Russia Coal 1.9 %
- Royal Dutch Shell PLC 1.7 %
- China National Petroleum Corp 1.6 %



1. https://b8f65cb373b1b7b15feb-c70d8ead6ced550b4d987d7c03fcdd1d.ssl.cf3.rackcdn.com/cms/reports/documents/000/002/327/original/Carbon-Majors-Report-2017.pdf?1499866813

What are the effects of climate change?

Today, climate change is the term scientists use to describe the complex shifts, driven by greenhouse gas concentrations, that are now affecting our planet's weather and climate systems. Climate change encompasses not only the rising average temperatures we refer to as global warming but also extreme weather events, shifting wildlife populations and and habitats, rising seas, and a range of other impacts.

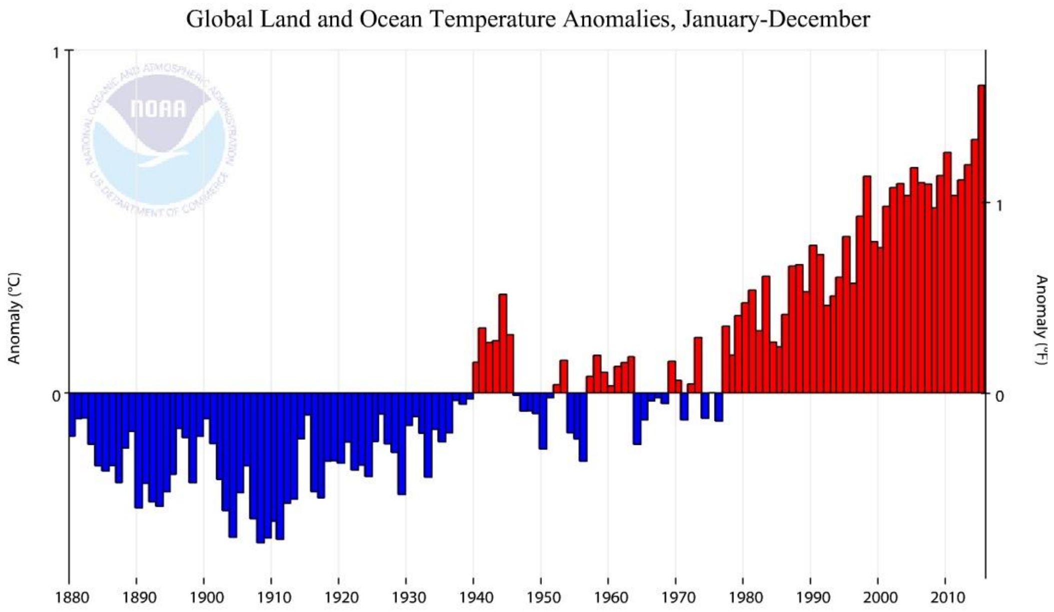
Although climate scepticism is rife in society and politics, the scientific evidence for warming of the climate system is unequivocal. According to the IPCC, the current warming trend is extremely likely (greater than 95% probability) to be the result of human activity since the mid-20th century and proceeding at a rate that is unprecedented over decades to millennia[1].

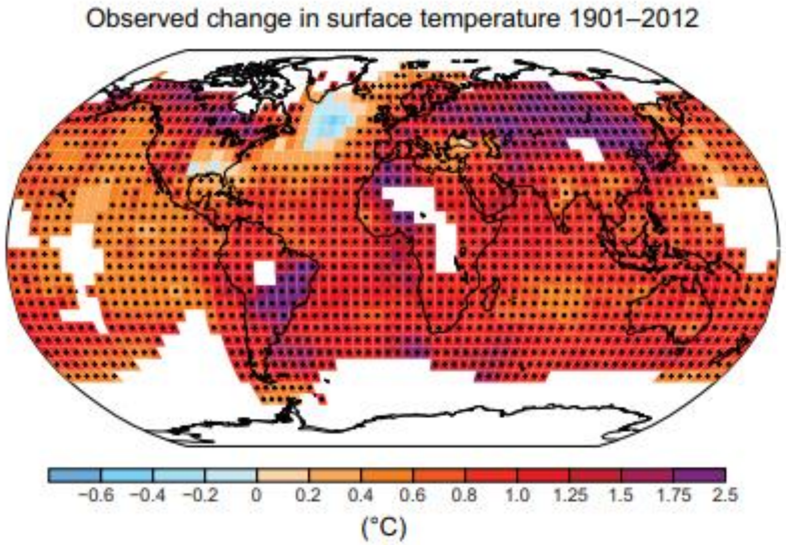
1. https://climate.nasa.gov/evidence/

Global Temperature Rise

The planet's average surface temperature has risen about 0.9 C since the late 19th century, with most of the warming occurred in the past 35 years. The five warmest years on record have taken place since 2010. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850[2]

Not only was 2016 the warmest year on record, but eight of the 12 months that make up the year — from January through September, with the exception of June — were the warmest on record for those respective months[1]





1. https://www.giss.nasa.gov/research/news/20170118/
2. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf

Graph source: https://www.climate.gov/maps-data/dataset/global-temperature-anomalies-graphing-tool

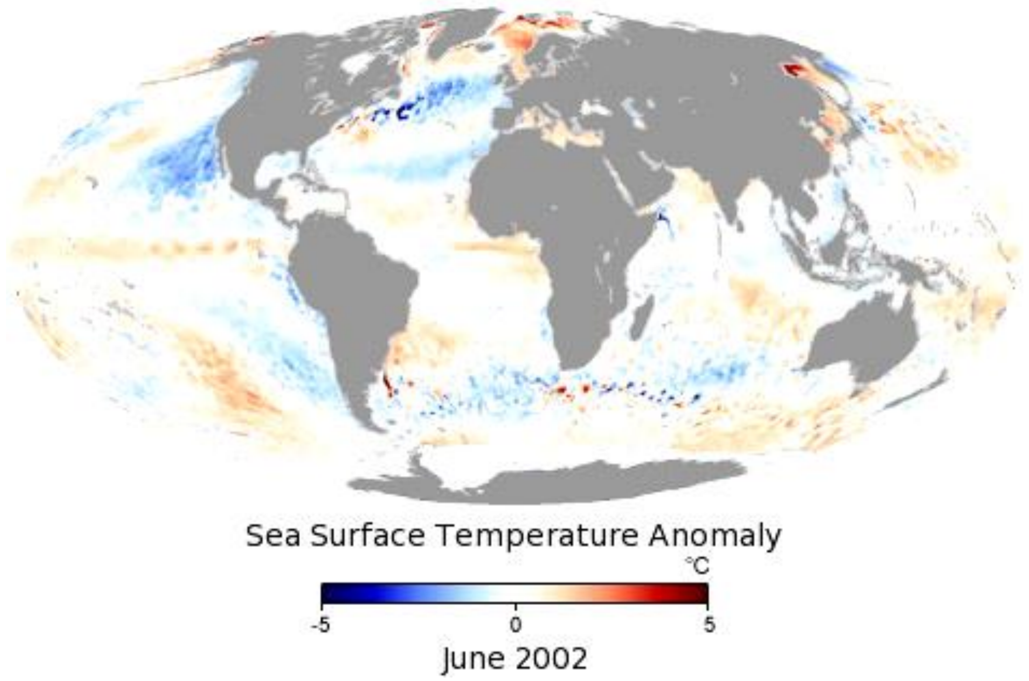
Ocean warming

The oceans have absorbed much of the increased heat from GHG emissions, accounting for more than 90% of the energy accumulated between 1971 and 2010 (high confidence)[2].

with the top 700 meters of ocean showing warming of 0.09 to 0.13 degrees C per decade over the past 40 years[1]. Rising temperatures cause coral bleaching and the loss of breeding grounds for marine fishes and mammals.

This video shows sea surface temperature anomalies each month from 2002-2011, with blue cooler than average and red warmer than average. Some anomalies are due to natural events (such as El Nino and La Nina, which refers to natural sea surface temperature changes every 3-6 years). However, a warm anomaly in the Arctic Ocean seems to intensify in the Northern Hemisphere summer. Here, sea ice is retreating to a smaller area in the summer : areas that were once covered with ice all summer are now open water.

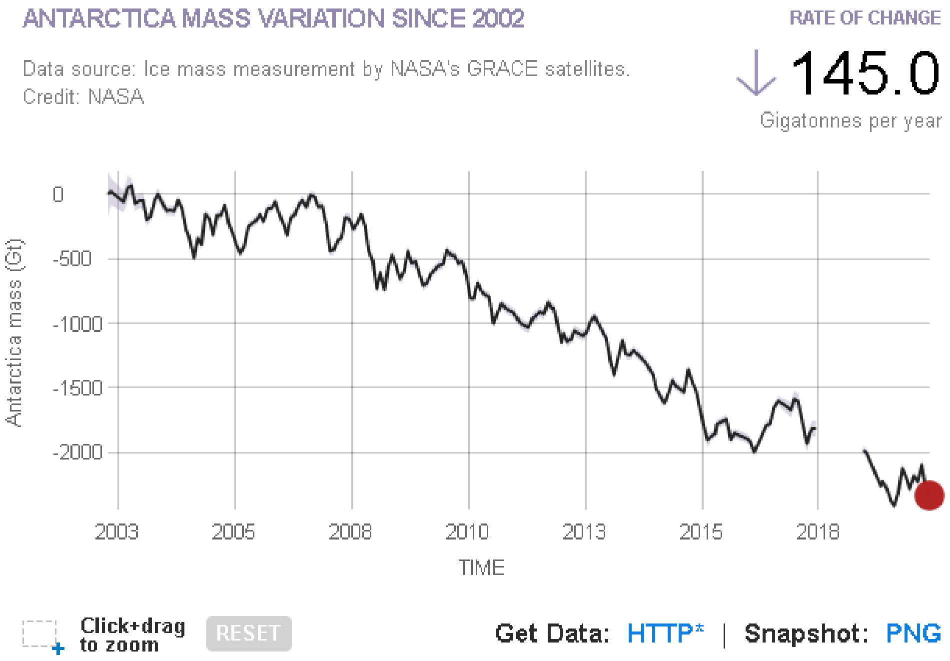
Hover over the image to play the video, and explore the data in more detail here:https://earthobservatory.nasa.gov/global-maps/AMSRE_SSTAn_M

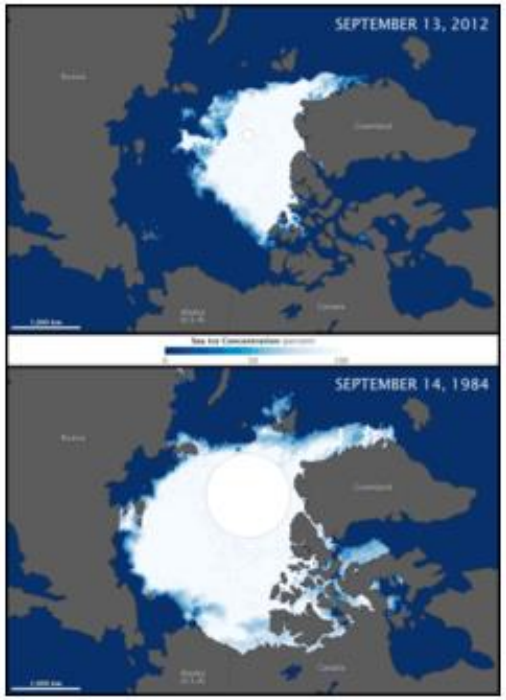


1. Levitus et al. (2017). NCEI ocean heat content, temperature anomalies, salinity anomalies, thermosteric sea level anomalies, halosteric sea level anomalies, and total steric sea level anomalies from 1955 to present calculated from in situ oceanographic subsurface profile data (NCEI Accession 0164586). Version 4.4. NOAA National Centers for Environmental Information.
2. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf

Shrinking ice sheets

The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost an average of 286 billion tons of ice per year between 1993 and 2016, while Antarctica is losing about 145 billion tons of ice per year. Between 1979 and 2012. The rate of Antarctica ice mass loss has tripled in the last decade[1].



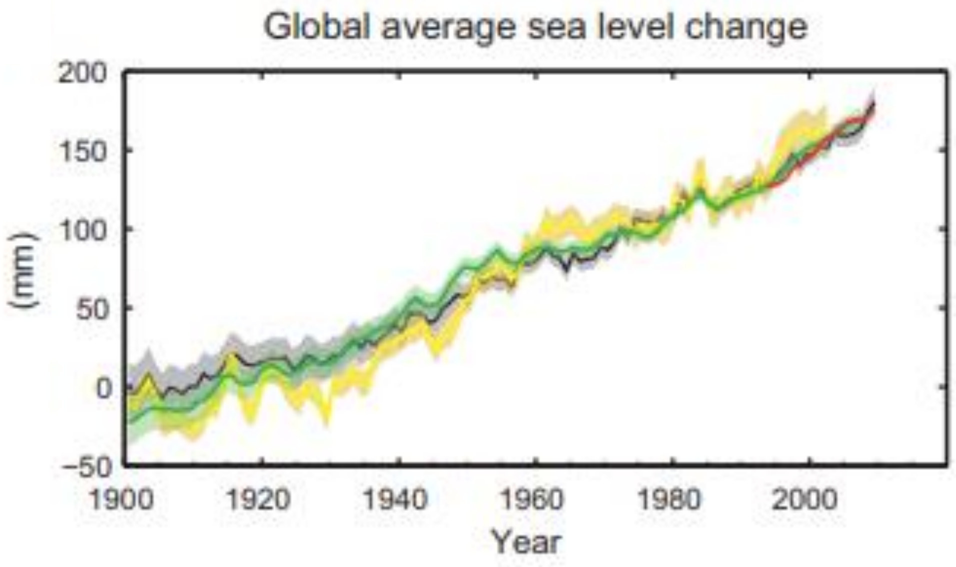


September minimum, 1984 and 2012. NASA

1. https://www.jpl.nasa.gov/news/news.php?feature=7159

Sea level

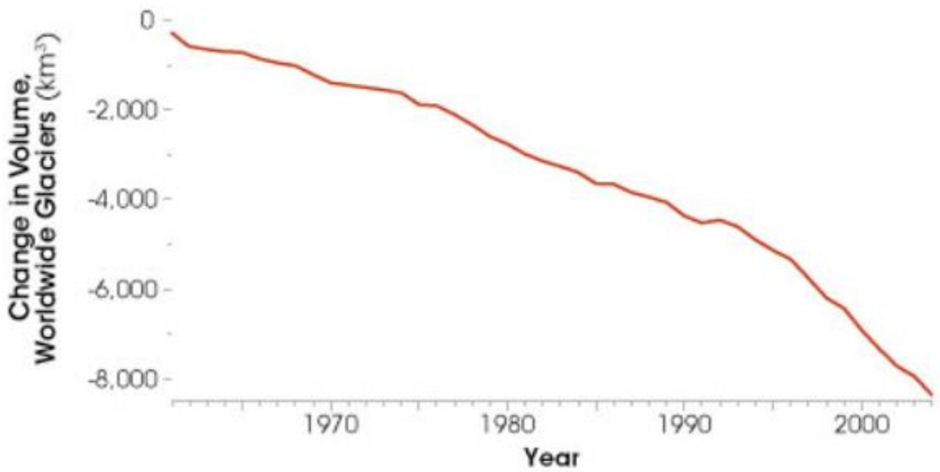
Between 1901 to 2010, global mean sea level rose by 0.19 m, or 1.77mm per year. The rate of sea level rise since the mid-19th century has been greater than observed during the previous two millennia[1]. Loss of glacier ice and ocean thermal expansion from warming explain about 75% of sea level rise since the 1970s.



1. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf

Glacial retreat

On average, glaciers worldwide have been losing mass since at least the 1970s and hundreds of small glaciers have disappeared. Since the 1960, glaciers have lost an estimated 8,000 cubic km of ice[1]. Furthermore, research shows that glaciers are major contributors to sea-level rise[2]. Between 2003-2009, 259 Gt glacier ice was lost each year, equivalent to a sea-level rise of 0.71 ± 0.08 mm/year[3,4]. More than 80% of this loss was from glaciers in the Canadian Arctic, Alaska, Greenland, the Southern Andes and the Asian Mountains[4].

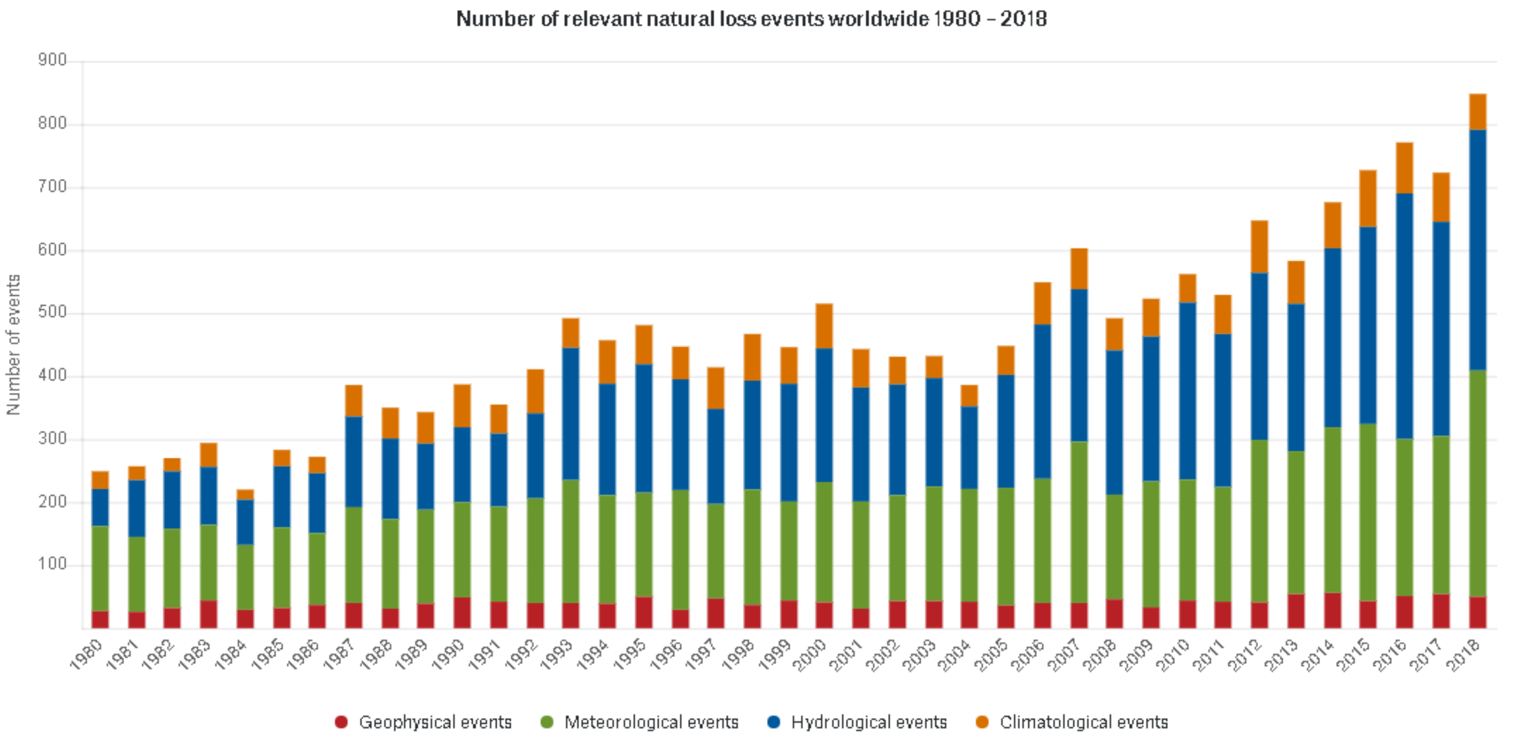


The Trift glacier in Switzerland has retreated about 1.17km between 2006 and 2015[5].

1. From Eggleton (2013) A Short Introduction to Climate Change. Cambridge University Press. Original data source: Dyurgerov and Meier, 2005. Glaciers and the Changing Earth system; a 2004 snapshot
2. Gardner et al. (2013). A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. *Science* 340, 852–857
3. Frezzotti, M., Orombelli, G. Glaciers and ice sheets: current status and trends. *Rend. Fis. Acc. Lincei* 25, 59–70 (2014).
4. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter04_FINAL.pdf
5. https://www.treehugger.com/climate-change/and-after-photos-show-dramatic-retreat-glaciers.html

Extreme weather patterns

Extreme weather patterns are being observed more and more frequently. There is a growing body of scientific evidence that indicates human-caused climate change is influencing extreme weather patterns we are observing across the planet.

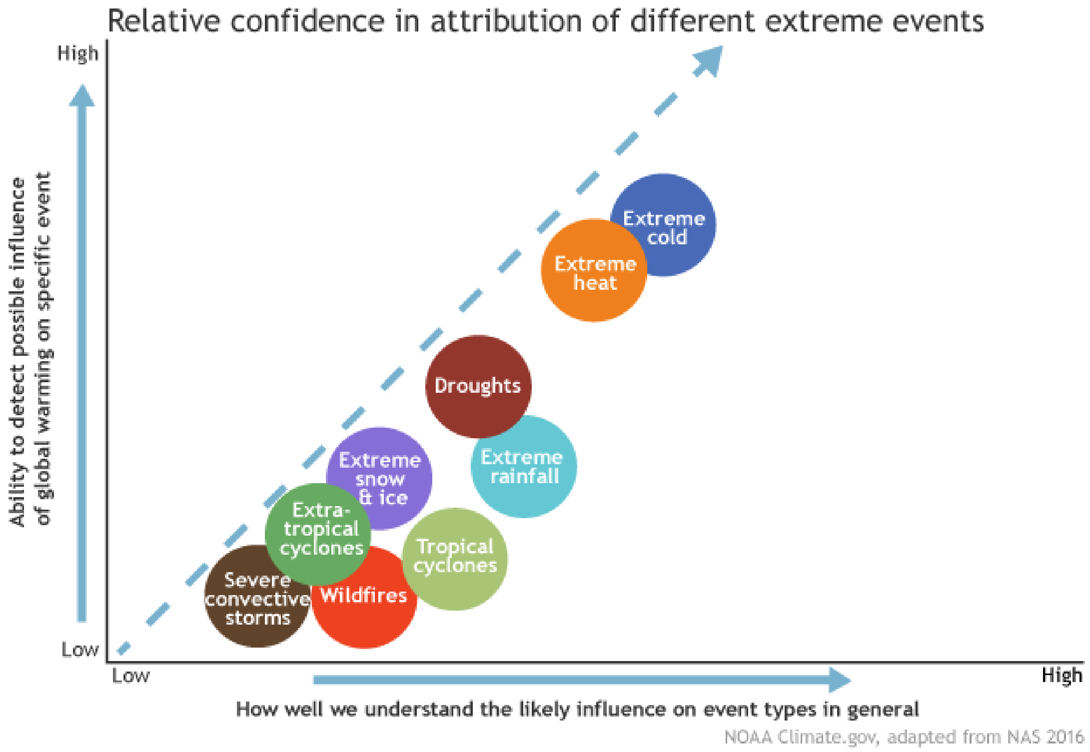


https://www.ucsusa.org/resources/science-connecting-extreme-weather-climate-change

Map source: https://natcatservice.munichre.com/events/1?filter=eyJ5ZWFyRnJvbSI6MTk4MCwieWVhclRvIjoyMDE4fQ%3D%3D&type=1

Extreme weather patterns

The practice of linking weather events to human-influenced climate change is called attribution studies. According to the IPCC[1], there is the strongest evidence that it is causing more hot days, fewer cold days, heat waves and coastal flooding; some evidence for extreme rainfall and drought and limited evidence that it is affecting the magnitude and frequency of cyclones and floods.



1. https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap3_FINAL-1.pdf

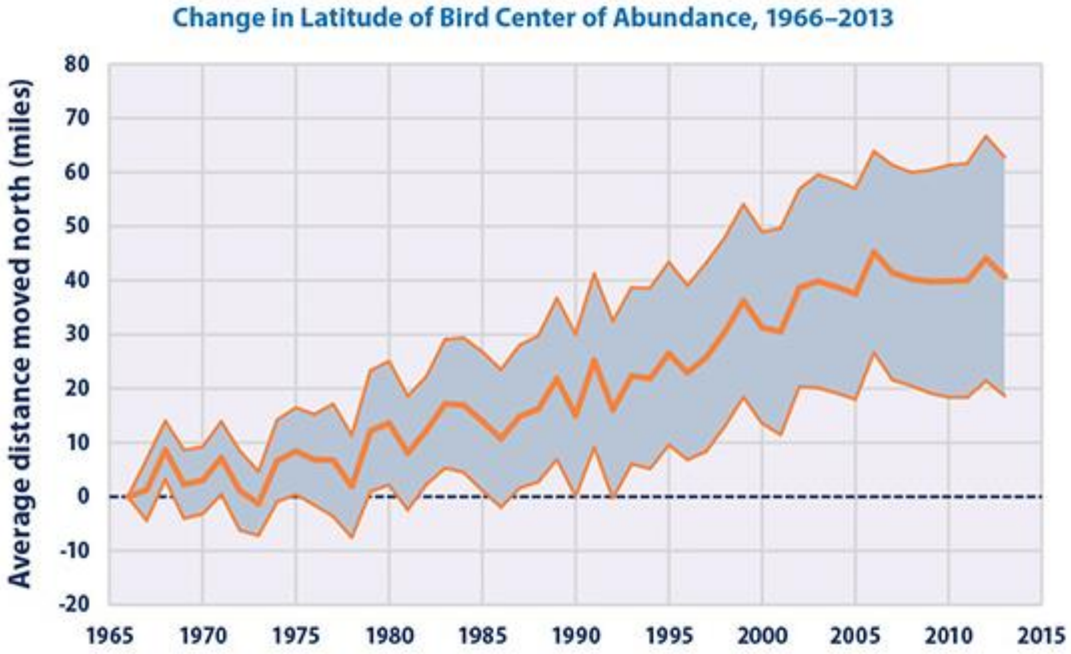
Species behaviour

The timing of periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate is known as **phenology**. Many animal and plant species rely on predictable environmental triggers such as temperature and precipitation for key biological events such as reproduction and migration. There is a growing body of evidence to suggest that phenological markers are affected by global warming.

As temperatures warm and precipitation patterns change, many species of plants, insects, and birds are shifting important phenological events.

For example, it has been shown that warmer temperatures are forcing birds to winter and breed farther north than in the past. An assessment of 305 common North American bird species found the average latitude of bird wintering range is now about 40 miles farther north than it was in the 1960s[1].

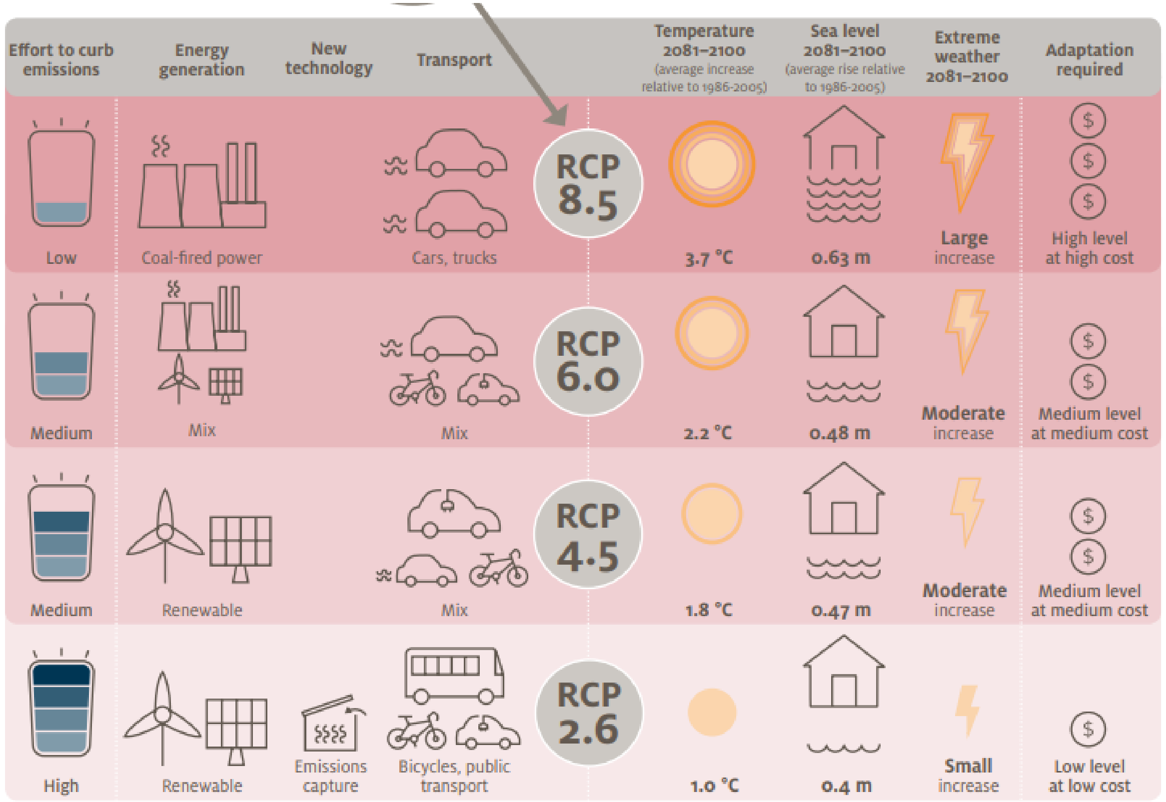
Some species require specific temperatures to trigger events, such as certain tropical trees for flowering: in these cases higher temperatures will lead to a loss of fruit production, with potential knock-on consequences for frugivore populations.



1. National Audubon Society (2014) & US Environmental Protection Agency (2016)

Climate Predictions

The most recent climate predictions are detailed in the IPCC Fifth Assessment Report (AR5). In it, future projections of changes in the climate system are modelled relative to four different scenarios, called **Representative Concentration Pathways (RCPs).** Each RCP describes an alternative emissions trajectory for CO_2 emissions and the resulting atmospheric concentration from 2000 to 2100. RCPs are linked to policies and human activity and encompass the range of possible climate policy outcomes for the 21st century. They are based on different assumptions about population, economic growth, energy consumption and sources and land use over this century. The four RCPs include one mitigation scenario leading to a very low emissions (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high emissions (RCP8.5). Current emissions are tracking close to the RCP8.5 scenario.

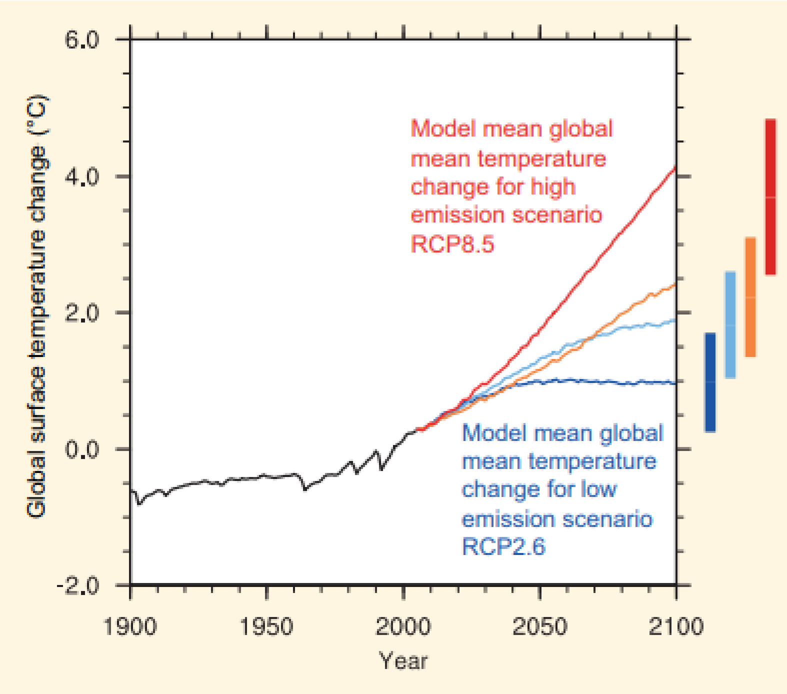


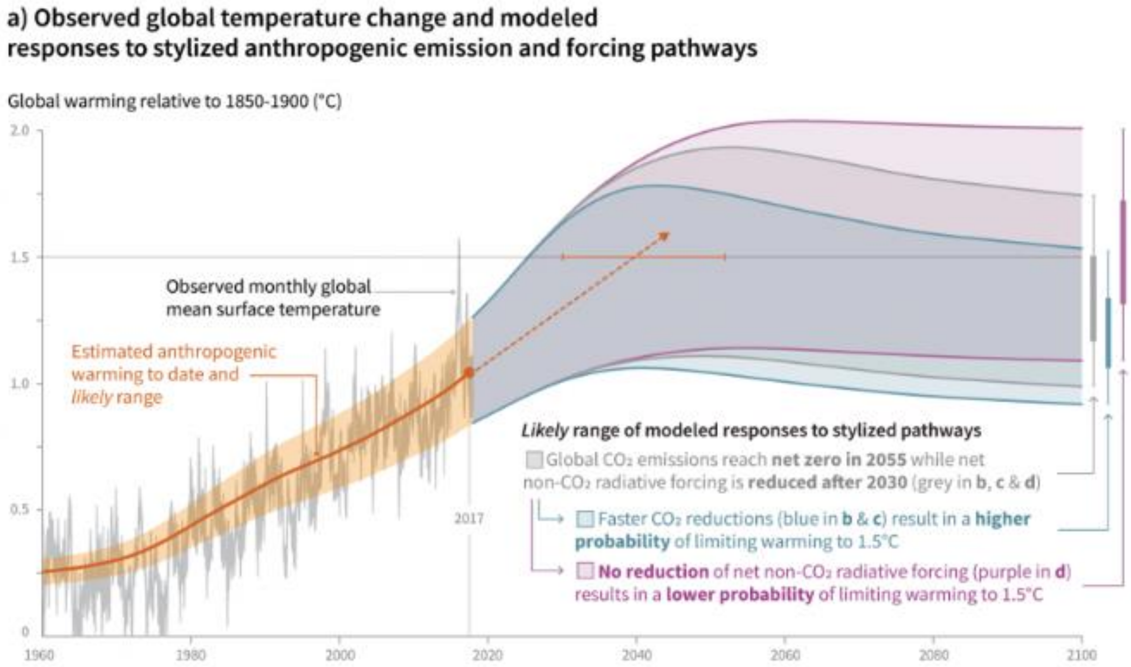
An excellent explanation of the different RCPs can be found here: https://medium.com/@davidfurphy/what-on-earth-is-an-rcp-bbb206ddee26

https://coastadapt.com.au/sites/default/files/infographics/15-117-NCCARFINFOGRAPHICS-01-UPLOADED-WEB%2827Feb%29.pdf

Climate predictions

What the models tell us is that if no climate mitigation measures are put in place, we are looking at temperature changes of greater than 4 C by the end of the century. However, limiting global warming to below 1.5 °C will require major and immediate transformation over the next few years. **This is unlikely- we would have to half our current emissions by 2030** and then achieve carbon neutrality by 2050 to meet this target. IPCC says with high confidence that global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. Given that fossil fuel emissions are now 4% higher than since the IPCC report was issued, it seems increasingly likely that temperature changes will exceed 1.5 °C between 2030 and 2052.





https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

Climate predictions

We are already 'locked in' to further climate change: warming from anthropogenic emissions from the pre-industrial period to the present are likely to persist for centuries to millennia (IPCC say this with 'medium confidence'). Under all scenarios, continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system.

It is virtually certain that there will be more frequent hot and fewer cold temperature extremes and very likely that heat waves will occur with a higher frequency and duration.

Warming is and will be higher over land than over the ocean, and two to three times higher in the Arctic.

		2046–2065		2081–2100	
	Scenario	Mean	*Likely* range[c]	Mean	*Likely* range[c]
Global Mean Surface Temperature Change (°C)[a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	Mean	*Likely* range[d]	Mean	*Likely* range[d]
Global Mean Sea Level Rise (m)[b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

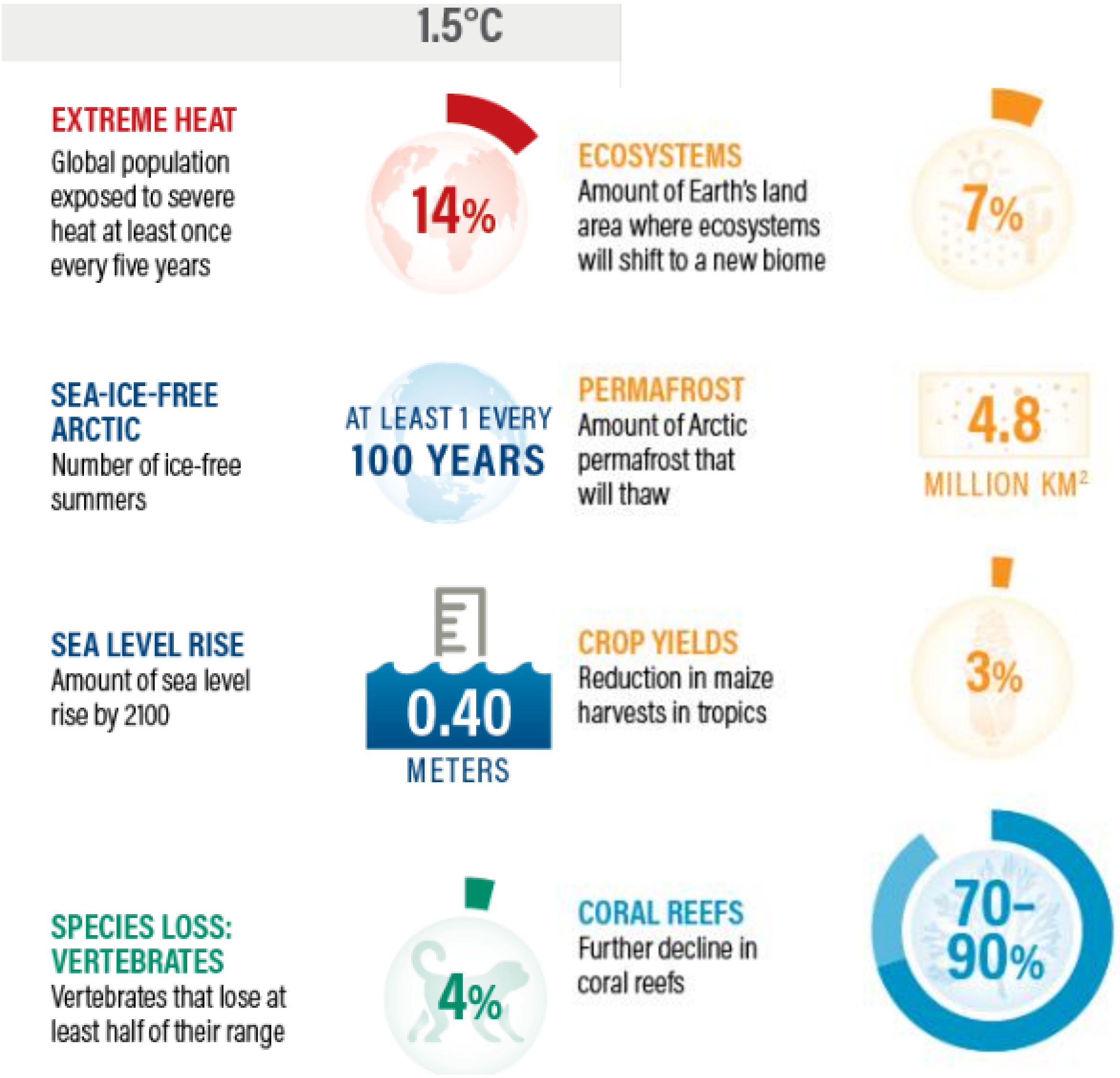
Notes:

	RCP2.6 (ΔT in °C)	RCP4.5 (ΔT in °C)	RCP6.0 (ΔT in °C)	RCP8.5 (ΔT in °C)
Global: 2046–2065	1.0 ± 0.3 (0.4, 1.6)	1.4 ± 0.3 (0.9, 2.0)	1.3 ± 0.3 (0.8, 1.8)	2.0 ± 0.4 (1.4, 2.6)
2081–2100	1.0 ± 0.4 (0.3, 1.7)	1.8 ± 0.5 (1.1, 2.6)	2.2 ± 0.5 (1.4, 3.1)	3.7 ± 0.7 (2.6, 4.8)
2181–2200	0.7 ± 0.4 (0.1, 1.3)	2.3 ± 0.5 (1.4, 3.1)	3.7 ± 0.7 (-,-)	6.5 ± 2.0 (3.3, 9.8)
2281–2300	0.6 ± 0.3 (0.0, 1.2)	2.5 ± 0.6 (1.5, 3.5)	4.2 ± 1.0 (-,-)	7.8 ± 2.9 (3.0, 12.6)
Land: 2081–2100	1.2 ± 0.6 (0.3, 2.2)	2.4 ± 0.6 (1.3, 3.4)	3.0 ± 0.7 (1.8, 4.1)	4.8 ± 0.9 (3.4, 6.2)
Ocean: 2081–2100	0.8 ± 0.4 (0.2, 1.4)	1.5 ± 0.4 (0.9, 2.2)	1.9 ± 0.4 (1.1, 2.6)	3.1 ± 0.6 (2.1, 4.0)
Tropics: 2081–2100	0.9 ± 0.3 (0.3, 1.4)	1.6 ± 0.4 (0.9, 2.3)	2.0 ± 0.4 (1.3, 2.7)	3.3 ± 0.6 (2.2, 4.4)
Polar: Arctic: 2081–2100	2.2 ± 1.7 (-0.5, 5.0)	4.2 ± 1.6 (1.6, 6.9)	5.2 ± 1.9 (2.1, 8.3)	8.3 ± 1.9 (5.2, 11.4)
Polar: Antarctic: 2081–2100	0.8 ± 0.6 (-0.2, 1.8)	1.5 ± 0.7 (0.3, 2.7)	1.7 ± 0.9 (0.2, 3.2)	3.1 ± 1.2 (1.1, 5.1)

The world at 1.5˚C

Why is it considered so important to limit global warming to below 1.5 C? Scientists agree that significant climate impacts will already occur at 1.5˚C, especially in regards to low-lying areas, human health and oceans.

However, in a special report[1], the IPPC says with high confidence that risks to natural and human systems are expected to be lower at 1.5°C than at 2°C of global warming. The probability of drought and risks to water availability, for example may be substantially reduced if warming is limited to 1.5°C. However, the impacts will hit the poor and most vulnerable the hardest due to loss of livelihoods, food insecurity, population displacement, health effects and more.



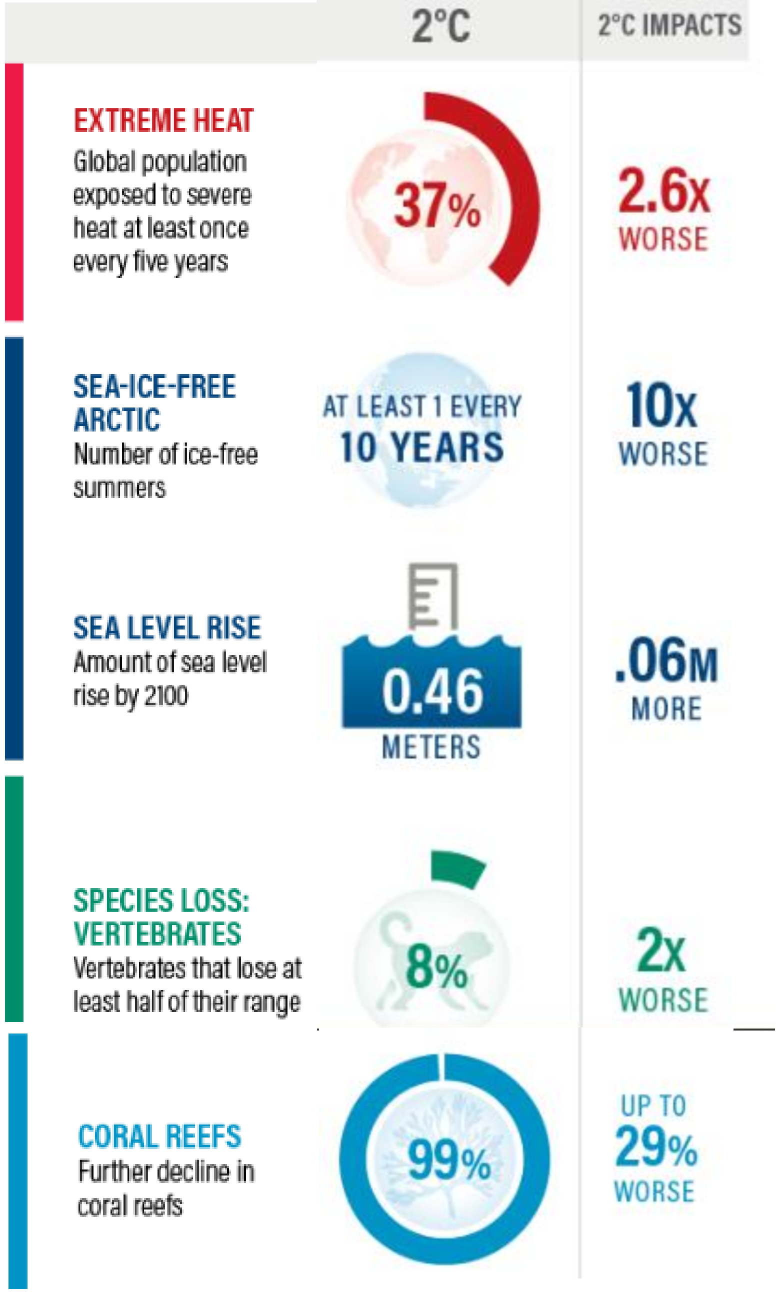
1. https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf
2. https://www.wri.org/blog/2018/10/8-things-you-need-know-about-ipcc-15-c-report

The world at 2˚C

Beyond 1.5 C, which is likely to happen, many more millions of people will be put at risk of potentially life-threatening heatwaves, coastal flooding and poverty. Entire ecosystems will threatened and species extinction rates higher. The IPCC projects that going from 1.5 degrees of global warming to 2 degrees could mean:

- 1.7 billion more people experience severe heatwaves at least once every five years.
- Seas rise another 6cm, exposing 10 million more people to coastal flooding.
- Up to several hundred million more people become exposed to climate-related risks and poverty.
- The coral reefs that support marine environments around the world could decline as much as 99 %.
- Global fishery catches could decline by another 1.5 million tonnes.

Explore this interactive chart to understand more about the impacts of 1.5C compared to 2 C warming: https://interactive.carbonbrief.org/impacts-climate-change-one-point-five-degrees-two degrees/?utm_source=web&utm_campaign=Redirect#



The world beyond 2°C ?

No-one knows exactly, but it is feared, based on knowledge of the Pliocene that at 3°C of warming the world could enter a ‘tipping point’ to an altered global state, free of glaciers and ice sheets, with sea-levels up to 25m higher, widespread flooding of islands and coastal cities, vegetation shifts of forest to savannah, and increased CO_2 emissions (as a result of negative feedbacks). In such a scenario, vast areas of earth would become uninhabitable, resulting in hundreds of millions of climate refugees.

The world at 6°C is unlikely to support most life-forms as we know it. At the end of the Permian period, 251 million years ago, temperatures rose by six degrees, and up to 95% of species went extinct as a result of a super-greenhouse event.

9.7

What can we do?

International treaties

In 1992, during the Rio Summit, 154 countries recognized the existence of climate change resulting from human activity and decided to work together to limit global warming. This heralded the birth of the United Nations Framework Convention on Climate Change (or UNFCCC) and its decision-making body, the Conference of Parties (or COP).

The UNFCCC came into force in 1994 and was ratified by 197 Parties. **Its aim is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate.** Every year a COP is held for all parties of the convention, to allow parties to review decisions of the convention and negotiate new commitments.

The UNFCCC's first practical and binding application was officialised by the Kyoto Protocol which was created to operationalise the UNFCCC and adopted in 1997 by 192 Parties. It's aim was to commit "developed" (Annex B) countries to limit and reduce greenhouse gases (GHG) emissions in accordance with agreed individual targets. The Kyoto Protocol expired in 2012, and is largely considered a failure, largely because "developing " (non-Annex B) countries such as China and India were not covered by the Protocol, yet went on to become major global emitters.

International treaties

The Paris Agreement was adopted in 2015 and ratified by196 Parties. This agreement aims to hold warming well below 2 C with efforts to limit warming to 1.5 C, and to achieve net-zero emissions in the 2nd half of the 21st Century. The first major difference compared to the Kyoto Protocol is that it is largely voluntary in nature, set up as a "hybrid of legally binding and non-binding provisions". Specific climate goals are politically encouraged, rather than legally bound. The second is that it does not distinguish between Annex B and non-Annex B countries, instead all parties are required to submit emissions reductions plans. Under the agreement, every country submits an individual plan (or "Nationally Determined Contributions") to the UNFCCC to commit to reducing greenhouse gas emissions by a particular date. Countries set their own targets.

Despite the provisions made in the Paris Agreement however, as time goes on it is becoming apparent that countries are not achieving their emissions targets. What's more, even if every country did manage to fulfil their individual pledges, the world would still be on pace to heat up well in excess of 2 C over preindustrial levels. Current commitments put the world on pace for around 3 C of warming this century.

Unfortunately, talks at the most recent COP25 in Madrid were considered a failure and observers say many countries seem reluctant to cooperate or show the willingness that is needed to effectively tackle the climate crisis.

It seems that while the Paris Agreement has global support and the potential to slow climate change, it is difficult to enforce and may not go far enough to slow global warming.

However, it is important the world keeps the conversation alive and mounts pressure on governments to respect the UNFCCC. Public support, lobbying and voting for leaders who are committed to the Paris Agreement have never been more important.

Lifestyle changes

Although avoiding plastic straws is unlikely to save the planet, one of the first and most obvious ways we can all make a difference is by making as many lifestyle changes as possible, and encouraging our friends and family to. Consumer behaviour has a huge influence on businesses: if enough consumers demand change, manufacturers will follow suit. There are many ways you can (and probably do) make small changes to your purchasing habits and lifestyle to reduce your own carbon footprint and pollution levels. The important thing is that many of us do it. Some examples below:

- Recycle, re-use and repair
- Avoid disposable plastic
- Choose public transport, walking and cycling
- Limit international flights
- Be energy aware: turn off light-switches, computers and devices at home and in the work-place.
- Buy less and buy locally: only buy what you really need and make ethical choices, where possible
- Avoid food waste
- Buy second-hand
- Grow your own vegetables
- Reduce your red meat consumption
- Live simply and frugally!

Involvement with grassroots actions

Taking positive action at any level is generally considered the best way to avoid climate anxiety and inspire people around you to change their behaviour. Some ways in which people are becoming increasingly engaged in climate action are:

- Taking part in climate strikes, supermarket 'plastic attacks' and other environmental protests
- Lobbying employers, local politicians, governments and manufacturers to change their policies
- Engaging in public debate
- Education and outreach
- Getting involved with citizen science projects
- Joining/ starting environmental groups- either local or online
- Being part of a community garden
- Join a beach clean-up

Know how to deal with climate change denial

Although the scientific evidence for anthropogenic climate change is now irrefutable, scepticism and denial around climate change is commonplace in society and politics. Scepticism is an essential part of science, based on critically examining and testing all claims with the best scientific evidence. However, most climate sceptics and deniers are not scientists, but normal people rejecting evidence-based science, sometimes on the basis of deeply held non-scientific beliefs.

Some people may not trust or believe the science, claiming that it is exaggerated or falsified as part of a social or political conspiracy. More sinister are climate opportunists, who promote climate denial because it is advantageous for financial or business interests. On the other hand many people have no strong views but are rather agnostic, perhaps because they are uninterested in science, think climate change is not imminent, has nothing to do with them, or feel they have more pressing priorities. Others still may feel desensitized or overwhelmed by the prospect of climate change and have switched off as a protective coping mechanism.

It is generally agreed that trying to change the minds of ardent deniers and sceptics with scientific facts is an ineffective strategy. It may even backfire and reinforce their views. Instead, focussing on winning over the more neutral fence-sitters by advocating positive action is likely to be much more effective. This approach is known as the 'spectrum of allies'[1] and is often used in social change campaigns. One study showed that it only takes 3.5% of the population actively participating in activism to cause political change. This makes sense, as people are much more likely to change their behaviour if there is a critical mass of people around them behaving in the same way.

So while it may be tempting to try and win over hard-core deniers with a barrage of facts, the most effective use of your energy is to prioritise action and influence those who are less entrenched in their views.

https://theconversation.com/facts-wont-beat-the-climate-deniers-using-their-tactics-will-24074
https://ensia.com/voices/climate-change-deniers/
https://trainings.350.org/resource/spectrum-of-allies/

Be inspired

If you are feeling as if nothing you can do invidivually will make a difference, take a moment to consider people around the world who have made a huge difference through individual action. Know that anything is possible if you put your mind to it!

Greta Thunberg started a solitary climate strike aged 15, triggering a global school climate strike movement involving millions of people. She has become one of the most influential climate activists of the 21st Century.

Ron Finley « Guerilla Gardener » turned abandoned spaces in deprived areas of Los Angeles into community gardens. He has taught local people to grow their own food, connect with nature, eat more healthily and stay out of trouble.

Mountain gorillas almost went extinct due to poaching. Thanks to the actions of Diane Fossey and all the people who followed her, there are now >1000, despite enormous challenges from civil war. Gorilla tourism now represents 3.7% Rwanda's GDP.