Supplementary Materials for the Planetary Health Check 2025

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Figure 4: Humanity’s Journey on Earth

Evolution of the global mean temperature over the last 500,000 years and projections until 2100 compared to past and projected human population size. Left and middle panels: Global mean temperature anomaly relative to the last millennium, estimated from Antarctic ice-core data. The reconstructed Antarctic temperature anomalies (Jouzel et al., 2007) were re-scaled by a factor of 0.5 following (Masson-Delmotte et al., 2010). The left panel shows the temperatures in the original temporal resolution (gray line) and averaged over the 1000 years (black line). Right panel: Observation-based global mean surface temperature anomalies from the HadCRUT data set (Climatic Research Unit (University of East Anglia), 2024); Morice et al., 2021; and Osborn & Jones, 2014, black line). Also shown is the expected temperature evolution for the IPCC Sixth Assessment Report Shared Socioeconomic Pathway (SSP) scenarios (Fyfe et al., 2024; Intergovernmental Panel on Climate Change (IPCC), 2021): SSP1-2.6 (blue), SSP2-4.5 (yellow) and SSP3-7.0 (red). Thick lines show the median estimates and thin lines show the lower and upper estimates (5%-95%) of the respective scenarios. The temperature anomalies are relative to the 1850-1900 average temperature. Estimate of the global population from 130,000 BCE to 2021 (lower light blue to red thick line) and population projections until 2100 (continuation of the line after 2021). The Holocene population estimates are from (Ritchie et al., 2024). The population estimate of 325,000 in 130,000 BCE is from (Sjödin et al., 2012). The straight thick line shows the median UN population projection (United Nations, Department of Economic and Social Affairs, Population Division, 2022) and the range shows the corresponding upper and lower 95% estimates.

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Figure 6: The Great Acceleration

Trends from 1750 to 2024 in indicators for socio-economic development.

1. World Population

Global population data according to the History Database of the Global Environment (HYDE) database v3.3.

Unit: Billion

Sources:
Klein Goldewijk (2024). *History Database of the Global Environment 3.3*. Utrecht University https://doi.org/10.24416/UU01-AEZZIT

Klein Goldewijk et al. (2017). Anthropogenic land use estimates for the Holocene – HYDE 3.2. *Earth Syst. Sci. Data* **9**, 927–953.

2. Real GDP

Global real Gross Domestic Product (GDP) in year 2011 U.S. dollars according to the Maddison Project Database 2023.

Unit: Trillion of real 2011 U.S. dollars

Sources:
Bolt & van Zanden (2024). *Maddison Project Database 2023*. DataverseNL, V1. https://doi.org/10.34894/INZBF2

Bolt & Van Zanden (2025). Maddison-style estimates of the evolution of the world economy: A new 2023 update. *J. Econ. Surv.* **39**, 631–671.

3. Foreign direct investment

Global foreign direct investment in current (accessed 2025) US dollars. Data before 1990 follows Steffen et al. (2015), based on International Monetary Fund (IMF) data from 1948–1969 and United Nations Conference on Trade and Development (UNCTAD) data from 1970–1989, both accessed in 2013, and adjusted for inflation. Data from 1990 to 2023 is from UNCTAD, accessed in 2025.

Unit: Trillion of 2025 U.S. dollars per year

Sources:
Steffen et al. (2015). The trajectory of the Anthropocene: The Great Acceleration. *Anthr. Rev.* **2**, 81–98.

IMF (n.d.). *International Monetary Fund eLibrary Data.* https://www.imf.org/ (accessed in 2013).

UNCTAD (n.d.). *United Nations Trade and Development Data Hub.* https://unctadstat.unctad.org/datacentre/dataviewer/US.FdiFlowsStock (accessed in 2013 and 2025).

4. Urban population

Global urban population data according to the HYDE database v3.3.

Unit: Billion

Sources:
Klein Goldewijk (2024). *History Database of the Global Environment 3.3*. Utrecht University https://doi.org/10.24416/UU01-AEZZIT (accessed in 2025).

Klein Goldewijk et al. (2017). Anthropogenic land use estimates for the Holocene – HYDE 3.2. *Earth Syst. Sci. Data* **9**, 927–953.

5. Primary energy use

World primary energy use according to Our World in Data, based on data from the Energy Institute (EI) and Smil (2017) with major processing by Our World in Data.

Unit: Exajoule per year

Sources:
Our World in Data (2024*). Global direct primary energy consumption.* https://ourworldindata.org/grapher/global-primary-energy (accessed in 2025).

Energy Institute (2024*). Statistical Review of World Energy.* https://www.energyinst.org/statistical-review

Smil (2017). *Energy Transitions: Global and National Perspectives* (Appendix A). Santa Barbara, CA: Praeger, an imprint of ABC-CLIO, LLC.

6. Fertilizer consumption

Global fertilizer (nitrogen, phosphate and potassium) consumption based on International Fertilizer Industry Association (IFA) data. Data prior to 1961 were retained as reported in Steffen et al. (2015), based on personal correspondence with Olivier Rousseau from IFA.

Unit: Million tonnes per year

Sources:
Steffen et al. (2015). The trajectory of the Anthropocene: The Great Acceleration. *Anthr. Rev.* **2**, 81–98.

IFA (2019). *IFASTAT Consumption Database* (Fertilizer Consumption - Historical Trends by Country or Region). https://www.ifastat.org/databases/graph/1_1 (accessed in 2025).

7. Large dams

Global total number of large dams built since 1900 according to data from the International Commission on Large Dams (ICOLD) as extracted from Figure 1 in Perera et al. (2021). Large dams are defined as having a minimum height of 15 metres above the foundation, or 5–15 metres height and impounding more than 3 million cubic metres.

Unit: Thousand dams

Sources:
Perera et al. (2021). *Ageing Water Storage Infrastructure: An Emerging Global Risk 11*. United Nations University (UNU).

ICOLD (2020). *World Register of Dams: General Synthesis*. https://www.icold-cigb.org/GB/world_register/general_synthesis.asp (accessed in 2020).

8. Water use

Global water use. Data from 1900 to 1999 follows Steffen et al. (2015), based on estimations from Flörke et al. (2013), aus der Beek et al. (2010), and Alcamo et al. (2003), using the WaterGAP model. AQUASTAT data from the Food and Agriculture Organization of the United Nations (FAO) is used from 2000 to 2022.

Unit: Thousand km³ per year

Sources:
Steffen et al. (2015). The trajectory of the Anthropocene: The Great Acceleration. *Anthr. Rev.* **2**, 81–98.

Flörke et al. (2013). Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study. *Glob. Environ. Change* **23**, 144–156.

aus der Beek et al. (2010). Modelling historical and current irrigation water demand on the continental scale: Europe. *Adv. Geosci.* **27**, 79–85.

Alcamo et al. (2003). Development and testing of the WaterGAP 2 global model of water use and availability. *Hydrol. Sci. J.* **48**, 317–337.

FAO (n.d). *AQUASTAT: FAO's Global Water Information System*. https://data.apps.fao.org/aquastat/ (accessed 2025).

9. Paper production

Global paper production (paper and paperboard) according to data from the Food and Agriculture Organization of the United Nations (FAO).

Unit: Million tonnes per year

Source:
FAO (n.d.). *FAOSTAT statistical database: Forestry Production and Trade*. https://www.fao.org/faostat/en/#data/FO (accessed in 2025).

10. Global infrastructure agreements

Number of global infrastructure agreements according to Haner (2023), based on an analysis of the Consolidated Treaty Series (CTS), the League of Nations Treaty Series (LNTS), and the United Nations Treaty Series (UNTS).

Unit: Thousand agreements

Source:
Haner (2023). *Organizing peace: An algorithmic analysis of four centuries of international law and the decline of war* (Doctoral dissertation, Northeastern University). ProQuest LCC Publishing.

11. Telecommunications

Global sum of fixed landlines and mobile phone subscriptions. Landline data are based on Canning (1998) for 1950-1989 and data from the United Nations Statistics Division (UNSD) from 1990-2022. Mobile phone subscription data are based solely on UNSD data from 1990-2022.

Unit: Billion telephone subscriptions

Sources:
Canning (1998). A database of world stocks of infrastructure: 1950–1995. *The World Bank Economic Review, 12*(3), 529–548.

UNSD (2014). *UNdata database: Landline telephones and mobile phones*. http://data.un.org/Data.aspx?q=telephones&d=MDG&f=seriesRowID%3a779 and http://data.un.org/Data.aspx?q=cellular&d=ITU&f=ind1Code%3aI271 (accessed 2025)

12. Transistors per microprocessor

Number of transistors per microprocessor according to data from Rupp (2022), processed by Our World in Data. A data point was added with the value 1 in 1947 for the first transistor.

Unit: Billion

Source:
Rupp (2022). *Microprocessor Trend Data*. https://github.com/karlrupp/microprocessor-trend-data (accessed in 2023). Processed by Our World in Data: https://ourworldindata.org/grapher/transistors-per-microprocessor

Trends from 1750 to 2024 in indicators for the structure and functioning of the Earth System.

1. Carbon dioxide

Global atmospheric carbon dioxide concentration according to data from the Indicators of Global Climate Change 2024.

Unit: Parts per million

Source:
Smith et al. (2025). *Indicators of Global Climate Change 2024*. https://doi.org/10.5281/ZENODO.7883757 (accessed in 2025).

2. Nitrous oxide

Global atmospheric nitrous oxide concentration according to data from the Indicators of Global Climate Change 2024.

Unit: Parts per billion

Source:
Smith et al. (2025). *Indicators of Global Climate Change 2024*. https://doi.org/10.5281/ZENODO.7883757 (accessed in 2025).

3. Methane

Global atmospheric methane concentration according to data from the Indicators of Global Climate Change 2024.

Unit: Parts per billion

Source:
Smith et al. (2025). *Indicators of Global Climate Change 2024*. https://doi.org/10.5281/ZENODO.7883757 (accessed in 2025).

4. Stratospheric ozone

Maximum percentage total column ozone decline (2-year moving average) over Halley, Antarctica during October, using 305 DU, the average October total column ozone for the first decade of measurements, as a baseline.

Unit: Percentage

Source:
Shanklin, British Antarctic Survey (n.d.). Antarctic Ozone. https://legacy.bas.ac.uk/met/jds/ozone/index.html#data (accessed in 2025).

5. Surface temperature

Global surface temperature anomaly according to the HadCRUT5 analysis by the Climate Research Unit (University of East Anglia and NCAS), and the Hadley Centre (UK Met Office). Combined land and ocean observations, relative to 1961-1990.

Unit: Degrees Celsius

Source:
Morice et al. (2021). An updated assessment of near-surface temperature change from 1850: The HadCRUT5 data set. *Journal of Geophysical Research: Atmospheres, 126*(e2019JD032361). Dataset version *5.0.2.0 retrieved from:* https://crudata.uea.ac.uk/cru/data/temperature/#sciref (accessed in 2025).

6. Ocean acidification

Ocean acidification expressed as global mean surface ocean hydrogen ion concentration from a model-data fusion product (using 14 models from CMIP6) based on observations until 2014 and thereafter SSP2-4.5.

Unit: nmol kg^{-1}

Source:
Jiang et al. (2023). Global Surface Ocean Acidification Indicators From 1750 to 2100. *J. Adv. Model. Earth Syst.* **15**.

7. Marine fish capture

Global marine fish capture according to data from the Food and Agriculture Organization of the United Nations (FAO).

Unit: Million tonnes per year

Source:
FAO (n.d.). *Fishery and aquaculture statistics: Capture production quantity*. https://www.fao.org/fishery/statistics-query/en/capture/capture_quantity (accessed in 2025).

8. Shrimp aquaculture

Global aquaculture shrimp production according to data from the Food and Agriculture Organization of the United Nations (FAO).

Unit: Million tonnes per year

Source:
FAO (n.d.). *Fishery and aquaculture statistics: Aquaculture production quantity*. https://www.fao.org/fishery/statistics-query/en/aquaculture/aquaculture_quantity (accessed in 2025).

9. Nitrogen to coastal zone

Model-calculated human-induced perturbation flux of nitrogen into the coastal margin (riverine flux, sewage and atmospheric deposition).

Unit: Million tonnes per year

Source:
Mackenzie et al. (2002). Century-scale nitrogen and phosphorus controls of the carbon cycle. *Chemical Geology*, 190, 13–32.

10. Tropical forest loss

Loss of tropical forests compared relative to the year 1700. Data for 1700 and from 1750 to 1992 are from Pongratz et al. (2008), based on reconstructions of land use and land cover. From 1993 to 2022, data from the Copernicus Climate Change Service (C3S) is used and is evaluated as the loss relative to 1992 (to avoid discontinuities at the transition from modeled to remote-sensing based data).

Unit: Percentage

Sources:
Pongratz et al. (2008). A reconstruction of global agricultural areas and land cover for the last millennium. *Global Biogeochemical Cycles, 22*(4), GB3018.

Copernicus Climate Change Service (2019). *Land cover classification gridded maps from 1992 to present derived from satellite observation.* https://doi.org/10.24381/cds.006f2c9a (accessed in 2024).

11. Domesticated land

Increase in agricultural land area, including cropland and pasture as a percentage of total land area. Data from 1750 to 1960 are based on reconstructions of land use from Pongratz et al. (2008). From 1961 to 2022, data is from the Food and Agriculture Organization of the United Nations (FAO).

Unit: Percentage

Sources:
Pongratz et al. (2008). A reconstruction of global agricultural areas and land cover for the last millennium. *Global Biogeochemical Cycles, 22*(4), GB3018.

FAO (n.d.). *FAOSTAT statistical database: Land Use*. https://www.fao.org/faostat/en/#data/RL (accessed in 2025).

12. Terrestrial biosphere degradation

Percentage loss of terrestrial mean species abundance relative to abundance in undisturbed ecosystems as an approximation for degradation of the terrestrial biosphere. The data follows Steffen et al. (2015) and is based on Alkemade et al. (2009) and ten Brink et al. (2010).

Unit: Percentage

Sources:
Alkemade et al. (2009). GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss. *Ecosystems* **12**, 374–390.

ten Brink et al. (2010). Global MSA baseline scenarios. In: *Rethinking global biodiversity strategies: Exploring structural changes in production and consumption to reduce biodiversity loss*. Netherlands Environmental Assessment Agency (PBL). The Hague/Bilthoven.

Figure 30: Global Risk Map of Earth's Freshwater Systems (I) - Blue Water.

This map shows boundary transgression at river basin scale for major basins (Lehner et al., 2013) of the world (n = 268). Transgression is based on the control variable, streamflow, with values potentially ranging from within the Safe Operating Space (green) to the Zone of Increasing Risk (yellow/orange), and extending to the High Risk Zone (red/purple). At the global scale, the high risk boundary (50%) is beyond the PB (12.9%) by a factor of 2.9, the current status (22.6%) transgresses the PB by a factor of 0.75, while the baseline state (10.3%) was below the PB by a factor of -0.20. Each basin has its specific safe level (evaluated similarly as the global safe level), and the risk level of each basin is determined by scaling its relative transgression factor with the global transgression factor (0.75). Basins depicted in the darkest shade of orange especially contribute to the global transgression, with regional land area deviations higher than the global factor. Based on data from Virkki et al. (2025).

Lehner, B. & Grill, G. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrol. Process. 27, 2171–2186 (2013).

Virkki, V. *et al.* Regionally divergent drivers behind transgressions of the freshwater change planetary boundary. Preprint at https://doi.org/10.31223/X54X7M (2025).

Figure 32: Global Risk Map of Earth's Freshwater Systems (II) - Green Water.

This map shows boundary transgression at river basin scale for major basins (Lehner et al., 2013) of the world (n = 268). Transgression is based on the control variable, root zone soil moisture, with values potentially ranging from within the Safe Operating Space (green) to the Zone of Increasing Risk (yellow/orange), and extending to the High Risk Zone (red/purple). At the global scale, the high risk boundary (50%) is beyond the PB (12.4%) by a factor of 3.0, the current status (22.0%) transgresses the PB by a factor of 0.77, while the baseline state (9.8%) is below the PB by a factor of -0.21. Each basin has its specific safe level (evaluated similarly as the global safe level), and the risk level of each basin is determined by scaling its relative transgression factor with the global transgression factor (0.77). Basins depicted in the darkest shade of orange especially contribute to the global transgression, with regional land area deviations higher than the global factor. Based on data from Virkki et al. (2025).

Lehner, B. & Grill, G. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. Hydrol. Process. 27, 2171–2186 (2013).

Virkki, V. *et al.* Regionally divergent drivers behind transgressions of the freshwater change planetary boundary. Preprint at https://doi.org/10.31223/X54X7M (2025).

2. Underlying Calculations for Chapter 3.1

Calculating the total mass of the ocean

Assuming an average density of $\rho = 1027\ kg/m^3$ for seawater:

Reservoir	Volume (km^3)	Mass (kg)
Total Ocean	~1.3 billion (Costello et al., 2015)	~1.34×10^{21} kg

Calculating the total mass of land and sea ice

Ice Reservoir	Volume (km^3)	Mass (kg)
Antarctic Ice Sheet	~26.4 million (Huybrechts et al., 2000)	~2.2×10^{19} kg
Greenland Ice Sheet	~2.6 million	~2.9×10^{18} kg
Glaciers and Ice Caps (non-polar)	~170,000 (Huss & Farinotti, 2012)	~1.7×10^{17} kg
Arctic Sea Ice (seasonal avg.)(Shepherd et al., 2018)	~18,000	~2×10^{15} kg
Antarctic Sea Ice (seasonal avg.)	~14,000	~1.5×10^{15} kg
Total		~2.4×10^{19} kg

Converting ocean carbon content into ppm equivalent

- Convert carbon to CO_2:
    - Carbon is often measured in gigatonnes of carbon (GtC), but atmospheric CO_2 is

tracked in gigatonnes of carbon dioxide ($GtCO_2$).

- 1 GtC = 3.67 $GtCO_2$, so 185 GtC = 680 $GtCO_2$

- Understand what 1 ppm CO_2 means in terms of mass:
  - The total mass of Earth's atmosphere is about 5.15×10^{18} kg.
  - Assuming the average molar mass of dry air is 28.97 g/mol, this equals approximately 1.78×10^{20} moles of air.
  - 1 ppm (part per million) of CO_2 means 1 millionth of that:
    $1.78 \times 10^{20} \div 10^{6} = 1.78 \times 10^{14}$ moles of CO_2 per ppm
  - CO_2 has a molar mass of 44.01 g/mol, so:
    1 ppm $CO_2 = 1.78 \times 10^{14} \times 44.01$ g $\approx 7.83 \times 10^{15}$ g = 7.83 Gt CO_2

- Estimate atmospheric CO_2 increase:
  - If the ocean has absorbed ~680 $GtCO_2$, then without this uptake and under the simplified assumption that the land carbon sink would not change in response to the missing ocean carbon sink, atmospheric CO_2 levels would be:
    $680 \div 7.83 \approx 87$ ppm higher

3. Table of Planetary Boundary Interconnections

Driver	Affected PB	Process	Impact on PB	Relative importance	Literature
Ocean Acidification (OA)	BI	Increased degradation of coral reefs can lead to collapse of marine food webs.	(-)	medium	Hoegh-Guldberg et al. 2017; Doney et al. 2009
	BI	increased OA can lead to a reduction in calcifying species and to the loss of habitat forming species	(-)	medium	Doney et al. 2009; Teixidó et al. 2024
	BI	Increased pCO2 can lead to increased photosynthesis rates	(+)	low	Das and Mangwani 2015
	AL	Decreasing pH can increases the potential for high dimethyl sulfides emissions by phytoplankton	(-)	low	Das and Mangwani 2015, Deng et al. 2021, Fung et al. 2022
	BI/BC	OA can lead to changes in nitrification and nitrogen fixation	(-/+)	low	Shi et al. 2012, Wannicke et al. 2018
	CC	OA can decrease the capacity of organisms to form carbonate shells, which allows oceans to absorb more CO2	(+)	low	Lade et al. 2019
	NE	Ocean acidification can alter the chemical behavior of pollutants, such as heavy metals	?	low	Jin et al. 2021
Freshwater Change (FW)	BI	Changes in streamflow (e.g. by dams) can causes habitat destruction	(-)	low	Gleeson et al. 2020, Broadley et al. 2022
	BI	Changes in streamflow and soil moisture alter transport and availability of nutrients	(-/+)	low	Gleeson et al. 2020, Lie et al. 2024
	BI	reduction in river flow/drain aquifers can lead to salinization and decrease productivity	(-)	low	Lade et al. SM, Broadley et al. 2022
	CC	Soil moisture, surface water and frozen water can alter earth surface albedo	(-)	low	Maina et al. 2022,
	BC	Changes in streamflow and soil moisture alter transport of nutrients	(-/+)	low	Gleeson et al. 2020, Lie et al. 2024
	LSC	Reduction of soil moisture/green water flow can lead to desertification/land degradation	(-)	high	AbdelRahman 2023
Biosphere Integrity (BI)	CC	Loss of biodiversity and ecosystem degradation can reduce the capacity for carbon uptake	(-)	high	Bustamante et al. 2015, Lade et al. 2020, Poorter et al. 2015, Cardinale et al. 2012

	CC	Increased productivity due to increased eutrophication can lead to increased GHG (Methane) emissions	(-)	medium	Beaulieu et al. 2019, Lade et al,. 2020, Rocher-Ros et al. 2023
	CC	Reduced biodiversity leads to a reduction of CO2 uptake in oceans	(-)	medium	Gruber et al. 2023, Lade et al. 2020, Nash et al. 2017
	BC	Biodiversity loss can alter nutrient cycles and lead to nutrients being added to ecosystems	(-/+)	low	Cui et al. 2022
	LSC	Degraded biosphere integrity can increase the vulnerability of forests to shocks or pests	(-)	high	Bustamante et al. 2015, Poorter et al. 2015
	FW	Loss of ecosystem functions reduce the capability to regulate the hydrological cycle that can lead to changes in water availability and quality	(-)	medium	Harrison et al. 2014
	OA	Decline in coral reefs and phytoplankton can exacerbate ocean acidification	(-)	low	Cornwall et al. 2021, Zhang et al. 2023
	NE	The capacity of ecosystems to degrade and assimilate pollutants is reduced leading to higher concentrations of harmful substances	(-)	low	Ferreira et al 2023
Stratospheric Ozone depletion (SO)	CC	Reduced absorption of UV in the stratosphere increases the UV radiation at Earth's surface	(-)	low	Lade et al. 2019
	BI	Reduced absorption of UV in the stratosphere increases UV radiation at Earth's surface with the potential to damage DNA and impair photosynthesis	(-)	low	Lade et al, EEPA 2019
	AL	Changes in UV radiation can influence the production of aerosols through chemical reactions in the atmosphere.	(-/+)	low	Lade et al. 2019
Biogeochemical Flows (BC)	BI	Nutrient runoff can degrade soil by increased acidification, eutrophication and simplification of ecosystems	(-)	low	Lade et al. 2019
	BI	Nutrient runoff from agricultural application into freshwater can lead to algal blooms, dead zones, loss of fish	(-)	medium	Lade et al. 2019
	BI	Nutrient runoff into the ocean can lead to large scale ocean hypoxic events, having strong impacts on the ocean ecosystems	(-)	low	Lade et al. 2019, Rockström et al. 2009
	LSC	Excessive use of fertilizers can lead to soil degradation (farmland)	(-)	medium	Lade et al. 2019

	FW	Nutrient runoff from agriculture, sewage and industrial processes can degrade freshwater quality	(-)	medium	du Plessis 2022
	AL	Nitrogen compounds, particularly ammonia (NH_3) from agriculture, can contribute to the formation of fine particulate matter ($PM_{2.5}$) in the atmosphere.	(-)	medium	Lade et al. 2019, Gu et al. 2021
	SO	Application of N fertilizers can lead to N_2O emissions that depletes ozone in the stratosphere	(-)	low	Lade et al. 2019, Campbel et al. 2017
Land system change (LSC)	CC	Deforestation and land conversion can reduce the capacity of these systems to absorb CO_2, contributing to higher atmospheric CO_2	(-)	high	Lade et al. 2020
	CC	Changes in land cover can alter the surface albedo. This affects the radiative forcing	(+)	high	Gibbard et al. 2005, Andrews et al. 2016
	BI	Land conversion can lead to habitat loss. Fragmentation of habitats can isolate populations, reducing genetic diversity	(-)	high	Lade et al. 2020, Lade et al. 2019, Campbell et al. 2017, Alkemade et al. 2009
	BI	Forest cover loss can lead to decreased water quality, altered flows etc. reducing species diversity	(-)	low	Semenchuk et al. 2022
	BI	Land system change can disrupt ecosystem services such as pollination, water purification, soil stabilization	(-)	medium	Bennet et al. 2020,du Plessis 2022, Delelegn et al. 2017, Borelli et al. 2020
	FW	Land system change can increase river discharge	(+)	low/medium	Lade et al. 2020
	FW	Deforestation can impact the hydrological cycle by reducing evapotranspiration and subsequent drying of the atmosphere	(-)	medium	Xu et al. 2022
	AL	Forest fires (associated with land clearing), as well as cleared agricultural land emit large amounts of aerosol	(-)	medium	Lade et al. 2020
Aerosol Loading (AL)	CC	Sulfate aerosols reflect sunlight, cooling the Earth's surface; Black carbon absorbs sunlight, warming the atmosphere	(-/+)	medium	IPCC AR5, Chapter 7 Clouds and Aerosols, Quaas et al. 2022
	CC	Aerosols act as cloud condensation nuclei, influencing cloud formation, properties and lifetimes. This can affect the energy balance as well as the hydrological cycle and climate	(-/+)	medium	IPCC AR5, Chapter 7 Clouds and Aerosols

		dynamics			
	BC	changes of bioaerosols in the atmosphere can lead to changes in nutrient deposition	?	low	Kanakindou et al. 2018, Fröhlich-Nowoisky et al. 2016
	BC	Acidic rains can lead to soil acidification	(-)	low	Grennfelt et al. 2020
	OA	Some aerosols (e.g. those containing sulfur compounds) can increase acidic rain. When entering the ocean, this can increase its acidification	(-)	low	Doney et al. 2009
	BI	Aerosol deposition can deliver nutrients like iron, stimulating net primary production	(+)	?	Lade et al. 2020
	SO	Aerosols in the stratosphere can provide surfaces for heterogenous chemical reactions that can contribute to ozone depletion	(-)	low	Solomon et al. 1987
	SO	Aerosols can absorb UV radiation therefore increasing the safe level of ozone depletion	(+)	low	Lade et al. 2020
	BI	Increase release of pesticides, industrial chemicals and heavy metals can intoxicate a wide range of organisms; leading diversity loss and disruption of ecosystem services	(-)	high	Sigmund et al. 2023
	BI	The release of genetically modified organisms can lead to genetic pollution, affecting genetic diversity	(-)	low	Tsatsakis et al. 2017
	FW	Increased release of pharmaceuticals, personal care products and industrial chemicals can contaminate freshwater systems	(-)	medium	Richmond et al. 2017
	OA	Abiotic plastic degradation can induce a decrease in seawater pH	(-)	low	Romera-Castilla et al. 2023
	AL	The release of volatile organic compounds and persistent organic pollutants can contribute to the formation of secondary aerosols	(-)	high	Nault et al. 2021
Climate Change (CC)	BI	Rising temperatures and shifting precipitation patterns lead to changing weather regimes that can affect biological events such as habitat loss, species extinction, migration and the introduction of invasive species	(-)	high	Lade et al. 2020, Jaureguiberry et al. 2022
	BI	Extreme events and rising sea levels can lead to the salinisation of freshwater ecosystems	(-)	medium	Lade et al. 2020

	BC	Increases in extreme precipitation events can lead to an increase of agricultural runoff	(-)	low	Skidmore et al. 2023
	LSC	Climate stress on forests (e.g. increased frequency of wildfires and droughts) can lead to deforestation and land degradation	(-)	high	Flore et al. 2024
	FW	Changes in precipitation patterns and the melting of glaciers can impact freshwater availability.	(-/+)	medium	Konapala et al. 2020, Haeberli et al. 2020
	FW	Precipitation patterns can change due to climate change	(-/+)	high	Lade et al. 2020
	OA	Increasing CO2 levels lead to an increased absorption of CO2 in the oceans, exacerbating ocean acidification	(-)	high	Doney et al. 2009
	OA	Increasing temperatures can reduce the solubility of CO2 in water	(+)	low	Lade et al. 2020
	AL	Increased droughts and changing atmospheric circulations can increase dust formation and distribution	(-)	low	Zhao et al. 2019
	SO	Climate change reduces stratospheric temperatures due to heat being trapped at lower levels of the atmosphere, slowing ozone depleting chemical reactions and increasing the destruction of nitrous oxides	(+)	low	Lade et al. 2019
	NE	Increasing temperatures can enhance the volatility of chemical pollutants, altering their atmospheric concentration	(-)	low	Balbus et al. 2013, Bolan et al. 2023
Novel Entities (NE)	BI	Increase release of pesticides, industrial chemicals and heavy metals can intoxicate a wide range of organisms; leading diversity loss and disruption of ecosystem services	(-)	high	Sigmund et al. 2023
	BI	The release of genetically modified organisms can lead to genetic pollution, affecting genetic diversity	(-)	low	Tsatsakis et al. 2017
	FW	Increased release of pharmaceuticals, personal care products and industrial chemicals can contaminate freshwater	(-)	medium	Richmond et al. 2017

		systems			
	OA	Abiotic plastic degradation can induce a decrease in seawater pH	(-)	low	Romera-Castilla et al. 2023
	AL	The release of volatile organic compounds and persistent organic pollutants can contribute to the formation of secondary aerosols	(-)	high	Nault et al. 2021