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Some Environment Research

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An independent academic psychologist, based in England, who has written extensively on different areas of psychology with an emphasis on the critical stance towards traditional ideas.

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1. CLIMATE CHANGE AND TWO ANIMALS

1.1. POLAR BEARS

Newediuk et al (2025) began: "Climate change is causing extreme environmental fluctuations and persistent warming, exposing species to conditions increasingly distant from those they evolved to tolerate. Species have typically responded to environmental change through range shifts, changes in seasonally timed behaviours, and population declines. However, the accumulation of our past emissions and current emission targets commits the planet to ongoing warming for the foreseeable future. Continued long-term environmental change means the persistence of many species will ultimately rely on their capacity to adapt genetically to the changed environment".

These researchers analysed genetic data from polar bears (Ursus maritimus) in western Hudson Bay, Canada. Decline in cellular function was used as a measure of ageing, and it was found that the stress of global warming had accelerated epigenetic ageing at "approximately one year faster, on average, for each degree Celsius temperature increase they experienced" (Newediuk et al 2025). The deterioration in cellular function will impact survival and fecundity. Note that the Arctic is estimated to have warmed in recent years by an average of 3 °C (Newediuk et al 2025).

Cumulative stress has a molecular wear and tear effect which reduces cellular function, and makes cells appear biologically older than the chronological age. This is called "biological age acceleration" (eg: Batson 2016). The measure of this by Newediuk et al (2025) was epigenetic age acceleration (ie: chronological minus estimated biological age) estimated from tissue samples.

The western Hudson Bay polar bear population on the southern edge of the Arctic has been studied since 1980. They move and hunt across the sea ice, and when that melts they rely on fat reserves usually. The ice-free period is estimated to be ten days longer today than in 1980 (Newediuk et al 2025). "During this time the western Hudson Bay polar bear population has declined by nearly 50% to its current estimated size of just over 600 individuals. Sea ice loss is firmly tied to this decline and is the most significant climate-related threat to this population. Longer ice-free seasons increase the bears' fasting period on land, and each additional day of fasting requires metabolising approximately one kilogram of body mass. Bears also risk losing stored body mass as thinning winter ice and rapid spring melts force longer swims between ice floes. Swimming is five times more energetically expensive for bears than walking, and dramatically longer swims are required for even small changes in sea ice" (Newediuk et al 2025).

Archived data (blood and skin tissue) for 144 individuals collected between 1988 and 2016 were used by Newediuk et al (2025). The researchers found "a signal of epigenetic age acceleration with time that paralleled climatic warming and lengthening ice-free periods. This suggests the accumulation of environmental stressors experienced by western Hudson Bay polar bears is associated with deteriorating cellular function through time. Polar bears born more recently aged faster as the climate warmed..." (Newediuk et al 2025).

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1.2. DESERT LIZARDS

"Climate warming can induce a cost-of-living 'squeeze' in ectotherms by increasing energetic expenditures while reducing foraging gains" (Wild et al 2025 p303).

Wild et al (2025) analysed data (over 2600 observations) on ten desert lizard species in African (Kgalagadi/Kalahari) and Australian (Great Victoria) deserts covering 1950 to 2020 to show this "squeeze".

Climate warming has been more intense in Africa, and impacted diurnal species particularly here. But nocturnal species had an "energetic relief" (ie: increased foraging time). It was calculated that future warming (eg: +2 °C) will impact diurnal species such that 10% more food intake per hour will be required. The researchers concluded: "The effects of climate warming on desert lizard energy budgets will thus be species-specific but potentially predictable” (Wild et al 2025 p303).

Ectotherms’ body temperature is dependent on the environmental temperature, and so, to cool down, for instance, behaviour strategies are used (eg: moving to a shaded spot). This explains the need for increased energy intake.

“The ability of an ectotherm to find food is also temperature-sensitive because activity is limited by body temperature. The joint influences of temperature on metabolic rate and potential foraging time lead to a required baseline feeding rate per hour of activity — the metabolic equivalent of a ‘minimum viable income’ —that must be met to survive, with additional energy allocated for reproduction and growth. Depending on how species’ potential foraging times, metabolic demands, and prey availability respond to warming, some scenarios with modest temperature increases could trap ectotherms in a cost-of-living ‘squeeze’, potentially reducing population densities and stabilities” (Wild et al 2025 p303).

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2. SURVIVING BIRD-BUILDING COLLISIONS

Collision with buildings is a leading anthropogenic cause of death for birds. In the USA, for example, estimates range from 365 million to one billion birds a year are killed in this way (Kornreich et al 2024). "Deadly collisions occur at both multi-story buildings and individual homes and in both urban and rural areas" (Kornreich et al 2024 p2) (appendix 2A).

Glass on buildings is a major risk factor. Kornreich et al (2024) explained: "Glass is transparent and largely invisible, so whereas humans are taught the concept of glass early in development and identify visual cues to identify it (but will still occasionally collide with it), birds do not understand glass and do not know or learn these visual cues. Presumably, birds perceive the image reflected off of glass or seen through glass as potential habitat or open space, especially open sky, or vegetation. Greenspace near reflective windows can be problematic as a result, and studies of bird-building collisions regularly consider the presence, height, and distance of vegetation from glass as risk factors. Architectural factors like glass area, building size and individual building facade characteristics have been shown to influence collision numbers. For homes, bird feeders have also been associated with increased collisions" (p2).

Bird-building collisions tend to be studied by collecting carcasses of victims. This assumes that collisions are fatal in the main, but Korner et al (2022), in a case study in Bonn, Germany, found that dead birds were less than 10% of collision victims. "Some birds survive the immediate collision and move away from the scene. Possibly, the survivors may recover from their sustained injuries, but they may be more vulnerable to predation or succumb to these injuries with time or suffer reduced fitness and reproductive disadvantages. Though post-collision prognosis for a disoriented or injured bird may be bleak, building collision survivors that are brought to wildlife rehabilitators are thought to have the best chance of recovery and subsequent survival. To fully understand the crisis of building collisions, these delayed deaths, or potentially disadvantaged survivors, matter, especially if these survivors are less of an exception to the rule than previously thought" (Kornreich et al 2024 p2).

Kornreich et al (2024) used data from wildlife rehabilitation in the USA to understand collision survivors. Data on over 3100 building collisions by 152 different bird species between 2016 and 2021 in eight northeastern US states were collected.

Approximately two-thirds of birds ("patients") died, either from their injuries (unassisted death during treatment) (head trauma most commonly) or by euthanasia (because healing or nursing not possible).

The study was based on surviving birds after a collision, who were found by humans and taken to a wildlife rehabilitation facility. There is no way of knowing what percentage of total collisions this sub-sample covers.

APPENDIX 2A - CONSERVATION AND MOVEMENT

Conservation planners needs to know the movement and distribution of a species. Such knowledge is particularly relevant with the growth of offshore wind farms and seabirds vulnerable to collisions. "For example, foraging northern gannets (Morus bassanus) face an elevated risk of collision when plunge-diving near wind turbines, whilst benthic foraging and deep-diving species (eg: auks) are particularly vulnerable to tidal and wave energy devices" (Wood et al 2025 p8).

Wood et al (2025) explained: "Conservation interventions that "fail to align with ecological needs risk misallocation of resources, stakeholder resistance, and sub-optimal conservation outcomes" (Wood et al 2025 pp8-9).

Wood et al (2025) used data showing resting, foraging, and transitioning behaviour from 566 GPS-tracked black-legged kittiwakes from fourteen colonies around the UK and Ireland between 2010 and 2015.

"Separating movement data by behaviour supports the delineation of targeted areas for conservation, however the distribution of specific behaviours may change over time as a result of intrinsic and extrinsic factors. This variation may be caused by seasonal, diurnal or circadian changes, underlying individual variation in decision making and habitat preferences, or in response to environmental change. Additionally, distribution may change with population structure, as behaviours can be exhibited unequally by different sex or age classes. To ensure that spatial and temporal limits for conservation efforts are future proof, conservation practitioners must account for these factors when planning protective actions" (Wood et al 2025 p9).

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3. REWILDING IN DIFFERENT WAYS

3.1. TWO STUDIES

Ungulates are often "keystone species" in an ecosystem; that is they have "a greater impact on ecosystem functions than would be expected based on their population sizes" (Lovell et al 2025 p1). Lovell et al (2025) explained further: "Through the combined effects of consumption, trampling, excretion and rooting, they impact both plant diversity and carbon storage—important ecosystem properties given the current biodiversity and climate crises" (p2). The consumption of plants, for instance, impacts "above-ground carbon", while "below-ground carbon" is impacted "directly, through grazing, trampling, excreta, rooting and carrion; and indirectly by altering plant–soil above-ground–below-ground relationships" (Lovell et al 2025 p2).

Lovell et al (2025) studied wild boar in a rewilding project area on the slopes of Loch Ness in Scotland. The study area was divided into survey plots based on twelve camera traps to estimate the visit frequency, and the plant species in each plot were measured.

No direct relationship between wild boar visit frequency to a plot and plant species diversity was found, but more visited areas had "more resource-acquisitive plant species" (Lovell et al 2025 p2). Having more than one ungulate species in rewilding projects was the conclusion.

The Kentish flats (off the coast of South-east England; eg: Whitstable beach) historically was associated with oyster cultivation, but "over-fishing, disease and changing culinary fashions put paid to the industry" (Hubbard 2025 p3). In the 21st century there has been a revival, both in oysters as a food, and in relation to rewilding.

Living oysters are "not inert, having the ability to 'collect, divide, dissolve, disperse and transform' sediments. As oysters suck in and filter out waters, they digest suspended phytoplankton and zooplankton. What they ingest and cannot digest, oysters eject as pseudo-faeces, which, coated in mucous, fall to the seabed to be processed by anoxic bacteria. The cleaner, deacidified water oysters leave behind is what just about everything else needs to live" (Hubbard 2025 p26). This is important with the polluted freshwater from the River Thames as it meets the salt waters of the North Sea. The presence of oysters "hence leads to increases of finfish and invertebrates, either as a source of food or through their wider contribution to biodiversity. In turn, this attracts the seabirds and other predators who reduce the number of starfish and slipper limpets that can quickly out-compete oysters in some areas. Through such processes, the presence of oysters enhances recreational and artisanal fishing, and contributes to the growth of avian populations, potentially encouraging birdwatching too" (Hubbard 2025 pp26-27).

The revival of oyster aquaculture in this area has involved conflict (eg: the frames as a hazard to local water sports), but also that "the oysters being cultivated are not Kentish Natives but imported triploid Pacific oysters" (Hubbard 2025 p3). These oysters are genetically modified and cultivated in plastic mesh bags suspended in the water from metal frames. The Pacific oyster was viewed as a "foreign other" by anti-groups, and Hubbard (2025) suggested evidence of "eco-nationalist sentiment" and "the protection of the community from changes associated with incomers" (p27). Protests against the oyster cultivation were as much about the threats of "rapid gentrification and touristification" (Hubbard 2025 p28).

3.2. ANIMATING THE CARBON CYCLE

The rewilding of areas by reintroducing animals has the potential to impact climate change positively. For example, the reintroduction of European bison to the Tarcu mountains in Romania has changed the environment (eg: compacting soil; dispersing seeds), and "turbocharged its ability to absorb carbon" (Lawton 2025 p39).

The idea of "animating the carbon cycle" (ACC) has been proposed (eg: Schmitz et al 2014). Herbivores, for instance, in an ecosystem influence the make up of vegetation, and consequently how much carbon can be taken up. While marine fish in the oceans fix carbon into soluble minerals in their intestines, which is excreted to the sea floor as a "sort of rock-like substance" (Lawton 2025 p40).

The amount of carbon that rewilding projects will drawdown is disputed (eg: Duvall et al 2024).

The largest terrestrial carnivores are usually at the top of the food webs. "Because of the high metabolic demands that come with endothermy and large body size, these carnivores often require large prey and expansive habitats. These food requirements and wide-ranging behaviour often bring them into conflict with humans and livestock. This, in addition to human intolerance, renders them vulnerable to extinction. Large carnivores face enormous threats that have caused massive declines in their populations and geographic ranges, including habitat loss and degradation, persecution, utilisation, and depletion of prey" (Ripple et al 2014 p151).

But these large carnivores are "necessary for the maintenance of biodiversity and ecosystem function" (Ripple et al 2014 p151). Ripple et al (2014) focused on seven of the 31 largest mammalian carnivores and their impacts ("cascades"):

i) "Tri-trophic cascades" - from large carnivores to prey to plants (sea otter, puma). The impact on the ecosystem is via carnivores eating herbivores who eat plants. For example, where sea otters declined, urchins increased and kelp decreased. Declining puma numbers are associated with increasing deer at the expense of hardwood trees and butterflies.

ii) "Meso-predator cascades" - from large carnivores to meso-predators to prey of meso-predators (lion, leopard, Eurasian lynx). Large carnivores eat smaller carnivores (meso-predators) who eat prey. Declining lion and leopards seen increasing olive baboons, but declines in small primates and ungulates.

iii) Both of the above - (dingo, grey wolf). For example, where there is a decline in dingo numbers, foxes and kangaroos increase, while grasses and dusky hopping mice decline.

3.3. REFERENCES

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4. THE BIOSPHERE IN THE ANTHROPOCENE

4.1. OVERVIEW

"Earth's biosphere is in a period of rapid change, resulting from anthropogenic pressures such as climate change, habitat loss and species translocation and extinction. The extraordinary pace of change has led to the suggestion that we live in a new geological epoch of time called the Anthropocene" (Williams et al 2026a p1).

Crutzen and Stoermer (eg: 2000) suggested that the Anthropocene Epoch (appendix 4A) (following the Holocene Epoch in geological time) began in 1784 to coincide with "the invention of James watt's steam engine, and emblematic of the Industrial Revolution and upturn in atmospheric CO_2" (Williams et al 2026a p2). Other start dates have been proposed (Williams et al 2026a) [1].

Williams et al (2026a) introduced a special issue of the "Philosophical Transactions of the Royal Society B" on the major changes to the biosphere in the Anthropocene.

Barnosky and Hadly (2026) outlined their view thus: "Already the Anthropocene biosphere differs from that of the Holocene in being less biodiverse, more homogeneous and dominated by humans and domestic animals and plants,

[1] "Although the International Union of Geological Sciences recently rejected the Anthropocene as a formal epoch/stage of the Geologic Time Scale, the debate between establishing it as a chronostratigraphic unit versus keeping it as a useful informal concept or event goes on, with new analyses still appearing" (Cohen 2026 p1).

and by interacting with an atmosphere, biogeochemical processes, and climate that differ in important respects from those of the Holocene. This differentiation only promises to intensify given ongoing Anthropocene trends — abnormally high rates of extinction and ecosystem transformation brought on by both local (habitat transformation, poaching) and global pressures (resource extraction to fuel an ever-growing and ever-consuming human population, human-caused climate change)" (p8).

4.2. EXTINCTIONS

Barnosky and Hadly (2026) observed that "Anthropocene extinction rates of vertebrates — even the most conservatively calculated — are considerably higher and faster than was the case even for the end - Pleistocene extinction, which wiped out over half of the species of Earth's large animals between approximately 50 000 and approximately 8000 years ago. That extinction event, and the way it contributed to changing the biosphere, was a major feature of the transition from the Pleistocene ice ages (lasting from 2.58 million to 11 700 years ago) to the Holocene (most of the past approximately 11 700 years)" (p2) (appendix 4B).

Overexploitation of species combined with human-caused global warming is the concern for Bonebrake (2026) (table), with particular reference to extinction of species [2]. "For the past several centuries, overexploitation has been one of the main dominant drivers of species declines and extinctions. Species that have survived past population declines from exploitation could then be particularly vulnerable to present and future climate change. The Chinese pangolin (Manis pentadactyla), for example, has declined largely as a consequence of overhunting, but climatic impacts are now causing local extinctions that are further endangering the species. Deep-sea fish with a history of exploitation are also vulnerable to warming, deoxygenation and continued fishing pressure in the future" (Bonebrake 2026 p2).

This is the clearest pathway to extinction - ie: overexploitation followed by climate change impacts. But there is the uncommon alternative - "climate change leading to population or distribution declines and

[2] Nikolaou and Katsanevakis (2023) outlined eighteen historical oceanic extinctions, of which overexploitation was the primary cause in thirteen (Bonebrake 2026).

leaving species vulnerable to exploitation. However, this is one of the primary hypotheses underlying the extinction of woolly mammoth and other species that have become extinct since the late Pleistocene (eg: European bison..., woolly rhinoceros...)" (Bonebrake 2026 p2). The third possibility is hunting and climate change occurring concurrently. Wan et al (2019), for example, documented this in China over 3000 years for the extinction of mammal species like elephants and rhinos (Bonebrake 2026).

- "Wicked problems" are "complex, intractable, open-ended, and unpredictable" (Rittel and Webber 1973 quoted in Schofield 2024a) (eg: social injustice; crime; conflict). They have certain characteristics (Rittell and Webber 1973), including no definite formulation, no clear solutions, possible solutions are good or bad (not true or false), and may have irreversible effects, while every wicked problem is essentially unique (and may be a symptom of another problem) (Schofield 2024a).

- There are also "super-wicked problems" (Schofield 2024b) (eg: climate change; environmental pollution), which have four additional characteristics to wicked problems - time is running out, there is no central authority to manage the problem, the same actors that cause the problem need to help solve it, and "the future is discounted radically so that contemporary solutions become less valuable" (Schofield 2024a p35).

- Dealing with wicked and super-wicked problems involves a "small-wins framework" (defined by Weick (1984) as "A series of concrete, complete outcomes of moderate importance [that] builds a pattern that attracts allies and deters opponents. The strategy of small wins incorporates sound psychology and is sensitive to the pragmatics of policymaking"; quoted in Schofield 2024a).

- Schofield (2024a) asserted: "Wicked problems are deeply entangled with one another, meaning that a solution to one problem may exacerbate other problems elsewhere" (p36).

Table 4.1 - Wicked Problems.

Overexploitation and climate change may not lead to extinction of a species, but they can affect species traits. "Size-selective harvesting represents probably the most obvious pathway through which exploitation will affect species traits. Bigger organisms will tend to be favoured in exploitation, resulting in artificial selection against larger body sizes. Because body size correlates with so many factors, this can then feature as a major force in evolutionary trajectories in marine and terrestrial ecosystems. Accordingly, vulnerability to thermal stress and climate change is likely to be altered under size-selective harvesting" (Bonebrake 2026 p3).

The "Insect Apocalypse" is a phrase to describe the decline in insect diversity and abundance in the last century. "Actual levels of decline and/or extinction are likely higher than estimated, because less than a fifth of all extant insects have been described. Some areas have seen up to an 80% decline within the last 50 years — highlighting that the Insect Apocalypse is clearly an Anthropocene global phenomenon" (Barnosky and Hadly 2026 p2). For no other reasons than "the human-centric perspective, insect declines jeopardise ecosystem services and threaten agriculture and food security via loss of pollination, pest control and soil" (Barnosky and Hadly 2026 p2) (appendix 4C).

Barnosky and Hadly (2026) made their view clear about what they called "a false promise": "Some have argued that biotechnology — in the form of so-called 'de-extinction' can play an important role in turning around the loss of biodiversity. That, however, is a false promise. Species are products of evolutionary and ecological processes that result in functioning ecosystems made up of organisms intimately connected through webs of interaction. When the habitats that built a species disappear or degrade past a certain point — as currently is the case for imperilled species even this early in the Anthropocene — it does little good to use biotechnology to bring long-vanished look-alikes into the present. Even if it becomes feasible to engineer such species and find potentially suitable refugia to release a few (or many), gone forever are the learnt behaviours, diets, predators or prey, and microbiomes that accumulated over millions of years, and which made the species what they were. Unleashing living technologies from the laboratory also poses myriad legal and ethical challenges" (p7).

4.3. OCEANS

Carlton and Schwindt (2026) listed the human impacts on the oceans as "fisheries operations, water 'quality' (chemical pollution (Appendix 4D) and eutrophication), habitat removal and alteration, species invasions and climate change" (p1).

Each one of these impact factors "umbrellas a wide array of phenomena and processes, which may often be over-simplified in diagrammatic presentations. Fisheries operations, for example, include (but are not limited to) over-extraction of species (by open-water netting, by bottom trawling of the sea bed (the latter often destroying benthic communities), by trapping and by dynamite fishing on coral reefs), by-catch of non-target species, ghost fishing by lost nets and traps and the replacement of large areas of natural coastal habitat by marine farming (aquaculture or mariculture), which may lead to, for the latter, the intentional or accidental introduction of species" (Carlton and Schwindt 2026 pp1-2).

Deep-sea ecosystems (defined as below 200 metres in depth) "are not immune to climate change and direct anthropogenic changes" (Yasuhara et al 2026 p2).

Shallow-marine ecosystems (0-200 metres depth) were impacted by humans (eg: industrial pollutants) before the deep-sea, and this came after terrestrial ecosystem degradation which humans started tens of thousands of years ago (Yasuhara et al 2026).

"In the deep sea, most major human impacts began much later than the industrial revolution, eg: deep-sea trawling from the 1950s. Major near-future concerns include deep seabed mining and marine carbon dioxide removal. Deep-sea Anthropocene biosphere degradation is delayed in this regard, and the ecological integrity of the deep sea remains much better than in other 'paradises' such as tropical rain forests and coral reefs that are already degraded substantially. The deep sea could soon be similarly degraded if large-scale implementation of mining and/or marine carbon dioxide removal (mCDR) technologies commences" (Yasuhara et al 2026 p1).

Strategies for mCDR as climate change impact mitigation include sinking large biomass (eg: wood waste, crops), iron fertilisation, ocean alkalinity enhancement, and direct ocean capture of CO_2 (Yasuhara et al 2026).

"The latitudinal diversity gradient (LDG) is one of the most prominent patterns in global biodiversity, typically described as a decline in species richness from the Equator toward the poles. This pattern has been consistently observed across terrestrial and freshwater taxa and has also been observed in marine ecosystems. Recent studies have increasingly revealed a more complex, bimodal pattern in the marine realm, with depressed richness at the Equator and peaks in the sub-tropics. This equatorial dip has become more pronounced over recent decades and coincides with rising sea surface temperatures (SSTs) and widespread poleward redistributions of marine species" (Chaudhary et al 2026 p1).

One explanation for this bimodal pattern is the maximum thermal limit for fish, particularly during the spawning stage (approximately 28 °C; Chaudhary et al 2026). Put simply, fish species are moving poleward because equatorial waters are too hot for them, particularly during reproduction. This can be described as a "life cycle bottleneck", and it suggests that "reproductive constraints may become key drivers of species redistribution, potentially initiating and intensifying both the equatorial richness dip and poleward shifts as temperatures rise" (Chaudhary et al 2026 p1).

"Intensive exploitation in the ocean has been ongoing for centuries, but it has accelerated exponentially in the past eight decades... [but] while trajectories differ across taxonomic groups, by far the largest removal of biomass from the ocean in human history has come through the targeted exploitation of wild-caught fisheries since World War II, with exploitation peaking for many taxa in the second half of the twentieth century" (McClenachan and Colby 2026 p1).

McClenachan and Colby (2026) noted four peaks and patterns in exploitation based on trade records:

i) Pacific maritime fur trade (1750 - mid-nineteenth century) - eg: sea otters.

ii) Mid-nineteenth to early twentieth century - coastal whales and seabirds.

iii) Industrialised exploitation of fish in the second half of the twentieth century.

iv) Since World War II (after 1945) crustaceans (crabs, lobsters, and shrimp).

These patterns are driven by consumer and industrial demand and social norms, geopolitics (eg: imperial expansion), and technology (eg: commercial fleets). Capitalism had an important role in the exploitation of the oceans, but the "drive for profit" was not solely to blame, argued McClenachan and Colby (2026). Depletion of resources, cultural change, and conservation awareness have slowed down, if not stopped, the exploitation (McClenachan and Colby 2026).

Dillon et al (2026) used fish otoliths (ear stones) as a means to assess fish populations over time. "Otoliths accumulate in sediments after a fish dies, where they store information about bony fish abundance, body size and taxonomic identity. Otolith accumulations form time-averaged death assemblages derived from fish that lived at different times but are preserved together. Death assemblages inherently incorporate demographic (eg: recruitment, growth and turnover) and mortality (eg: predation) processes that are difficult to capture in static snapshots of standing biomass but are crucial for understanding community-level fish productivity" (Dillon et al 2026 p2). Samples were taken from the Caribbean and Pacific coasts of Panama, which showed different patterns of fish biomass and anthropogenic impact since 7000 years ago.

In the geological past, marine organisms moved slowly over generations from the present-day Mediterranean Sea (known as the Tethys Sea in the past) to the "Coral Triangle" (southeast Asia and Melanesia) (the "Hopping Hotspots" process; Renema et al 2008). This was reversed after the opening of the Suez Canal in 1869 in what is called the "Lessepsian invasion" (Weerachai et al 2026).

This is "a partial human-induced reversal" (p2), and Weerachai et al (2026) analysed fossils of small crustaceans off the coast of Israel.

Cohen (2026) talked of "biological invasions" [3] (appendix 4E), the movement of species to new areas, which can be natural events or caused by human activities [4]. An example of the latter is seen in San Francisco Bay in California: "The bay was discovered in 1769 by a squad of Spanish soldiers who had lost their way, and the first ship entered the bay 7 years later. Non-native marine

[3] Biological invasion or bioinvasion refers to "the establishment of reproducing populations of a species in a geographic region where that species was historically absent" (Carlton and Schwindt 2026 p2). A related term is anthropogenic "global bioflow" (eg: Carlton 2011), defined as "the past, present and future of the human-mediated (by physical vectors) and human-influenced (by climate change and habitat alteration) movement of what have been, are and will be many tens of thousands of terrestrial, freshwater and marine species between and across all continents and oceans" (Carlton and Schwindt 2026 p2).

[4] Carlton and Schwindt (2026) distinguished between "invasion" and "invasive": "The former... is a biogeographical process referring to the movement of species between locations; the latter refers to their post-establishment behaviour or the consequences of invasions" (p6).

organisms were first carried to the bay as ships' hull fouling and in inter-tidal and shallow water materials — mud, sand and rocks —loaded into ships' holds as ballast and discarded when no longer needed" (Cohen 2026 p2). Further human development in the area produced other non-native species to arrive (eg: oysters from further north during transportation in the 19th century) (Cohen 2026). Natural movements through human built canals as mentioned above is another way of biological invasions.

The biological invasions in coastal marine and estuarine waters can be studied from fossils; specifically, new species appearance, reductions or disappearances of other species, and physical changes in the bodies of species (Cohen 2026).

Cohen (2026) argued that governments should take regulatory actions around ship's ballast water tanks and their release of the water near shore as this is a key means of biological invasion.

4.3.1. Ocean Darkening

"Ocean darkening" (ie: the surface waters becoming less opaque to incoming light) has been observed in recent years. It is estimated that one-fifth of the oceans have darkened in some way (Smyth 2026).

The drivers of this process include suspended particulates from agriculture, say, in rivers that flow into the seas, and this is linked to phytoplankton blooms stimulated by fertilisers. Such blooms are also increased by weather changes like sunnier conditions and increasingly stable surface waters (Smyth 2026).

"The photic zones of the oceans — where sunlight and moonlight drive ecological interactions — are one of the most productive habitats on the planet and fundamental to the maintenance of healthy global biogeochemical cycles" (Davies and Smyth 2025 p1). Ninety percent of marine life lives in the photic zone. "Considered to be around 200 m deep on average, the photic zone is critical for global nutrient and carbon budgets..., sustains global fish stocks... and supports aphotic marine ecosystems where light does not penetrate" (Davies and Smyth 2025 p1).

Davies and Smyth (2025) analysed twenty years of NASA satellite data. The photic zone depths were calculated to have been reduced by more than 50 metres between 2003 and 2022. These researchers concluded: "The implications of ocean darkening for marine ecology and the ecosystem services provided by the surface oceans are currently unknown but likely to be severe" (Davies and

Smyth 2025 p1). Though they also said: "Without sufficient light with which to grow, move, hunt, communicate, reproduce and photosynthesise, marine organisms will be forced to migrate vertically into an increasingly smaller belt of sufficiently lit surface waters, exposing them to higher levels of competition for resources and elevated risk of predation. The implications for marine food webs, global fisheries, carbon and nutrient budgets could be severe" (Davies and Smyth 2025 p7).

4.4. FRESHWATER

The "Living Planet Index" (LPI) produced by the "World Wildlife Fund" in 2024 summarises the average changes in wild vertebrate populations, and it was calculated that freshwater animals declined by 85% between 1970 and 2020 (compared to 69% of terrestrial species and 56% of marine animals) (Dudgeon and Liew 2026).

"Human activities have altered freshwater ecosystems during the Anthropocene, with a combination of multiple threats causing the 'great thinning' in abundance manifest in the LPI. There has also been a 'great shrinking' in body size, reflecting population collapses of freshwater megafauna, as well as declines in the average size at maturity of other species. These changes have been accompanied by a 'great mixing' or homogenisation of biotas as non-native species have occupied habitats that they could not colonise in the absence of some human involvement" (Dudgeon and Liew 2026 p2).

Dudgeon and Liew (2026) preferred the term "Homogenocene" (rather than "Anthropocene") to describe the mixing of species caused by humans, and based on the ideas of Charles Elton (eg: 1958).

Dudgeon and Liew (2026) used the example of non-native fish being the climate change "winners" in East Asia as they outperformed their native counterparts in a warmer world, "leaving a distinctive Anthropocene fingerprint upon freshwater ecosystems" (p1).

McCarthy et al (2026) reported a study of Crawford Lake in Ontario, Canada, over the last 8000 years. Agriculture, beginning from the late 13th century, in particular, altered the chemistry of the lake (eg: phosphorus, nitrogen), and subsequently the rise of green algae. These authors placed a greater emphasis on the recent past (ie: humans since the mid-20th century), and favoured the concept of the "Anthropocene epoch" (ie: they supported Crutzen and Stoermer's (2000) view).

4.5. LAND

On land, the conversion of natural ecosystems to agricultural lands is a key human impact. One estimate is six million hectares of cropland and thirty million hectares of grazing land by 5000 years ago (Borrell 2026).

Agricultural intensification (ie: increasing yield per hectare) through the 20th century, along with the abandonment of spared former agricultural land offer the opportunity for restoring biodiversity loss from human agriculture, argued Borrell (2026). "While global conservation efforts have struggled to measurably bend the curve of biodiversity loss, innovations in agriculture have convincingly succeeded in bending the curve of agricultural expansion" (Borrell 2026 p1).

Islands [5] constitute approximately 7% of the Earth's land area, but contain 20% of species, 50% of endangered species, and 75% of known extinctions (Cowie et al 2026).

"Oceanic islands and other marine islands support highly endemic and diverse biotas. But they have suffered extensive habitat destruction, especially deforestation, caused by agricultural and urban/suburban development and the impacts of invasive species, notably ungulates (pigs, sheep, goats, cattle), leading to decline and extinction of native plants and native animals as their habitat vanished. Other invasive species have preyed on the native species, or perhaps out-competed them, some of these predators becoming widespread globally" (Cowie et al 2026 p2). These researchers used the example of land

[5] "Islands come in many kinds and many sizes: oceanic islands that have never been connected to a continent and are either volcanic 'high' islands (eg: Galapagos, Ogasawara, Iceland, Azores, Mauritius, St. Helena), some now only represented by atolls (eg: Maldives), including raised limestone islands (eg: Makatea in French Polynesia, Henderson in the Pitcairn group, Rock Islands of Palau); or land-bridge islands that were connected to a continent prior to sea level rise (eg: Great Britain, Tasmania); continental islands that became isolated as a result of continental drift or fragmentation (eg: New Zealand, Madagascar, Seychelles) and may have been inundated by subsequent sea level rise (New Caledonia); and others that reflect complex series of vulcanism, uplift, sedimentation, plate movement and terrane accretion (eg: Aegean Islands, Jamaica, New Guinea, Socotra, Sulawesi). In addition to these marine islands, there are numerous islands within rivers and lakes, and ancient lakes can themselves be considered 'islands' surrounded and isolated as they are by terrestrial environments. Karst outcrops (eg: in Southeast Asia) surrounded by more acidic soil substrates may be considered islands and even mountain tops on continents may be referred to as 'sky islands'" (Cowie et al 2026 pp1-2).

snails in Hawaii.

4.6. RESPONSES

In response to the human impact on the planet, two emotions are traditionally presented - defiance and resignation. "Either we cling to the fragile hope that catastrophe can still be averted and act accordingly, or we abandon hope altogether" (Johnsen and Gasparin 2026 p1).

But there is also "a new emotional landscape" (Johnsen and Gasparin 2026 p1) with "a new kind of sorrow" (Pettman and Thacker 2024). "This feeling is captured in a range of emerging concepts, each emphasising different facets of emotional response. For example, environmental melancholia, as described by Lertzman [2015], refers to a persistent and unresolved mourning for ecological loss, while environmental grief and ecological grief highlight the acute bereavement experienced as ecosystems degrade and disappear. Other terms foreground related but distinct dimensions: ecodistress, as discussed by Marks and Hickman [2023], encompasses broader feelings of anxiety, helplessness and moral distress linked to environmental change. Solastalgia [Albrecht 2005] captures the distress produced by the transformation of familiar places while one still inhabits them" (Johnsen and Gasparin 2026 p1).

Johnsen and Gasparin (2026) continued later: "What first stands out in this emerging framing of the Anthropocene is its recognition that climate change is not merely a problem to solve or a crisis to overcome, but a condition we must learn to live with and through — an unfolding reality for which we have no final script or shared language. It is not an isolated event to be managed and contained, but a chronic condition that reshapes our emotional, social and ecological existence. Grief and mourning are not responses external to this condition — they are constitutive of it. They reflect a growing awareness of irreversible loss, and the fundamental human need to seek connection, care and meaning in the face of what can no longer be undone" (p2).

Walker et al (2026) concentrated on the experience and response of Indigenous peoples and local communities (IPLC) to changing Nature, specifically Maori activism in Aotearoa New Zealand.

4.7. FUTURE EARTH

Lyon et al (2026) explained: "Popular narratives stress escalating loss of species and ecosystems, and the potential collapse of the benefits they provide to people. In the public sphere, this can present the spectre of an uninhabitable Earth and the extinction of the human species. Research suggests that these crisis narratives can raise awareness, but are counter-productive in stimulating mitigating or adaptive action. They also omit evidence of biodiversity gains and ongoing adaptation alongside losses. Archaeological evidence also highlights the human ability to take advantage of and thrive under an extremely wide range of changing and challenging ecological conditions and the provisioning opportunities these provide. This perspective provides an evidenced counter-argument to claims of civilisational collapse amid environmental change. Projections show that rather than universal ecological decline, a cosmopolitan biosphere of losses and gains will probably emerge" (p1). These researchers aimed for a more optimistic view of the future based on human adaptability to gains and losses in biodiversity.

Redford and Sanjayan (2003) had taken a similar view, arguing that the "crisis narrative" offered no "wise or workable solutions". "To move beyond this paralysis, these writers pleaded that conservation biologists join forces with other researchers and non-scientists, to 'offer humans the means to envision a positive and achievable vision of the future — one that details how the world should look for their children and all children to come'" (Lyon et al 2026 pp2-3).

Lyon et al (2026) favoured a "social-ecological-technological systems (SETS) lens". "Social (S) in SETS is shorthand for 'social–cultural–economicgovernance' systems, which incorporate culture, law, governance, power and inequity considerations. Ecological (E) likewise describes the climate–biophysical–ecological systems, with the technological (T) meaning technological–engineered–infrastructural systems, including things like buildings, energy, transportation, information technology and communications" (Lyon et al 2026 p4). This approach helps us "understand the co-evolutionary nature of interactions between human and ecological systems" (Lyon et al 2026 p4), and it has emerged in (urban) sustainability research (eg: McPhearson et al 2022).

These researchers outlined three historical examples of human adaptability - hunter-gatherers in Pacific

Northwest 12 000 years ago, the Wari empire, South America (600 - 1000 CE), and the Sami in Northern Europe.

Fossil records help in our understanding of past extinctions, but Williams et al (2026b) imagined the fossil record as examinable by future generations, with particular reference to extinction, and non-native species.

4.8. APPENDIX 4A - ANTHROPOCENE

The current geological epoch is the Holocene, which began approximately 11 700 years ago (with the end of the last glacial period). In order for a new epoch to be agree, the Anthropocene, there needs to be a "Global Boundary Stratotype Section and Point" (GSSP). The GSSP signals a key event which is the boundary between two epochs. For example, the end of the Cretaceous epoch is 66 million years ago when an asteroid triggered a mass extinction. A proposal for the GSSP for the Holocene/Anthropocene is plutonium isotopes from nuclear weapons testing in the 1950s (found in the sediments of Crawford Lake in Canada) (Vaughan 2022).

Ellis (2023) argued against an Anthropocene epoch beginning in 1950: "Human transformation of Earth's ecosystems, biodiversity and climate began long ago, and expanded dramatically through five centuries of European colonialism" (p21).

"Some scientists proposed that the Anthropocene be considered a geological event: something that contributes to the transformation of Earth's systems, but doesn't constitute a new unit of geological time" (Ly 2024 p25).

Smil (2023) proposed twelve innovations that would "secure the future of humanity and the environment" (p39). These included a universal vaccine precursor, a cure for Alzheimer's disease, better batteries, greener plastics, and a "planetary sunshade". Meanwhile, improvements in recycling, and eliminating micro-nutrient deficiency would help, for instance.

4.9. APPENDIX 4B - TAXONOMY

Taxonomists have described around two million species in the world today. But it is estimated that over 90% of all living species have not yet been identified by scientists (Douglas 2022).

There are different species, for example, that are grouped as one (known as "hidden species"), but genetic analysis allows the differentiation. This is important because traditionally taxonomists have used physical attributes (morphology) to distinguish species. For example, one study of horseshoe bats found 44 potential hidden species within eleven categorised species (Douglas 2022).

However, there is a risk of "taxonomic inflation". "'Genetic diversity is higher in species with larger populations and high gene flow. So increasing genetic diversity does not mean more species', says Mark Costello at Nord University, Norway. Stephen Garnett at Charles Darwin University, Australia, agrees. 'Many taxonomic groups separated on the basis of a few mitochondrial genes do not stand up when examined closely', he says. They both highlight the need to combine genetic analyses with studies of morphology" (Douglas 2022 p49).

4.9.1. Mathematical Phylogenetic Models

The evolutionary descent of species as a tree-like process was mentioned by Charles Darwin (1859) [6], and separately by Arthur Cayley (1857) in the 19th century, but an early 20th century publication by George Yule (1925) is viewed as key (Rosenberg et al 2025).

This is the beginning of phylogenetic models or "a mathematical theory of evolution" (Yule 1925) as known today. Put simply, it is the process of showing the branches of past species and common ancestors leading to current species using statistical and inference techniques.

"Phylogenetic relationships among species are a consequence of complex historical processes, including population fragmentation and divergence, genetic drift and ecological adaptation, ultimately leading to increased genetic isolation and generating new species. These processes naturally lead to hierarchical relationships among extant and extinct species, including shared ancestral species existing at various times in the past" (Rannala and Yang 2025 p1).

[6] "Darwin explained how the tree could both represent the descent of biological lineages and provide a scheme for taxonomic grouping: 'The limbs divided into great branches, and these into lesser and lesser branches, were themselves once, when the tree was small, budding twigs; and this connexion of the former and present buds by ramifying branches may well represent the classification of all extinct and living species in groups subordinate to groups' [Darwin 1859]" (Rosenberg et al 2025 p1).

4.10. APPENDIX 4C - INSECT BIODIVERSITY

Time-series data provides the best evidence of biodiversity changes. "However, insect time series are typically too short and too variable to show clear trends, and geographic coverage is too patchy for global inference. Increasingly, data from experiments, spatial comparisons, expert elicitation, and other sources are being used to make large-scale assessments of biodiversity change. These alternative evidence types have their own strengths, weaknesses, and gaps" (table 4.2) (Cooke et al 2025 p45).

METHOD	DESCRIPTION	STRENGTHS	WEAKNESSES
Time-series	Data from same geography over time	Able to show trends over time and the changes	Limited to context in which data collected
Experiments	Controlled lab-based or field studies	Able to show cause and effect	One-shot in time usually
Spatial comparisons	Comparison across sites	Possible to combine data to show larger picture	Tends to be a static picture at that point in time
Expert elicitation	Information from experts include indigenous peoples	Specific knowledge about particular species or places over time	Data not necessarily systematically collected

(Source: Cooke et al 2025 figure 4)

Table 4.2 - Key strengths and weaknesses of different methods of insect data.

Cooke et al (2025) advocated for the combination of sources (time series, spatial comparisons, experiments, and expert opinion) to understand insect biodiversity change. The challenges to this task include that insects are hyperdiverse, influenced by a range of interactions, and evolve in response to environmental changes. "For example, climate change in the temperate zone is causing insects to complete their life cycles more quickly, leading some to attempt additional generations (and often fail) before winter sets in. These short-term changes in turn affect insect population dynamics and can be translated into long-term adaptation. Temperature changes are a key driver of evolutionary adaptation in insects, and as suitable climates shift, insects are challenged with adapting to new conditions or tracking suitable ones. Conversely, pesticide resistance may actively select for certain species in agricultural settings, increasing their abundance, whereas the majority are adversely affected" (Cooke et al 2025 p2).

4.10.1. Declining Butterfly Numbers

"Quantifying insect diversity patterns is challenging given that many species are obscure or still undescribed. However, the bright colours of butterflies are a source of delight that have captivated observers for centuries, enabling the collection of valuable data on butterfly diversity and abundance and making it possible to study long-term changes in butterfly communities" (Inouye 2025 p1037). For example, the combination of historical records, and citizen science today suggest a decline in butterfly populations in Western Europe (eg: Warren et al 2021) and the USA (eg: Edwards et al 2025).

Edwards et al (2025) combined data from sightings and catches in over 75 000 surveys in 2500 locations throughout the contiguous USA in the 21st century. In total, data entries for over twelve million butterflies from professional and amateur naturalists. Overall, a 22% decrease in butterfly abundance between 2000 and 2020 was calculated. The steepest decline was in the southwest of the country. While over seventy species had declined by more than 50%. Butterfly species were also moving northwards.

4.11. APPENDIX 4D - CHEMICAL POLLUTION

Polychlorinated biphenyls (PCBs), once widely used in industrial manufacturing, were banned in the UK in 1981 and internationally in 2001, but they are still causing problems in the oceans (Hobson 2025).

Williams et al (2025) found PCB blubber concentrations in the short-beaked common dolphin were linked to increased risk of mortality from infectious diseases. The data came from post-mortems of 836 dolphins stranded in the UK between 1990 and 2020.

The average concentration was 32 milligramme of PCBs per kilogramme of blubber (mg/kg), where 22 mg/kg is seen as a significant risk. A rise of 1 mg/kg was linked to a 1.6% increase in risk of infectious diseases being fatal.

However, a 1 °C rise in sea surface temperature increased the mortality risk from infectious disease by 14% (Hobson 2025).

4.12. APPENDIX 4E - ECOSYSTEM DISRUPTION

Frank (2024) opportunistically used the sudden emergence of the deadly disease, white-nose syndrome (WNS), in bats to show the importance of their loss on the ecosystem. Insect-eating bats are important in limiting the crop pest populations. The loss of bats could result in farmers' use of insecticide to compensate.

Using US data since 2006, when WNS emerged due to an invasive fungus species, Frank (2024) found an average increase in insecticide use of about one-third. Also Frank (2024) found an increase of around 8% in human infant mortality in the areas (county-level analysis) where insecticide use had increased. "These findings provide empirical validation to previous theoretical predictions about how ecosystem disruptions can have meaningful social costs" (Frank 2024 p1).

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5. TWO EXAMPLES OF CLIMATE CHANGE MITIGATION

5.1. SOLAR RADIATION MODIFICATION

Blocking sunlight (or more correctly, solar radiation modification; SRM) with sulphur dioxide aerosols in the stratosphere, say, could be one way to combat increasing temperatures with climate change (Luhn 2026a).

But such strategies would need to continue for a long time because the temperature rebound (or "termination shock"; Estrada et al 2026) would be highly dramatic. The point is that global warming will be masked by SRM [7] and its removal will reveal the full temperature change that has occurred during the period of SRM.

Modelling different scenarios for the use and ending of SRM, Estrada et al (2026) came to the conclusion that "solar-radiation modification can lower expected climate damages only within a narrow intersection where three conditions coincide: (i) rapid and sustained global mitigation, (ii) a very low probability of abrupt SRM failure, and (iii) controlled, slow phase-out" (p15).

5.2. DIRECT AIR CAPTURE

Direct air capture (DAC) involves machines that extract CO_2 from the atmosphere. Steve Smith of the University of Oxford described DAC as the "carbon equivalent of litter-picking; hard work, expensive, not the first-best way to deal with the problem, but necessary in our imperfect world" (quoted in Cuff 2024).

Zhao et al (2025) review concluded that the "integration of DAC with renewable energy sources, such as photovoltaic/ electrochemical regeneration, offers significant cost-reduction potential and can cut reliance on conventional heat by 30%" (p1), but increased

[7] It has been suggested that sulphur aerosols had been doing this already, and the reduction of their pollution was one of the possible explanations for higher global temperatures in the 2020s than expected by global warming models. Other explanations for the warming included natural cycles (eg: 11-year solar cycle; "El Nino"), unexpected climate feedback loops, statistical anomalies, and human behaviour that increased warming (eg: reversal of policies to lower fossil fuel use) (Luhn 2026b).

efficiency is still needed.

Among other possibilities are "carbon capture and storage" (CCS), Bioenergy with CCS (BECCS), and nature-based solutions (Zhao et al 2025). "While each approach contributes to decarbonisation, they also face distinct limitations such as geographical constraints, land use implications, infrastructure dependencies, or vulnerability to reversal - highlighting the need for complementary technologies that can address these gaps" (Zhao et al 2025 p2).

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6. MISCELLANEOUS

6.1. URBAN PAVEMENTS

"Although urbanisation poses a major threat to biodiversity..., cities have been described as 'sanctuaries' (Lepczyk et al 2023) and 'hotspots' (Ives et al 2016) for specific taxonomic groups and can entail locally very species rich habitats" (Weber et al 2024 p2454).

One example is the inhabitants of urban pavements, or more specifically, pavement cracks. For example, Haeseler (1982 quoted in Weber et al 2024) discovered 22 species of pavement nesting bees and wasps in one city in Germany.

More recently in the same country, Weber et al (2024) undertook a survey of urban pavements at twelve sites in Berlin. In total, 66 species of wild bees, solitary and parasitoid wasps, ants, and flies were identified. "Pavements located within 200 m to an insect-friendly flower garden were covered with significantly more nests of wild bees and solitary wasps, and showed higher species richness of these groups..." (Weber et al 2024 p2453).

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6.2. CROPS UNDER STRESS

Crops around the world are under stress. Mittler et al (2025) explained: "When compared with pre-industrial revolution conditions, the severity and frequency of droughts, heat waves, storms, floods, cold snaps and freezing episodes have dramatically increased in recent years. These occur in the background of deteriorating soil conditions that include enhanced salinity, micro-plastics content and pH extremes, as well as reduced microbiome diversity, which are also considered an outcome of modern industrial and agricultural practices. In some instances, for example when a heat wave occurs during a drought or following a flood, plants and crops are further subjected to a combination of two or more different abiotic stress factors, simultaneously or sequentially. The combined effects of altered weather patterns and weakening of plants are also thought to result in substantial outbreaks of diseases and/or insect attacks" (p1) [8]. The outcomes are reduced growth, reproduction, and yield as well as plant death. Meanwhile, human demand for food increases [9].

One solution is the "Resilience Revolution" - ie: to "increase the resilience of crops to the different stresses that anthropogenic activities inflict on them" (Mittler et al 2025 p2). This includes the use of technologies like genetic engineering and selective breeding [10], and artificial intelligence tools.

Importantly, a holistic approach is required rather than a laboratory-based reductionist approach that focuses upon one element at a time. Mittler et al (2025) argued thus: "In the field, crops are routinely subjected to a combination of multiple stressors. For example, elevated temperatures in the middle of the day could happen in combination with conditions of low or moderate levels of water deficit, nutrient imbalance, and other factors such as high ozone levels and/or pathogen/insect attack. As was demonstrated over 20 years ago with drought and heat, the response of plants to a combination of two different abiotic stresses cannot be predicted from simply summing up the effects of each of these individual stresses on plants. The state of 'stress

[8] It is important to understand changes in both average weather conditions (eg: increased average temperature; reduced mean rainfall), and extreme events (eg: increased frequency of such events) (Long 2025).

[9] Note that increased carbon dioxide concentration (CO2) since the industrial revolution period (mid-18th century) has produced physiological changes in plants called a "CO2 fertilisation effect", which contributed to greater crop yields. "However, CO_2 is a greenhouse gas and has been the major contributor to increased radiative forcing and warmer global temperatures, resulting in more extreme weather events, with negative consequences for crop production. While the benefits of rising CO_2 have stimulated productivity to date, they may soon be outweighed by the challenges of rising temperatures and altered precipitation on plant productivity. Rising atmospheric CO_2 also reduces the nutritional value of crops, reducing protein content and the concentration of key micro-nutrients" (Ainsworth et al 2025 p1).

[10] For example, genetic manipulations of photosynthesis and water use could be one strategy (Long 2025).

combination' should therefore be considered as a new type of stress that requires a new type of acclimation response" (p4).

Extreme weather events, like drought or torrential rain, disrupt food production. "But current efforts to compensate for the impact of poor harvests - such as clearing forests to grow more crops - make many other problems worse, from biodiversity loss to increasing carbon dioxide levels" (Le Page 2024 p45).

Initially modelling of future weather and crops (eg: Intergovernmental Panel on Climate Change (IPCC) in 2007) suggests that yields will fall in areas near the equator (ie: where crops are already close to their heat tolerance limits), but increase in areas further north or south (until a certain temperature rise, say), and then fall (Le Page 2024). Models, however, involve assumptions (eg: not including the risk of pests and diseases). For example, a new bacterium found in 2013 in Italy that impacted olive trees, which is spread by warmer temperatures (Le Page 2024).

More recent models (eg: IPCC in 2022) and actual studies suggest that it is "proving harder for farmers to adapt to changing climate than we thought - which is deeply worrying, given that the changes now are small compared with those expected in the next few decades" (Le Page 2024 p45). But this is hidden by rising overall food production (eg: wheat and maize) due to fertilisers and mechanisation, for instance. "Alarmingly, we seem to be at the start of a vicious cycle: global warming is making it harder to grow food, so farming is becoming more emission-intensive to keep up, leading to yet more warming" (Le Page 2024 p46).

David Lobell of Stanford University asserted: "The risk that we face is not a risk just to the food system. The risk we face is to the entire climate system, to the entire ecosystems of the world" (quoted in Le Page 2024). The upshot is that in the short term "isn't that those on a high income will go hungry, but that we will continue to damage the planet trying to keep supermarkets stocked" (Le Page 2024 p46).

Key solutions include changes in diet (eg: eating less meat), and reducing food waste in rich countries, and the application of technology (eg: genetically modified crops) (Le Page 2024).

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6.3. EXERCISE

Cycling or walking has benefits for health, and for the climate. Millard-Ball et al (2025) analysed data on walking and cycling rates from over 11 500 cities worldwide. Certain variables influenced the number of people doing these behaviours in a city, including the relative price of petrol, the terrain of the area (eg: hills discouraged cycling), climate (eg: wet weather a negative impact), poverty (eg: no choice but to walk), and infrastructure (eg: bike lanes) (Greenspan 2025). The latter was calculated by the researchers to be most important to both individual and population health, and global emissions. Copenhagen in Denmark was a good example, and Millard-Ball et al (2025) asserted that if every city extended the bicycle infrastructure to its level, private vehicle emissions would be reduced by around 6% per year, and US$435 billion would be saved in health costs annually (primarily due to reduced cardiovascular disease).

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