Planetary Health Check 2025

A Scientific Assessment of the State of the Planet

Executive Summary

Planetary Boundaries
SCIENCE

Key Terms

Scientific Term	Scientific Definition
Planetary Health	Refers to how well the planet sustains the conditions necessary for life on Earth, including humans. Healthy means it supports stable conditions, has the ability to recover from disruptions (resilience), and supports essential processes for life (life-support functions).
Safe Operating Space	Refers to the range of environmental conditions in which humanity can safely live, grow, and prosper long-term. Staying within this space ensures Earth's systems remain stable and supportive of life. Going outside it is very different from anything humans have experienced in approximately the last 12,000 years, a stable period called the Holocene Epoch.
Planetary Boundary / Boundaries (PB/PBs)	Refers to the thresholds that keep life on Earth within a safe operating zone or safe boundaries. If you pass over, or transgress, the boundaries you increase the risk of losing stability, life support and nature's ability to absorb shocks and damage. The Planetary Boundaries framework identifies the nine Earth system processes essential for maintaining global stability, resilience and life-support functions.
Zone of Increasing Risk	Refers to the stage when human activities push Earth beyond the Planetary Boundaries, entering a "Zone of Increasing Risk." In this zone, the further boundaries are exceeded, the greater the chance of causing serious damage, destabilizing key Earth system processes, and disrupting life-support functions.
High-Risk Zone	Refers to Earth entering the "High-Risk Zone," where there is a strong possibility of severe, irreversible damage to key planetary functions that support life. In this zone, immediate action becomes critical to prevent locking in permanent changes and moving even further away from the stable conditions of the Holocene epoch (a period of stability on Earth covering approximately the last 12,000 years).
Control Variable (CV)	Refers to measurable indicators used to check whether an Earth system process is staying within its safe operating zone (Planetary Boundary). Usually, scientists track one or two control variables per boundary. For instance, atmospheric CO_2 concentration is a control variable for climate change.
Tipping Point	Refers to a critical point at which small changes can suddenly trigger large, often irreversible shifts in Earth's environment. Once a tipping point is crossed, self-reinforcing (positive feedback) processes drive the system further away from its previous state, increasing the magnitude and extent of change. For example, melting ice exposes less reflective ocean water, which absorbs more sunlight and accelerates melting, creating a self-reinforcing cycle.
Tipping Element	Refers to major Earth subsystems that, if pushed past their tipping points, shift into a qualitatively different state which can cause dramatic changes to the entire planet. Examples include large ice sheets (Greenland or Antarctica), major ocean currents (like the Gulf Stream), or critical ecosystems (such as the Amazon rainforest). When these elements cross tipping points, it can trigger widespread, possibly permanent environmental shifts.
Drivers of Transgression	Refers to human actions that push the Earth beyond its safe limits (Planetary Boundaries), such as excessive fossil fuel burning (driving climate change), deforestation (affecting biodiversity, climate and land system change), unsustainable agriculture (affecting nutrient cycling), and overuse of freshwater resources. These activities threaten Earth's stability and our ability to thrive.

Executive Summary

The Planetary Health Check (PHC) report provides an assessment of the state of our planet. It is based on the Planetary Boundaries (PBs) – the nine processes that are known to regulate the stability, resilience (ability to absorb disruptions) and life-support functions of our planet. Each of these processes, such as Climate Change or Ocean Acidification, is currently quantified by one or two control variables. The 2025 PHC report concludes that **seven out of nine Planetary Boundaries have been breached**, with all of those seven showing trends of increasing pressure – suggesting further deterioration and destabilization of planetary health in the near future (Fig. ES 1).

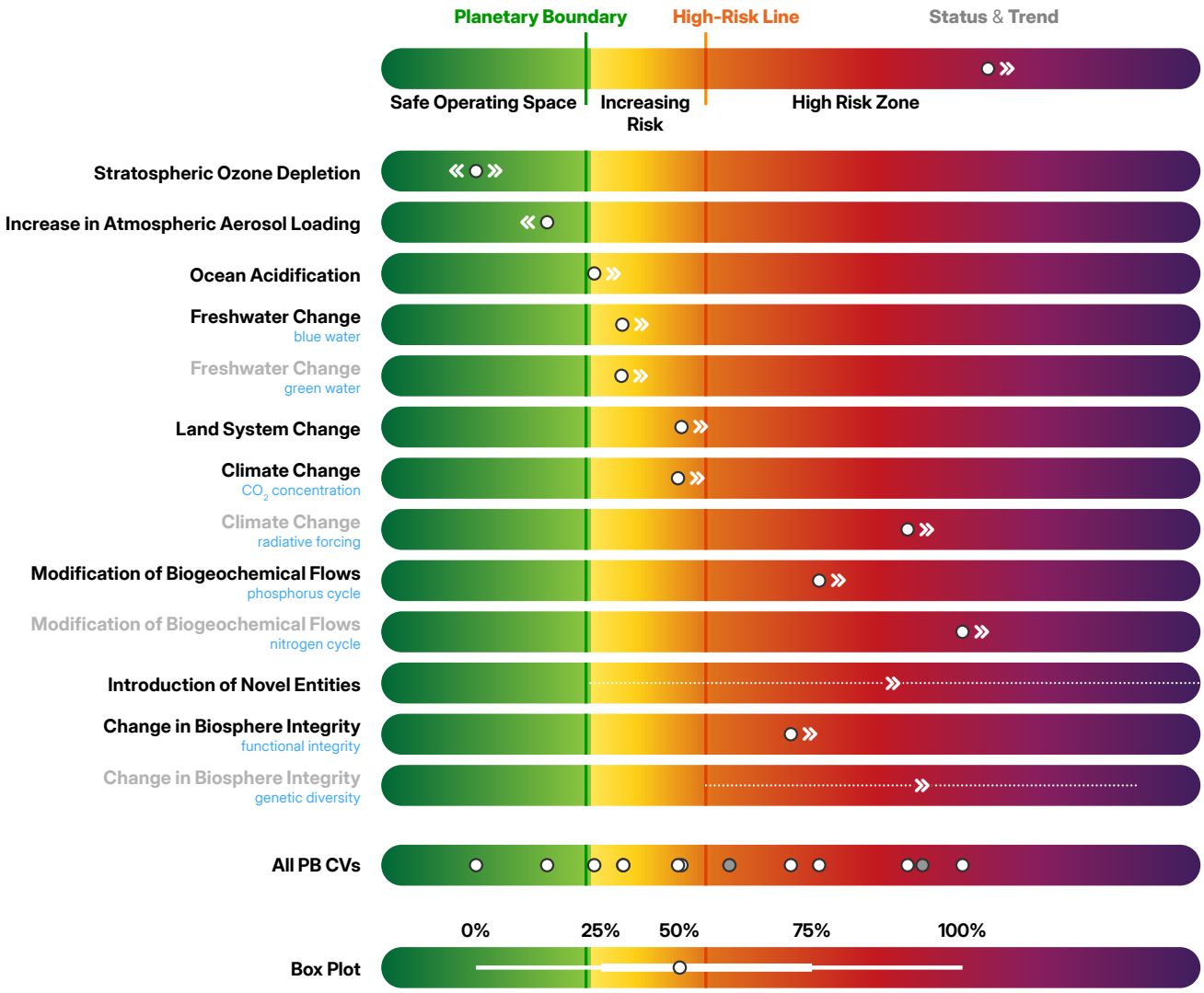


FIGURE ES 1 - Planetary Health at a glance. Just as a blood test provides insights into a human body's health and identifies areas of concern, this Planetary Health Check evaluates the 13 measured control variables across the 9 Planetary Boundary (PB) processes to report on Earth's stability, resilience, and life-support functions – the overall health of our planet. The 2025 assessment shows that seven of the nine PBs have been breached: **Climate Change**, **Change in Biosphere Integrity**, **Land System Change**, **Freshwater Change**, **Modification of Biogeochemical Flows**, **Introduction of Novel Entities**, and **Ocean Acidification**. All of these show increasing trends, suggesting further deterioration in the near future. Two PB processes remain within the Safe Operating Space: **Increase in Atmospheric Aerosol Loading** (improving global trend) and **Stratospheric Ozone Depletion** (currently stable). The Planetary Health Check Symbol (Fig. ES 2) summarizes all of these findings, showing the Planet's overall health at a glance.

The Basics of Planetary Boundaries

For over 10,000 years, humanity has thrived within a period of climatic stability and a resilient Earth system. This epoch is called the Holocene, and it provided conditions that enabled the rise of agriculture, urbanization, and complex civilizations. However, since the mid-20th century, we have entered a new epoch marked by what is called "The Great Acceleration", where both socio-economic activity and environmental impact have surged exponentially (see Ch. 2.1). This was the beginning of the Anthropocene – the current era, in which human activity has become the dominant force of shaping the Earth system.

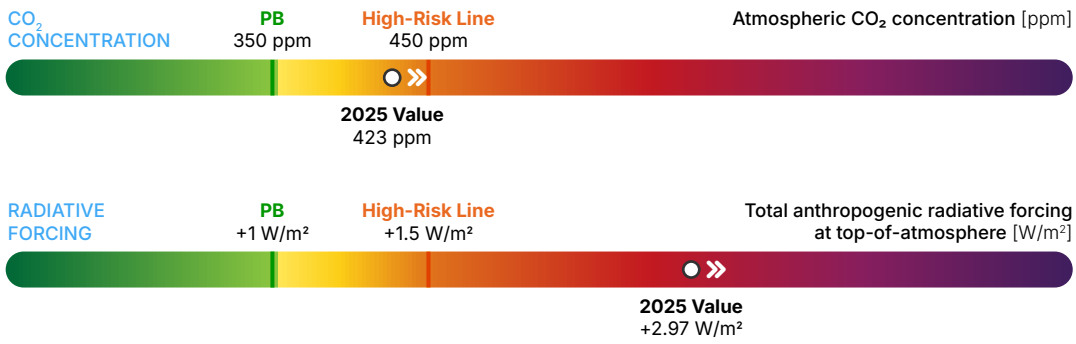
Human activities have collectively pushed Earth beyond its Safe Operating Space.

The Earth system possesses an intrinsic capacity for self-regulation that has historically helped maintain Holocene-like conditions favorable to civilization (see Ch. 2.2). This resilience stems from tightly coupled interactions and feedback processes among the biosphere, climate, and other planetary processes, evident in the long-term stability of the Holocene and previous interglacial periods. Over the past 150 years, this resilience has absorbed more than half of human-induced greenhouse gas emissions through land and ocean carbon sinks. However, mounting evidence shows that this carbon uptake capacity is weakening: Natural carbon sinks on land are saturating or turning into carbon sources, global warming appears to be accelerating, and early warning signs of tipping behavior are emerging in key systems. This loss of planetary resilience is further compounded by regional-scale ecological regime shifts and reduced functional integrity in ecosystems.

Human activities have collectively pushed Earth beyond its Safe Operating Space (see Ch. 2), driven by interconnected stressors such as fossil fuel combustion, land-use changes, and pollution. These interactions (see Ch. 2.4) amplify negative effects across multiple boundaries, such as climate change intensifying biodiversity loss or land degradation triggering severe droughts and heatwaves. Crucially, these pressures increase the risk of crossing critical tipping points – thresholds at which Earth system components can shift irreversibly to destabilized states, such as the collapse of major ice sheets, disruption of ocean currents, or the degradation of vital ecosystems like the Amazon rainforest (see Ch. 2.3). For instance, synthetic pollutants like plastics disrupt ocean ecosystems, weakening their capacity to sequester carbon and potentially accelerating tipping behavior. Likewise, deforestation and land degradation reduce vegetation's ability to moderate local climates, increasing vulnerability to tipping points and regime shifts that could trigger widespread ecological collapse. Understanding these interconnected drivers and their tipping potential through a systems-based approach reveals leverage points where targeted interventions can yield broad, systemic improvements. Effective solutions (see Ch. 3.3) must therefore recognize and address these interconnections and tipping risks, integrating local, regional, and global efforts, supported by robust measurement and monitoring, to return humanity safely within Earth's planetary boundaries.

Current Status and Updates of Each Planetary Boundary

Climate Change

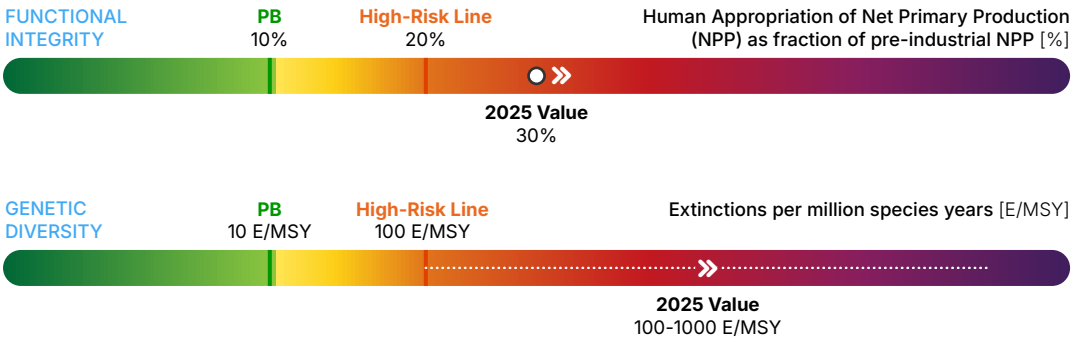


Earth's climate is in the danger zone: Greenhouse gas concentrations have reached record levels, global warming appears to be accelerating, and conditions are continuing to worsen.

Key Drivers: Fossil fuel burning, processes leading to non-CO_2 greenhouse gas emissions, Land System Change, Change in Biosphere Integrity, Increase in Atmospheric Aerosol Loading.

Atmospheric CO_2 is now at 423 ppm in 2025, far above the Holocene baseline and the Planetary Boundary of 350 ppm, while total anthropogenic radiative forcing stands at about +2.97 W/m², twice the high-risk threshold of +1.5 W/m². Both variables have increased since 2024, with atmospheric CO_2 also approaching the High Risk Zone. Global warming appears to be accelerating with no sign of stabilization. PHC2025 introduces global maps and graphs attributing temperature anomalies and emissions to sectors and locations, shows the Arctic warming fastest with urban-industrial regions as emission hotspots, and highlights the rising importance of methane and nitrous oxide. Recent research draws urgent attention to tipping points like abrupt shifts in the Amazon, Atlantic Meridional Overturning Circulation, and polar ice sheets, calling for early-warning indicators and the integration of ocean heat content in Planetary Boundaries assessments.

Change in Biosphere Integrity



Nature's safety net is unraveling: Extinctions and loss of natural productivity are far above safe levels, and there is no sign of improvement.

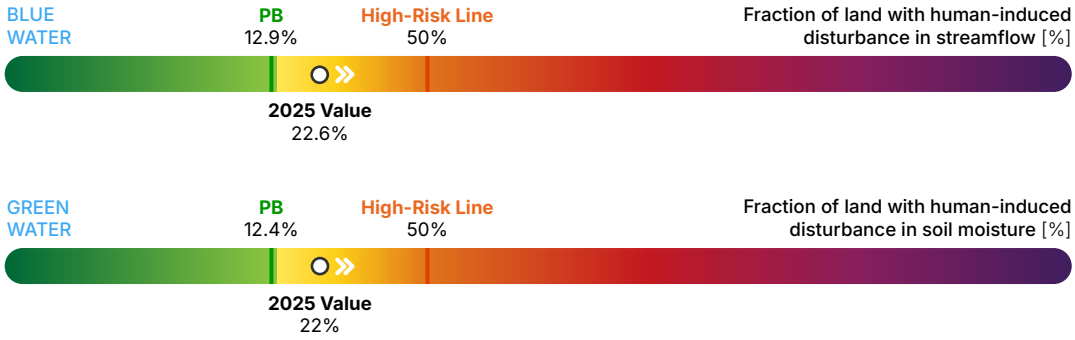
Key Drivers: Harvesting of biomass (agriculture, forestry, fishing), introduction of invasive species, Land System Change, Climate Change, Freshwater Change, Modification of Biogeochemical Flows, Introduction of Novel Entities, Ocean Acidification.
The extinction rate remains above 100 E/MSY, far beyond the Planetary Boundary of 10 E/MSY, while Human appropriation of net primary production (HANPP) sits at 30% – triple the 10% Planetary Boundary and above the 20% high-risk level. This situation has persisted or slightly worsened since 2024, with ongoing loss of genetic diversity and ecosystem function. PHC2025 debuts the first global SEED index map showing severe biocomplexity declines, introduces the EcoRisk indicator (with up to 60% of land exceeding either local HANPP or ecosystem risk), and shows converging hotspots of degradation across multiple metrics. The report also expands focus on the ocean biosphere's regulatory role and prepares for a future marine functional integrity measure.

Land System Change

Earth's forests are shrinking, and most are already below safe levels, with the overall trend still negative – although the pace of forest loss has slowed.

Key Drivers: Expansion of cropland and livestock grazing, wood harvesting, expansion of settlements and infrastructure, Climate Change, Freshwater Change, Biosphere Integrity.
Global forest cover has fallen to ~59% – well below the 75% safe minimum – and all major biomes have breached their safety thresholds. While the rate of decline has slowed, the situation remains deep in the Zone of Increasing Risk (approaching high-risk at ~54% cover), with ongoing deforestation and degradation keeping land-system health on a gradually worsening trajectory. PHC2025 stresses the importance of forest quality, ecological connectivity, and function, calls for future PHCs to include fragmentation and forest integrity, and considers recalibrating boundaries as biome data improves.

Freshwater Change

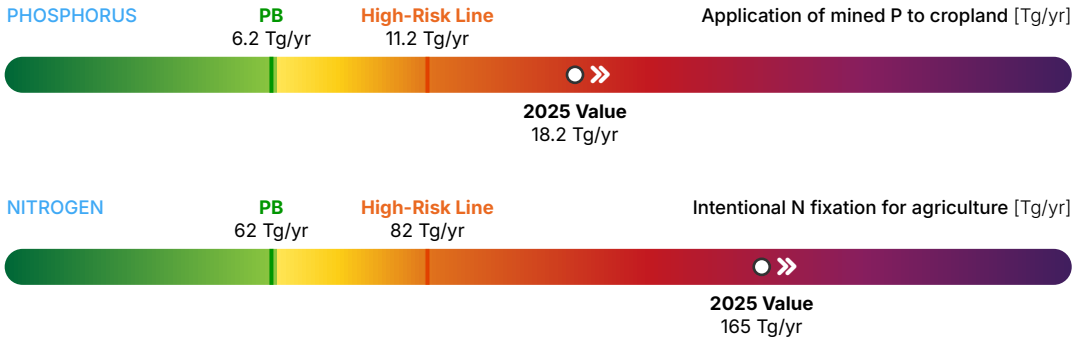


Human impact on rivers and soil moisture is growing, pushing water systems further from stability and heightening drought and flood risk.

Key Drivers: Irrigation and agriculture, industrial water use, household water use, Climate Change, Increase in Atmospheric Aerosol Loading, Land System Change.

More than a fifth of global land area now faces significant dry or wet deviations in streamflow (22.6%) and soil moisture (22.0%), roughly twice the preindustrial-like baseline state and far beyond the safe levels (12.9% and 12.4%). Both indicators are rising, putting freshwater firmly in the Zone of Increasing Risk, with major river basins such as the Indo-Gangetic Plain and North China exceeding safe levels and more pronounced extremes undermining water availability and resilience. PHC2025 introduces basin-scale mapping of blue and green water boundary transgressions. It revises the control variable-specific boundaries and data, reflecting the current status of conditions from 2010 to 2019 (an update from the 1995 to 2005 conditions in PHC2024). PHC2025 also identifies climate change as the dominant driver of freshwater instability and provides new explanations of feedback effects and implications.

Modification of Biogeochemical Flows



Fertilizer overuse continues to overload land and water with nitrogen and phosphorus, causing pollution and dead zones with no improvement in sight.

Key Drivers: Application of mined mineral phosphorus to fields as fertilizer, application of industrially-fixed nitrogen to fields as fertilizers, cultivation of nitrogen-fixing crops.

Regional phosphorus application is about 18.2 Tg P/year (triple the 6.2 Tg P/year Planetary Boundary and above the high-risk threshold), while intentional nitrogen fixation is at about 165 Tg N/year (over two times the Planetary Boundary and beyond the high-risk threshold). Both metrics remain in the High Risk Zone, with worsening trends. PHC2025 updates all data and boundaries, systematically details nutrient pathways, inefficiencies, and legacy pollution, and proposes shifting to agricultural surplus-based control variables for both N and P, as well as including uncounted sources like fossil fuel–derived nitrogen.

Ocean Acidification

The ocean is turning more acidic, threatening marine life as we cross into unsafe conditions with a worsening trend.

Key Drivers: Fossil fuel burning.
The global mean surface aragonite saturation state (Ω) is now 2.84, just below the revised Planetary Boundary of 2.86 (corresponding to 80% of the newly-updated preindustrial Ω). **This means that, for the first time, we assess that the Planetary Boundary for Ocean Acidification has been transgressed**. Marine organisms are at increasing risk, with evidence of shell damage already occurring today, especially in polar and coastal regions. PHC2025 applies up-to-date global Ω maps, adjusts the Planetary Boundary level upward (due to a better understanding of the preindustrial state of Ω), and underscores the need to monitor impacts on sensitive species and ecosystem functions as early warning signals.

Increase in Atmospheric Aerosol Loading

Air pollution differences between hemispheres are decreasing. This is a positive sign, as global air quality slowly improves.

Key Drivers: Fossil fuel burning, biomass burning, industrial activities.
The interhemispheric aerosol optical depth difference is now about 0.063 (lower than last year and well below the safe threshold of 0.10), meaning this PB remains within the Safe Operating Space. Global aerosol emissions are declining, even as some regions still face significant particulate pollution. PHC2025 includes new, high-resolution, chemically explicit datasets and models, explains aerosols' dual climate role (cooling from sulfates, warming from black carbon), and emphasizes health and justice issues tied to PM2.5 – even though these regional risks aren't yet fully captured in the Planetary Boundary metric.

Stratospheric Ozone Depletion

The ozone layer remains stable and is showing signs of slow recovery, maintaining protection against harmful UV radiation.

Key Drivers: Production/Emissions of Ozone-depleting substances, such as synthetic Chlorofluorocarbons and Nitrous Oxides.
Global ozone concentrations remain within the Safe Operating Space, averaging 285–286 Dobson Units, above the safe threshold of ~277 DU. Although recovery due to the Montreal Protocol continues, ozone remains below historical levels and the Antarctic ozone hole persists, so recovery is steady but incomplete. PHC2025 does not update the control variable given in the previous report, but more explicitly connects ozone recovery to Southern Hemisphere climate changes, notes emerging risks from space debris and rocket launches, and underscores the extra-polar ozone metric as most relevant for planetary health.

Introduction of Novel Entities

Human-made chemicals, plastics, and other novel entities continue to increase without sufficient testing or control, with environmental risks continuing to grow.

Key Drivers: Industrial production of artificial chemical compounds for industry, agriculture and consumer goods.

Each year, thousands of inadequately tested chemicals, plastics, and other novel entities are released into the environment, and the Planetary Boundary of zero untested entities remains persistently breached. This burden is worse than in 2024, as production and waste volumes increase and regulations lag behind. With the current control variable for novel entities remaining difficult to quantify, PHC2025 proposes to broaden the conceptual framework and propose measurable, impact-linked candidate indicators to support a multi-faceted risk assessment. This should include tracking stages such as production, release, fate, and Earth system effects, and refining these for key groups like plastics or genetically modified organisms. The assessment of novel entities should thus shift from isolated evaluation to a system-oriented approach that considers mixture effects, foregrounding interdependencies and ongoing scientific uncertainties.

Spotlight Chapters of This Year's Report

This year, three special chapters offer a deeper look into how Planetary Boundary transgressions intersect with real-world risks and opportunities for action:

The Ocean: The Unsung Guardian of Planetary Health

→ Chapter 3.1.

We examine the ocean's critical but underrepresented role in stabilizing the Earth system. Amid record ocean heat and coral bleaching in 2025, the ocean's role as climate regulator and life-support system is more visible – and more threatened – than ever. Storing most of the heat and a quarter of human-made CO_2 emissions, the ocean sustains planetary health. Yet it faces mounting stress from warming, acidification, biodiversity loss, and pollution, often interacting in ways that risk crossing tipping points. Integrating the ocean into Earth system governance is essential to ensure long-term resilience and stability.

Extreme Weather and Disasters in 2024/25 – an Attribution-Based Perspective

→ Chapter 3.2.

We explore how extreme weather events are becoming deadlier as climate change interacts with ecological degradation and social vulnerability. As 2024 marked the first year with global temperatures above 1.5 °C, extreme weather events claimed lives and caused widespread damage at an unprecedented level. But these disasters are not due to climate alone. They are intensified by the transgression of other Planetary Boundaries (like land-system change and freshwater use) and shaped by deep inequalities in exposure and vulnerability. Addressing both planetary instability and social risk is crucial for protecting people and ecosystems.

Putting Planetary Boundaries to Work: Emerging Practices, Actors and Tools

→ Chapter 3.3.

We map how governments, cities, businesses, and civil society are beginning to operationalize the Planetary Boundaries framework, translating global thresholds into practical strategies. A growing movement is bringing Planetary Boundaries into practice. From national climate targets and city planning to business strategies and financial risk disclosure, actors around the world are beginning to align decisions with Earth's boundaries. This shift signals not only a systems-based approach to environmental action, but a broader rethinking of how humanity operates on a finite planet.

Outlook – A Planetary Boundaries Initiative

We are living in an era of unprecedented scientific and technological opportunities, which we must harness given the urgency of the planetary crisis. To meet this challenge, Planetary Boundaries researchers around the world are currently forming the Planetary Boundaries Initiative (PBI). As a growing next-generation and multi-institutional platform, the PBI seeks to track, assess, and help to respond to the environmental risks identified in the Planetary Health Check. Therefore, it sets up 3 working clusters on 1) Diagnostics, 2) Solutions and 3) Communication in an integrative workflow.

Its core integrative engine, the **Planetary Boundaries Analyzer (PBAnalyzer)**, is a work-flow that links relevant empirical and modelled socio-economic and Earth system data as well as insights from literature inside an AI model and connects it with human expert feedback. The **PBAnalyzer** aims to deliver continuously refreshed diagnostics, maps causal leverage points, and offers interactive decision-support services within a **Planetary Mission Control Centre** for scientists, policymakers, and civil society. Lessons learned in practice, along with insights from domain experts will be fed back into the system to ensure that its results and recommendations are both scientifically rigorous and practically relevant.

The PBI is open for collaborations to constantly improve its products.

Please contact: pbscience@pik-potsdam.de

Planetary Boundaries
INITIATIVE

Conclusion – Planetary Health at a Glance

Our overall assessment of the health of the Planet in 2025 places the planet at the upper end of the (yellow) danger zone, pushing closer to the (red) high risk zone (Fig. ES 2). The 2025 assessment shows that we continue moving closer to the point where the planet as a whole exceeds the zone of increasing risk and enters the high risk zone (with higher certainty of large scale and irreversible changes). Nevertheless, Earth's current health – through its remarkable biological, physical, and chemical resilience – keeps the window open for returning to a safe operating space. However, this window is closing fast.

FIGURE ES 2 - The dynamic Planetary Health Check symbol represents the summary of each year's findings. The stylized boxplot (white lines and blue dot) describes the distribution of all PB control variables, which are individually shown in Fig. ES 1. The thin line represents the full range of all control variable values, while the thicker line represents the range that half of all control variable values fall into. The blue dot represents the median of all control variables.

Acknowledgements

Editors

Niklas Kitzmann, Levke Caesar, Boris Sakschewski and Johan Rockström

Authors

Boris Sakschewski*, Levke Caesar*, Lauren S. Andersen, Max Bechthold, Lotta Bergfeld, Arthur Beusen, Maik Billing, Benjamin Leon Bodirsky, Svetlana Botsyun, Donovan P. Dennis, Jonathan F. Donges, Xinyu Dou, Axel Eriksson, Ingo Fetzer, Dieter Gerten, Tiina Häyhä, Sophie Hebden, Tim Heckmann, Adrian Heilemann, Willem Huiskamp, Annika Jahnke, Jonas Kaiser, Niklas H. Kitzmann, Jonathan Krönke, Dana Kühnel, Nicole C. Laureanti, Chaohui Li, Zhu Liu, Sina Loriani, Josef Ludescher, Sabine Mathesius, Albert Norström, Friederike Otto, Anja Paolucci, Dimitry Pokhotelov, Kasra Rafiezadeh Shahi, Emmanuel Raju, Masoud Rostami, Sibyll Schaphoff, Christian Schmidt, Norman J. Steinert, Fabian Stenzel, Vili Virkki, Katrin Wendt-Potthoff, Nico Wunderling, Johan Rockström

**equal contributors to this work and designated as co-first authors*

Reviewers

Marty Anderies, Yana Yuge Bai, Joshua E. Buxton, Helen Findlay, Dieter Gerten, Jens Heinke, Andreas Huth, Wolfgang Lucht, Josef Ludescher, Maria Martin, Christoph Müller, Dimitry Pokhotelov, Stefan Rahmstorf, Katherine Richardson, Johan Rockström, Masoud Rostami, Yinglin Tian, Lan Wang-Erlandsson

Art & Figures: Globaïa

Layout Design: Simpelplus

The Planetary Boundaries Science (PBScience) project was launched in 2023 to address critical gaps in our understanding and monitoring of the Earth system. Utilizing advanced simulation modeling, incorporating the latest available measurement datasets and synthesizing new insights from Earth system science literature, PBScience provides annual Planetary Health Checks based on the Planetary Boundaries framework. Collaborating closely with the Planetary Guardians and other partners, PBScience strives to elevate global awareness and drive action towards maintaining planetary stability.

Contact: pbscience@pik-potsdam.de

PIK Potsdam Institute for Climate Impact Research

Planetary® Guardians

Special thanks go to all supporters of PBScience, including those who have provided financial contributions, in-kind support, and other resources that enable us to carry out our research and produce this report. We would also like to thank all those who contributed in various other ways to the success of this report. For helpful scientific input and discussions, we thank Wolfgang Lucht, Stefan Rahmstorf, Katherine Rilchardson, Miriam Sinnhuber and Gunter Stober. Thanks also to Aeon Alvarado Amaro, Reinhild Costa, Juliane Glinski, Bastian Grudde, Özge Kart Tokmak, Clara Nicolai, Bruce Phillips, and Hannes Rauhe for editing and organizational support.

Disclaimer

In 2025 we aim to provide a concise, updated Planetary Boundaries assessment, offer a thorough explanation of the Planetary Boundaries framework and methods, and identify potential advancements. It is not possible in this report to produce a full review which encompasses all relevant literature on recent Planetary Boundaries research. We are currently developing the methods to advance Earth system review and analysis, and welcome and appreciate feedback to help us improve the accuracy and comprehensiveness of future reports. If you have any suggestions or corrections, please do not hesitate to contact us.

Portions of this work were facilitated by the use of AI-based tools, which supported literature synthesis and text drafting. All outputs were critically reviewed and revised by the authors to ensure accuracy and integrity.

Suggested citation

Short form

Planetary Boundaries Science (PBScience). 2025. *Planetary Health Check 2025*. Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany.

Long Form

Planetary Boundaries Science (PBScience). 2025. *Planetary Health Check 2025,* edited by Kitzmann, N.H., Caesar, L., Sakschewski, B. and Rockström, J. with contributions from Sakschewski, B.*, Caesar, L.*, Andersen, L. S., Bechthold, M., Bergfeld, Beusen, A., L., Billing, M., Bodirsky, B. L., Botsyun, S., Dennis, D. P., Donges, J. F., Dou, X., Eriksson, A., Fetzer, I., Gerten, D., Häyhä, T., Hebden, S., Heckmann, T., Heilemann, A., Huiskamp, W., Jahnke, A., Kaiser, Kitzmann, N.H., J., Krönke, J., Kühnel, D., Laureanti, N. C., Li, C., Liu, Z., Loriani, S., Ludescher, J., Mathesius, S., Norström, A., Otto, F., Paolucci, A., Pokhotelov, D., Rafiezadeh Shahi, K., Raju, E., Rostami, M., Schaphoff, S., Schmidt, C., Steinert, N. J., Stenzel, F., Virkki, V., Wendt-Potthoff, K., Wunderling, N., Rockström, J.
Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany. https://planetaryhealthcheck.org

**equal contributors to this work and designated as co-first authors*

DOI: 10.48485/pik.2025.017