Planetary Health Check

A Scientific Assessment of the State of the Planet

Executive Summary

2024

Planetary Boundaries
SCIENCE

Acknowledgments

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Planetary Boundaries Science is an international scientific partnership established at the end of 2023 to provide annual *Planetary Health Checks*, while steadily advancing the underlying science and ensuring contemporary and efficient science communication. *PBScience* will improve Planetary Boundaries assessments by a) applying cutting-edge data analysis techniques, b) utilizing the latest available data sets, c) enhancing Earth system modeling, and d) using modern, comprehensive communication tools to convey its messages to a broad audience. Collaborating closely with the *Planetary Guardians*, *PBScience* strives to elevate global awareness and drive action towards maintaining planetary stability.

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This inaugural annual report represents a crucial step in monitoring and safeguarding Earth's stability, resilience, and life-support functions — what we refer to as "Planetary Health". Our recently established and fast-growing international science partnership, called *Planetary Boundaries Science (PBScience)*, will work on advancing the Planetary Boundaries (PBs) framework by integrating new data and methodologies while fostering innovative science communication.

The PBs framework analyses and monitors the nine PB processes and systems that scientifically are proven to regulate the health of our planet. Each of these processes, such as **Climate Change** or **Ocean Acidification**, is currently quantified by one or two different control variables. The *2024 Planetary Health Check* report reveals that six out of nine PB processes have breached the safe PB levels, with all six showing trends of increasing pressure in all control variables, suggesting further boundary transgression in the near future (Fig. 1).

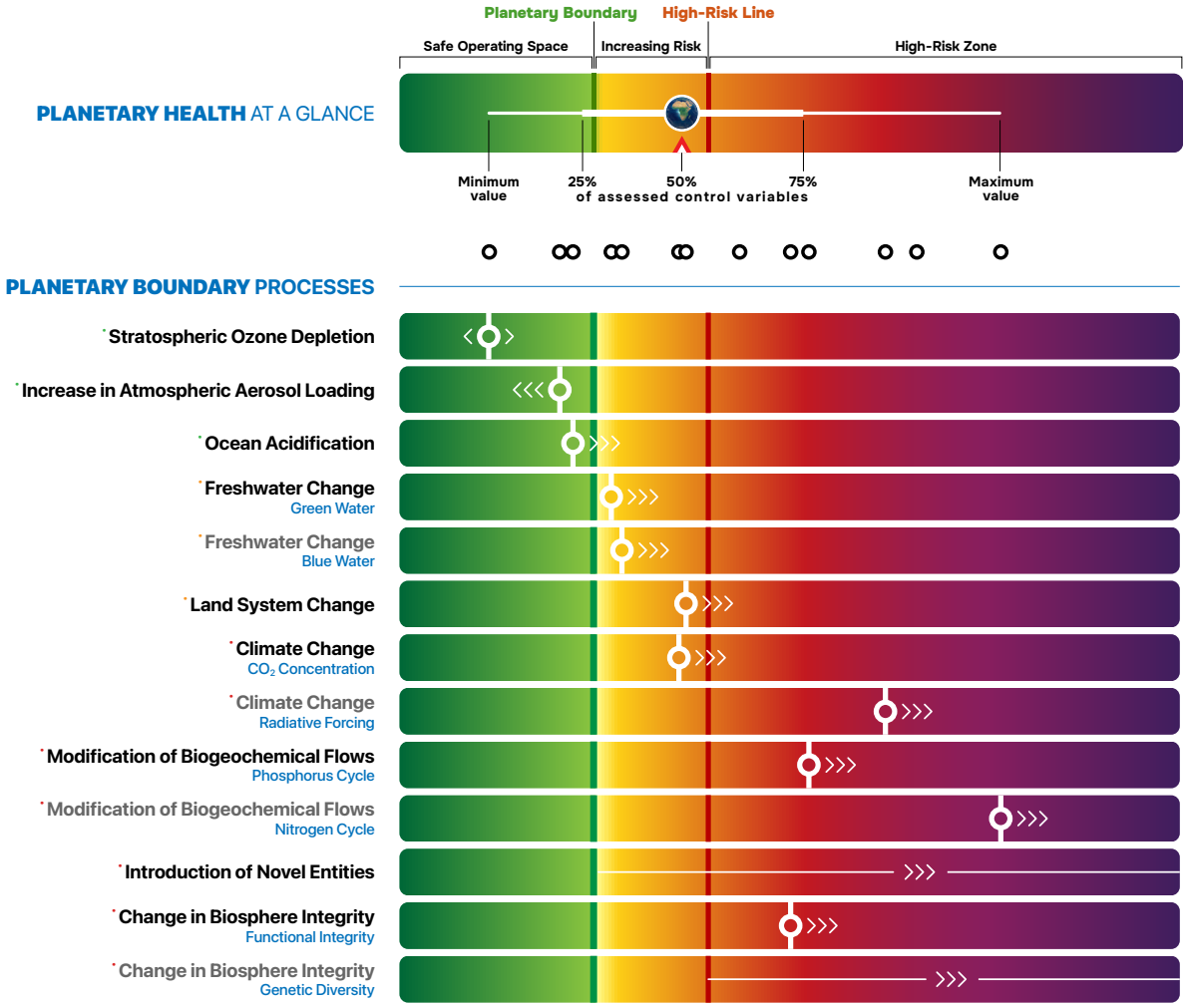

FIGURE 1 Planetary Health at a Glance. Just as a blood test provides insights into a human body's health and identifies areas of concern, this *Planetary Health Check* evaluates the 13 control variables across the 9 Planetary Boundary (PB) processes to report on Earth's stability, resilience, and life-support functions — the overall health of our planet. The 2024 assessment shows that six of the nine PBs have been transgressed: Climate Change, Biosphere Integrity, Land System Change, Freshwater Change, Biogeochemical Flows, and the Introduction of Novel Entities. All of these show increasing trends, suggesting further transgression in the near future. Three PB processes remain within the Safe Operating Space: Ocean Acidification (increasing trend and close to PB), Atmospheric Aerosol Loading (decreasing global trend), and Stratospheric Ozone Depletion (no trend). On the top colorbar, a classic boxplot summarizes the distribution of all 13 control variable values at once. We make this the dynamic symbol of the Planetary Health Check.

Executive Summary

The six PB processes that have breached safe PB levels are:

Climate Change (6.1): Atmospheric CO_2 levels are at a 15-million-year high, and global radiative forcing continues to rise, with a persistent warming trend that has accelerated since the late 20th century. Global mean temperatures are now higher than at any point since human civilizations emerged on Earth.

Change in Biosphere Integrity (6.2): The global loss of genetic diversity and the loss of functional integrity (measured as energy available to ecosystems) are both exceeding safe levels and accelerating, particularly in regions experiencing intensive land use. The vast decrease in biosphere integrity raises concerns that Earth's biosphere is losing resilience, adaptability, and its capacity to mitigate various pressures, including those from transgressing other PBs.

Land System Change (6.3): As a result of land use and increasingly due to climate change, global and regional forests have been steadily declining over the last few decades across all major forest biomes. Most regions are already in the High Risk Zone, well beyond their safe boundaries, while some areas have only recently breached safe levels (e.g., temperate and tropical America).

Freshwater Change (6.4): Local streamflow and soil moisture deviations have significantly increased since the late 19th century, surpassing their respective PBs in the early 20th century. The increasing variability and instability in global freshwater and terrestrial water systems signal growing concerns for water resource management and environmental stability.

Modification of Biogeochemical Flows (6.5): The use of phosphorus and nitrogen in agriculture has exceeded safe boundary levels, driving significant ecological change. Breaching this boundary has led to severe environmental impacts such as water pollution, eutrophication, harmful algal blooms, and "dead zones" in freshwater and marine ecosystems. This issue has been prevalent in industrialized countries for a long time and is increasingly becoming a concern in developing regions as well.

Introduction of Novel Entities (6.9): The global introduction of novel entities — such as synthetic chemicals, plastics, and genetically modified organisms — is vast, yet a significant portion of these substances remains untested for their environmental impacts. This indicates that the boundary is likely exceeded, although exact figures are uncertain. Novel entities can disrupt critical Earth system processes (e.g., CFCs notably damaged the ozone layer), harm ecosystems (e.g., pesticides have caused significant declines in insect and pollinator populations), and lead to long-term, possibly irreversible changes in the environment, including the contamination of soil and water bodies and the alteration of natural habitats.

Even though **Ocean Acidification** is close to transgressing its PB, the three PB processes that remain within the **Safe Operating Space (2)** are:

Ocean Acidification (6.6): Ocean acidification is approaching a critical threshold, with significant declines in surface aragonite saturation, particularly in high-latitude regions like the Arctic and Southern Ocean. These areas are vital for the marine carbon pump and global nutrient cycles, which support marine productivity, biodiversity, and global fisheries. The growing acidification poses an increasing threat to marine ecosystems, especially those reliant on calcium carbonate for shell formation.

Atmospheric Aerosol Loading (6.7): The difference in aerosol optical depth between hemispheres is decreasing, indicating progress toward safer levels, though some regional patterns show opposing trends. Aerosols influence the Earth's energy balance by reflecting sunlight back into space and altering cloud formation. This impacts global and regional climate systems, including temperature regulation, precipitation patterns, and the distribution of solar energy. Managing aerosol levels is crucial for maintaining the stability of the Earth's climate system and preventing shifts that could disrupt weather patterns and ecosystems.

Stratospheric Ozone Depletion (6.8): Ozone recovery has plateaued, with mixed trends and ongoing challenges in addressing the Antarctic ozone hole. The stratospheric ozone layer plays a vital role in shielding the Earth from excessive ultraviolet (UV) radiation. This protection is essential for maintaining the integrity of the Earth's biological systems, as UV radiation can harm phytoplankton, disrupt marine ecosystems, and alter terrestrial plant growth – elements that are foundational to the global food web and carbon cycle. Stabilizing and restoring the ozone layer is critical for preserving these interconnected Earth system processes.

A New Era

Humanity has thrived for over 10,000 years within a period of climatic stability and a resilient Earth system, which has allowed the development of advanced technologies and cultures. However, as the 2024 PHC report shows, we are now entering a dangerous new era marked by increasing symptoms of PB transgressions, such as more frequent extreme weather events, wildfires, reduced plant productivity, and water scarcity. These challenges are compounded by a still-growing global population that must navigate unprecedented difficulties. Beyond these immediate concerns, a more profound threat lies in the gradual weakening of Earth system resilience. As we approach – and potentially cross – critical **tipping points (5)**, these slow changes may not result in abrupt shifts but could lead to irreversible trends, such as accelerated sea-level rise and self-reinforcing pathways that move us further from the stable, Holocene-like conditions crucial for human life.

The interconnectedness of PB processes **(Interconnections & Drivers, 3)** means that addressing one issue, such as limiting global warming to 1.5˚C, requires tackling all of them collectively. This holistic approach, though daunting, offers the potential to transform what seems like a burden into an opportunity for sustainable progress. Reversing the multiple drivers currently pushing systems toward tipping points can yield synergistic effects of conservation and resilience. Immediate and coordinated global action, involving governments, businesses, and civil society, is essential to return to the **Safe Operating Space (2)** across all PBs and secure a prosperous future for both people and the planet **(Solution Space, 9)**.

A Path Forward

In the near future, *PBScience* plans to establish a broader *Planetary Boundaries Initiative (PBI)* in collaboration with a growing network of partners. PBI aims to provide decision support to guide global development back into the Safe Operating Space by using the PBs framework as a scientific accounting system that guides policy, stimulates innovation, and drives transformative change.

To achieve this, the PHC will play a central role, beginning with annual reports that update on PB science and human progress toward reaching safe boundary levels. The approach includes introducing new control variables that focus on human-system interfaces, advancing Earth system simulation models with AI-powered analysis, and developing a near-real-time dashboard with data to guide investments and paths to safety. The PBI also emphasizes the importance of public awareness and scientific understanding, with a communications team working to make these insights widely accessible.