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Global ocean change in the era of the triple planetary crisis

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Abstract. This ocean narrative is grounded in global ocean indicators and framed around climate, biodiversity, and sustainable development. In 2024, global ocean heat content (OHC) reached record levels, with continued heat uptake of $0.35 \pm 0.1\,\mathrm{W\,m^{-2}}$ and steady acceleration of $0.14 \pm 0.1\,\mathrm{W\,m^{-2}}$ per decade since the 1960s. Sea surface temperatures (SSTs) exceeded 21 °C globally in both 2023 and 2024, while global mean sea level rise reached its highest recorded rate of $4.1 \pm 0.1\,\mathrm{mm\,yr^{-1}}$ (2016–2024). No part of the ocean is untouched by the so-called triple planetary crisis as proclaimed by the United Nations, where pollution, biodiversity loss, and climate change are putting pressure on marine systems worldwide. Over 8 % (10 %) of marine biodiversity hotspots, 8 % (11 %) of large marine ecosystems (LMEs), and 14 % (32 %) of Areas Beyond National Jurisdiction (ABNJ) are exposed to warming (acidification) beyond global rates. The triple planetary crisis converges across all ocean basins, with 16 % (30 %) of endangered (critically endangered) corals exposed to rapid ocean warming or acidification (rapid pH loss), and 75 % of countries emitting > 10 000 t plastic waste are near critically endangered and endangered corals. These overlapping pressures threaten key species, ecosystems, and the ocean's role in climate stability. These findings underscore the need for enhanced and sustained ocean observing systems, improved information on uncertainties in indicator design, and robust science-based information to guide policy, planning, and action for protecting the ocean. The ocean is our sentinel, reflecting the health of the planet and the trajectory of future environmental changes. Protecting the ocean through concerted global cooperation informed by integrated evidence-based and strategic ocean knowledge is essential to ensure the ocean can continue to play its crucial role in sustaining life and regulating Earth's climate.

1 Introduction

The ocean, often viewed as a vast remote frontier, is increasingly recognized as central in maintaining the planet's environmental balance (Bindoff et al., 2019). The ocean regulates global temperatures (von Schuckmann et al., 2023), absorbs anthropogenic carbon dioxide (Friedlingstein et al., 2025), and sustains biodiversity in ways that are vital for life on Earth (IPBES, 2019; Ward et al., 2022). The ocean's ability to act as a natural buffer against climate change – from absorbing heat to moderating weather patterns – makes it vital for global environmental health. The protection of the ocean is hence essential, not only for preserving the health of marine life, but as an active integral force driving environmental resilience for the stability of the planet's climate, ecosystems, and long-term sustainability (Horton and Horton, 2019; Roberts et al., 2024; Yadav and Gjerde, 2020). The essential role of the ocean in sustaining life is receiving heightened recognition – not just as a source of economic opportunity (Jouffray et al., 2020), but as a fundamental pillar for achieving environmental and societal goals (Hoegh-Guldberg et al., 2019).

Providing regular reporting on global and regional ocean indicators offers the opportunity for a broader perspective of ocean change, which allows us to monitor larger systemic shifts or changes in the ocean state and climate and allows informed decision-making, international cooperation, and the development of strategies to address both local and global challenges. Some of the ocean changes are inherently global in nature, such as the ocean carbon and heat sink, revealing insight into overall trends that transcend regional boundaries (Friedlingstein et al., 2025; von Schuckmann et al., 2023; Xing et al., 2024). Also, a global perspective allows us to identify changes in interconnected systems, such as the water, carbon, or energy cycle of the Earth, and their ultimate influence worldwide (Barnard et al., 2021; Cheng et al., 2022; Talukder et al., 2022).

Global-scale ocean indicators are effective in informing multilateral and international policy developments and international cooperation, which is essential today, as the ocean is faced with transboundary pressures, such as climate change, pollution, overexploitation, and biodiversity loss (Evans et al., 2025; Polejack, 2021; Ryabinin et al., 2019; von Schuckmann et al., 2020). They can highlight how environmental issues are disproportionately affecting different regions, helping to strengthen the voice of vulnerable communities not overlooked in environmental policies. This can foster more equitable solutions in areas where regional data might mask global patterns of inequality in environmental impacts. Also, global-scale indicators can serve as benchmarks to track progress towards common goals, such as in the context of the 2030 Agenda for Sustainable Development or under the UN Decade of Ocean Science for Sustainable Development. By monitoring ocean and climate change globally, it is possible to identify emerging risks and understand the global capacity for resilience (Abraham et al., 2022; Bouwer et al., 2022; Izaguirre et al., 2021; Rockström et al., 2021).

Here, we provide an ocean narrative to tell a compelling story that communicates the ongoing change in the global ocean in relation to people and the planet, while also drawing on implications from the triple planetary crisis of biodiversity loss, climate change, and pollution (UNEP, 2021). Besides global mean indicators, the concept of large marine ecosystems (LMEs) (Sherman, 2005) – which encompass coastal areas, from river basins and estuaries to the seaward boundaries of continental shelves, along with enclosed and semi-enclosed seas and the outer margins of major current systems – is also addressed. LMEs are of significant socioeconomic importance, as they account for the majority of global fisheries biomass (Guiet et al., 2025; Sherman et al., 2009). Additionally, areas beyond national jurisdiction are included, enabling a comparison between changes occurring in the open ocean and those observed within large marine ecosystems. This narrative aims to further connect scientific understanding with social, economic, and cultural dimensions, helping audiences grasp why there are changes in ocean matter. It aims not only to raise awareness but also to shape how we perceive risks, responsibilities, and opportunities – ultimately encouraging informed decision-making and collective action for a sustainable and healthy ocean future.

2 Method

This study employs a structured multi-indicator approach to describe and assess the state of and change in the ocean. The analysis is grounded in a core set of ocean indicators, which include surface and subsurface ocean warming, surface ocean acidification, sea level rise, and marine heatwaves. These indicators are derived using scientifically validated methods and form part of the Copernicus Ocean Indicator Framework (see Product Table, Supplement).

Primary data sources include products from the Copernicus Marine Service, which are supplemented, where available, by additional publicly accessible datasets to enhance spatial and temporal coverage. A multi-product methodology is applied wherever feasible, combining data from different ocean products. This approach enables an assessment of internal consistency and uncertainty by comparing the spread across product ensembles. Uncertainty ranges are obtained using standard deviation at the 95 % confidence level. A regional trend is considered amplified relative to the global trend when its 95 % confidence interval lies entirely above the global trend. All datasets utilized are documented and referenced in the product table, including links to associated metadata and scientific publications. Each ocean indicator has been updated with the most recent data available at the time of analysis, subject to product-specific update frequencies and data availability constraints.

To integrate the physical changes in the marine environment with broader sustainable development perspectives, additional datasets from the economic and social domains were included. This integrative approach reflects the three pillars of sustainability: environmental, economic, and social. Only data that are publicly available and accompanied by appropriate metadata were used. Metadata documentation and source references are provided in the product table. The three domains – environment, economy, and society – were then brought together to develop an ocean narrative, aimed at contextualizing observed and reported changes. This narrative is not intended as a new quantitative scientific analysis, but rather as a synthesis of available information to support decision-making and communication. Scientific rigour is maintained by basing this synthesis on peer-reviewed literature and established datasets, ensuring an evidence-based assessment framework underpins the development of the narrative.

3 Tracking ocean change: ocean warming, ocean acidification, sea level rise, and Earth's energy imbalance

The global ocean is undergoing widespread and accelerating change. Global ocean warming reached record levels in 2024, continuing a long-term trend in ocean heat uptake at a rate of $0.35 \pm 0.1\,\mathrm{W\,m^{-2}}$ ($0.61 \pm 0.2\,\mathrm{W\,m^{-2}}$ with ocean surface), with a steady acceleration of $0.14 \pm 0.1\,\mathrm{W\,m^{-2}}$ per decade since the 1960s (Fig. 1). The rate of ocean heat content (OHC) has increased since the 1960s, shifting from a near-equilibrium state in Earth's energy balance to a positive Earth energy imbalance of approximately $0.71 \pm 0.1\,\mathrm{W\,m^{-2}}$ (rel. to the top of the atmosphere) over the 2015–2024 average (Fig. 1a, updated from Minière et al., 2023). Ocean warming undergoes large decadal variations over the period 1960–2024, influenced by massive volcanic eruptions (Fig. 1a) (Trenberth et al., 2014). The acceleration of ocean warming remains consistent across different time periods, with no significant increase observed over the past 2 decades (Fig. 1b).

Global ocean surface temperatures in 2023 and 2024 reached exceptional highs, temporarily exceeding 21 °C on average, reflecting the combined effect of long-term climate-driven warming and natural variability. The global mean sea surface temperature (SST) has increased from decade to decade since satellite records began in 1982 (Fig. 1c). The global mean sea surface temperature exceeded 21 °C during the boreal spring of 2024 – an unprecedented high on record – and, while slightly lower in 2025, remains well above the long-term reference baseline (Fig. 1c). In both 2023 and 2024, intense, persistent, and widespread marine heatwaves were reported in several areas of the global ocean, exceeding previous ocean surface temperature records (e.g. 2015/2016) by 0.25 °C (Terhaar et al., 2025). The record ocean surface temperatures observed are the result of natural variability intensified by long-term global warming – an event that would have been highly unlikely in the absence of the ongoing climate trend (Guinaldo et al., 2025; Terhaar et al., 2025).

Global mean sea level is rising at an accelerating pace, reaching record-high values in 2024. The highest decadal average rate of increase – $4.1 \pm 0.1\,\mathrm{mm\,yr^{-1}}$ – was observed over the period 2016 to 2024. This value is slightly lower than the estimated $4.5\,\mathrm{mm\,yr^{-1}}$ estimated over the period 2017–2024 by Hamlington et al. (2024). Rates of global mean sea level rise increased from 31.4 ± 1.1 mm per decade in 1999–2006 to 39.3 ± 0.8 mm per decade in 2007–2015 to 40.8 ± 1.1 mm per decade in 2016–2024 (Fig. 1d). This amounts to a 25 % increase from the 1990s (1999–2006) to the 2000s (2007–2015), then +4 % for 2007–2015 to the 2010s (2016–2024), resulting in +30 % from the late 1990s to the 2010s (Fig. 1d). Over the period 1901–2024, global mean sea level rise amounts to 228 mm (Forster et al., 2025). Causes of sea level rise are attributed to increasing ice loss from the Greenland and Antarctic ice sheets, ongoing glacier mass loss, and thermal expansion due to ocean warming (WMO, 2025; IPCC, 2021).

4 Ocean warming and acidification: marine biodiversity, ocean protection, and the high seas

Regionally, the ocean is undergoing rapid change, with both warming and acidification occurring at rates above the global average largely affecting the tropics, the northern subtropics, and the southern subpolar ocean areas. Ocean warming from the ocean surface to depth (0–2000 m) at rates exceeding the global mean rates covers 15 % of the ocean area in the tropics (15° S–15° N), 41 % of the northern subtropics (20–40° N), and 16 % in the southern subpolar ocean areas (40–60° S) (Fig. 1e). A total of 13 % of the ocean areas in the tropics, 55 % of the northern subtropics, and 60 % of the southern subpolar ocean areas are exposed to rapid ocean acidification above global mean rates (Fig. 1e). Ocean areas which are concurrently experiencing both rapid ocean acidification and ocean warming are centred around 42° S and 36° N (31 % and 42 % of the ocean area, respectively). In contrast, ocean areas not experiencing rapid ocean acidification or warming are limited to 24 % in the northern subtropics and 34 % in the southern subpolar oceans.

Marine biodiversity is exposed to changes in the physics and biogeochemistry of the ocean. A total of 8 % of marine biodiversity hotspots are experiencing rapid ocean warming above global rates, and 10 % are experiencing surface acidification at rates exceeding the global average. Ocean warming and ocean acidification are known to induce a decline in species richness and harm habitats (Alter et al., 2024; Chaudhary et al., 2021; ter Hofstede et al., 2010; Wernberg et al., 2011). The species richness of many groups in marine biodiversity has been shown to decline from the Equator to the poles, but exceptions such as baleen whales and seafloor species near nutrient-rich margins reveal complex patterns (IPBES, 2019, Chap. 2). Ocean biodiversity hotspots are challenging to define due to widespread species dispersal, but unique habitats, such as the warm-water shallow coral reefs of the western Pacific, are characterized for their rich marine life (IPBES, 2019, Chap. 2; Fig. 2) (Tittensor et al., 2010).

Areas Beyond National Jurisdiction (ABNJ) have been warming at an average rate of $0.58 \pm 0.1\,\mathrm{W\,m^{-2}}$ since the 1960s, and their pH has been decreasing at a rate of -0.0173 ± 0.001 since the early 1980s, with 14 % of ABNJ facing rapid ocean warming exceeding the global rate and 32 % facing rapid surface ocean acidification (Fig. 2). These changes highlight the urgent need to accelerate progress toward the 30×30 target, protecting 30 % of coastal and marine waters by 2030 (UNGA, 2023). Although ABNJ – encompassing the high seas (UNCLOS, art. 86) and seabed (UNCLOS, art. 1) – cover 60 % of the global ocean and support complex ecosystems vital to life and essential services, they remain largely unprotected, and increasing pressures from human activities threaten their health (Gjerde et al., 2016). Fishing in high seas poses the greatest threat to marine biodiversity in ABNJ, disrupting entire ecosystems, while shipping and deep-sea mining are also growing concerns (Caldeira et al., 2023). The share of protected marine territorial waters is unevenly spread across the globe (Fig. 2). Advances are underway as global criteria for Marine Protected Areas are increasingly unified, recognizing their role

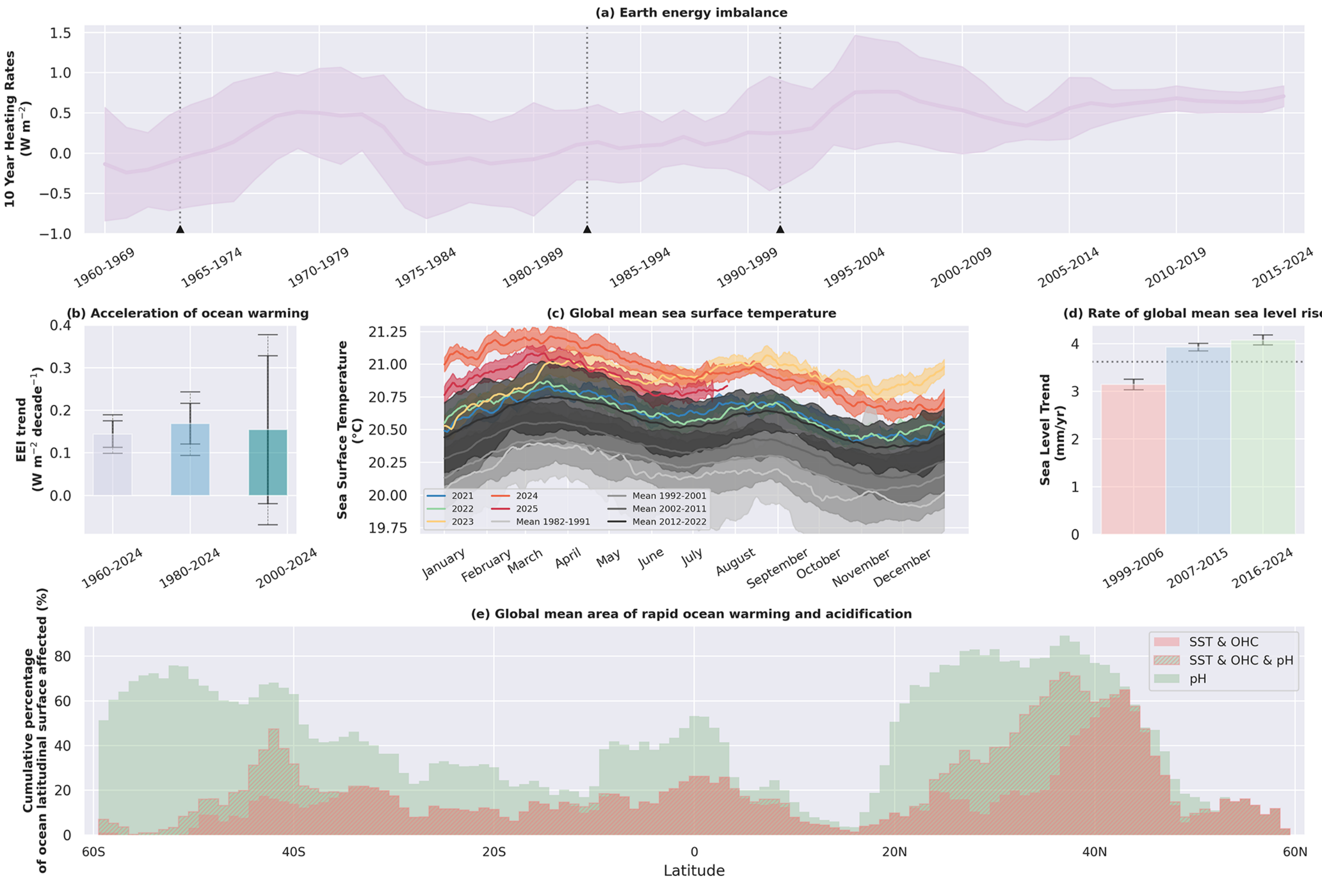

Figure 1. Ocean change acceleration. **(a)** Earth's energy imbalance for the period 1960–2024, with the 95 % uncertainty range shown by shading, based on product ref. no. 1 (Minière et al., 2023). Vertical dashed lines show massive volcanic eruptions from product ref. no. 1. **(b)** Acceleration of the ocean warming for past periods of 64, 44, and 24 years, with the 95 % uncertainty range shown by solid whiskers, based on product ref. no. 1 (Minière et al., 2023). Dashed whiskers indicate the 95 % uncertainty range based on product ref. no. 1 (Minière et al., 2023). **(c)** Global mean surface temperature. Gradients of grey show decadal means (bold lines) and 95 % uncertainty ensemble ranges (shadings) for the period 1982–2022, based on product ref. no. 2. Similarly, the years 2021 to 2025 are shown in colours, based on product ref. no. 3, with the 95 % uncertainty range based on product ref. nos. 3–7 and 21. **(d)** Rate of global sea level rise for the periods 1999–2006, 2007–2015, and 2016–2024, with the 95 % uncertainty range shown by whiskers, based on product ref. no. 8. The horizontal dashed line indicates the trend for the period 1999–2024. **(e)** Cumulative percentage of ocean latitudinal surface (%) experiencing rapid warming (pink), rapid acidification (green), and both rapid changes (pink and green hatches) for the periods 1982–2024 for SST (based on product ref. nos. 2, 4–7, and 21), 1982–2024 for OHC (based on product ref. nos. 9–11), and 1985–2022 for pH (based on product ref. no. 12).

in climate mitigation and embracing broader goals such as sustainability, resilience, and ecosystem health (Maestro et al., 2019).

At the regional level, a total of 8 % of LME areas show rapid ocean warming exceeding the global average rate, 9 % of tropical LME areas show rapid ocean warming, and 7 % show rapid ocean acidification (Fig. 2). For the subpolar LME, the share of impacted areas amounts to 9 % for ocean warming and 6 % for ocean acidification (Fig. 2). Estimates for polar LMEs are challenging due to data limitations resulting from measurement gaps in these areas.

5 The ocean under the triple planetary crisis

No part of the ocean is untouched by the triple planetary crisis, as pollution, biodiversity loss, and climate change are putting pressure on the ocean worldwide (Fig. 3). In 2022, the United Nations General Assembly endorsed the declaration "our ocean, our future, our responsibility", recognizing the ocean's vital role in sustaining life and affirming the urgency of its conservation and sustainable use (UNGA, 2022). However, the reality remains deeply concerning. Despite regional differences, plastic waste from land is polluting all ocean basins (Fig. 3). Rapid ocean warming, acidification, and sea level rise exceeding global mean trends are impacting all ocean basins (Fig. 3), threatening both marine ecosys-

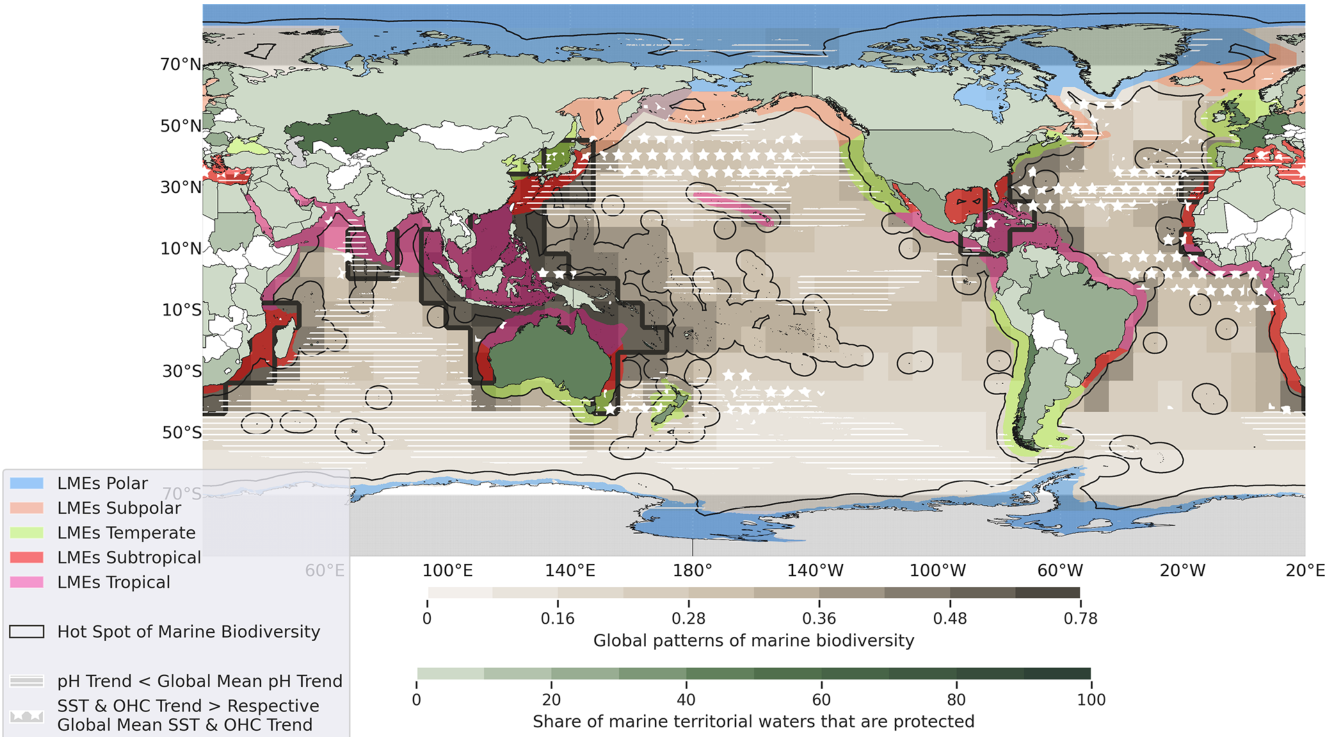

Figure 2. Biodiversity of the ocean under rapid changes. Global patterns of marine biodiversity shown in the ocean (brown gradient, product ref. no. 13), with hotspots surrounded by bold dark-brown polygons (product ref. no. 13). Share of marine territorial waters that are protected in 2022 shown on land (green gradient, product ref. no. 14). Large marine ecosystems (LMEs; product ref. no. 15) are shown in colours along the coasts. The boundaries of Areas Beyond National Jurisdiction (ABNJ) are materialized by black lines off the coasts (product ref. no. 16). Stars represent where 95 % of the local sea surface temperature (SST) and ocean heat content (OHC) trend ranges surpass the global average for the period 1982–2024, based on product ref. nos. 2, 4–6, 9–11, and 21. Horizontal hatching is the same but for the pH trend for the period 1985–2022, based on product ref. no. 12. The Caspian Sea is shaded in grey, as data were not available, except for the share of marine territorial waters of the surrounding countries.

tems and human communities (Bindoff et al., 2019; IPCC, 2022). Biodiversity loss and the degradation of marine habitats are also threatening the foundation of ocean life across all ocean basins (Fig. 3; IPBES, 2019). Although the global data products suffer from limitations in the polar areas due to measurement gaps (Fig. 3, grey mask), region-specific studies show high consensus that these ocean areas are also faced with pollution, biodiversity loss, and climate change (Bindoff et al., 2019; Cai et al., 2023; De-la-Torre et al., 2024; Gutt et al., 2021; IPBES, 2019; Linse et al., 2021; Nissen et al., 2024; Qi et al., 2022; Thomas et al., 2022; Townhill et al., 2022).

The triple planetary crisis converges across all ocean basins. About 16 % (30 %) of endangered (critically endangered) corals are exposed to rapid ocean warming or acidification, putting already at-risk species under even greater pressure (Fig. 3). Nearly 75 % of countries with high plastic waste emissions (> 10 000 t) are adjacent to critically endangered and endangered corals, and 83 % are adjacent to vulnerable corals (Fig. 3). These pressures are deeply interconnected: plastic pollution contributes to climate change and accelerates biodiversity loss (Ford et al., 2022; IPBES, 2019; Jeong et al., 2024), while climate change itself is a major driver of species decline (Bindoff et al., 2019; IPBES, 2019; IPCC, 2022). These reinforcing interactions intensify the overall crisis, making it more urgent to address them together. Plastic pollution poses a well-documented threat to coral reefs (Akhtar et al., 2022), with most large plastic items accumulating along shorelines (Lebreton et al., 2019). Tuna fisheries play a crucial role in global food systems – especially in Oceania – and carry important cultural, social, and public health value (Bell et al., 2015, 2021; Fache and Pauwels, 2016), and they are faced with key stressors from ocean warming and acidification (Fig. 3) known to threaten their survival (Monllor-Hurtado et al., 2017; Erauskin-Extramiana et al., 2019; Nicol et al., 2022). Tuna is classified as endangered or vulnerable in all ocean areas south of 40° N, and large parts of these areas are affected by rapid ocean warming and/or ocean acidification (Fig. 3).

Ocean warming can increase the degradation of plastics into microplastics (Ford et al., 2022), and about 33 % of high-emitting countries for plastics (> 10 000 t) are adjacent to

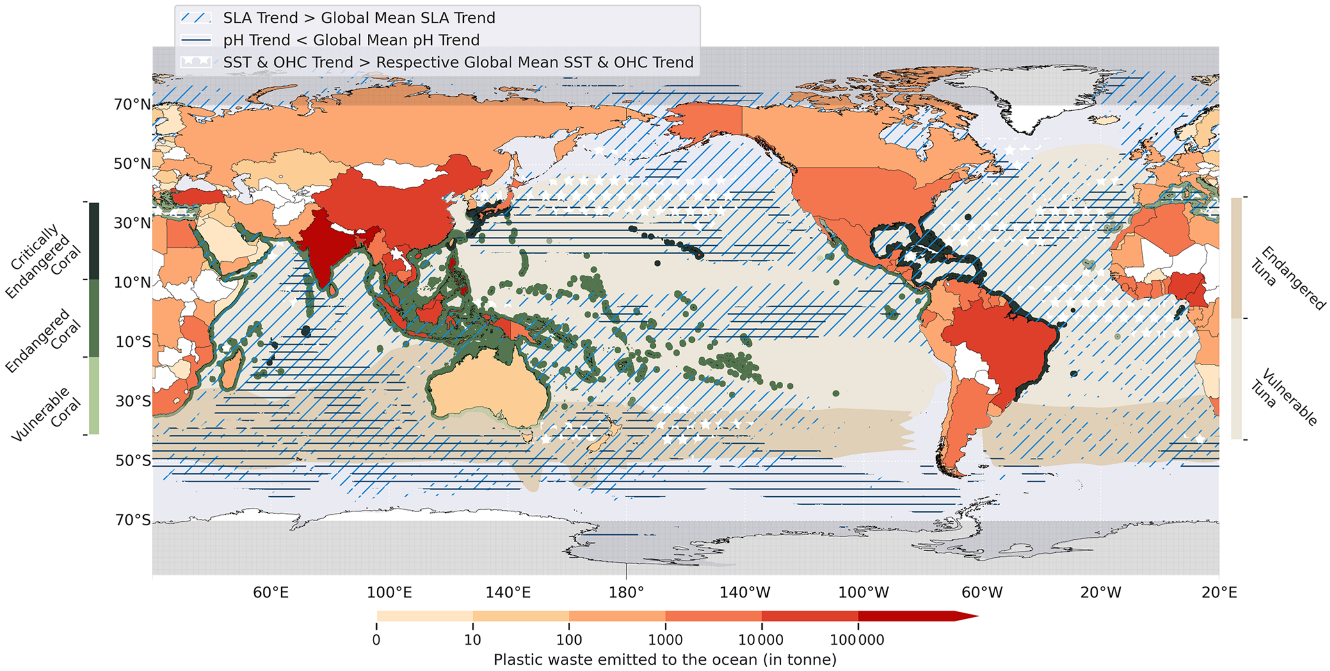

Figure 3. Illustration of the triple planetary crisis. Plastic waste emitted into the ocean by each country is shown on land (red gradient, product ref. no. 17). Vulnerable and endangered tuna is shown in oceans (sand–grey gradient, product ref. no. 18). Vulnerable, endangered, and critically endangered coral is shown with a green gradient (product ref. no. 19). Stars represent where the local sea surface temperature (SST) and ocean heat content (OHC) trends surpass the global average for the period 1982–2024, based on product ref. nos. 2, 4–6, 9–11, and 21. Horizontal hatching is the same, but for the pH trend, for the period 1985–2022, based on product ref. no. 12. Oblique hatching shows where the local sea level rise (SLR) trend surpasses the global trend for the period 1999–2024, based on product ref. no. 20.

areas of rapid ocean warming (Fig. 3). Once in the ocean, plastics break down into microplastics, which also originate directly from sources such as cosmetics, plastic pellets, synthetic textiles, and the wear of tyres and road markings (Woodall et al., 2014). Microplastics can harm marine life, carry toxic chemicals through the food web, and alter water and sediment properties, disrupting ecosystems and biodiversity (Jeong et al., 2024; Li et al., 2024; Lorenz et al., 2019). At the land–ocean interface, sea level rise and plastic pollution intersect, amplifying environmental risks. The majority (92 %) of countries emitting more than 10 000 t of plastic waste also face sea level rise in adjacent ocean areas that exceeds global rates (Fig. 3). Rising seas exacerbate coastal erosion and flooding, increasing the transport of microplastics from land-based sources – such as landfills, waste facilities, and sewage systems – into the ocean (Tang, 2023).

6 Conclusion

Together, these findings provide clear evidence that the ocean is not only a key regulator of the Earth's climate system but also one of the most sensitive global climate indicators of ongoing and accelerating global change. The simultaneous rises in ocean heat content, acidification, and sea level are not isolated; they are interconnected, compounding, and increasingly persistent. They affect the ocean physics and biogeochemistry, the functioning of marine ecosystems, and the wellbeing of coastal societies that depend on them. As scientific analysis and reporting continue to reach more and more robust consensus, the message becomes more urgent: sustained and coordinated measuring, modelling, and monitoring of the ocean are essential to understanding the pace of planetary change and informing decisions that affect climate resilience, biodiversity, and long-term sustainability. The ocean is our sentinel for all our futures to come.

Changes from ocean warming, ocean acidification, and sea level rise are further exacerbated by the adverse impacts of plastic pollution and biodiversity loss. Notably, the changes in ocean warming and sea level rise are not merely linear trends but rather exhibit acceleration over time, indicating that we are facing increasingly rapid change and underscoring the critical need for a unified global response and integrated evidence-based approaches. As ocean health is intricately linked to climate stability, the urgency of addressing these interconnected and rapid environmental pressures cannot be overstated. Only through collective efforts can we ensure the resilience of marine ecosystems and secure the future of our planet's ocean-based resources.

The rapid and interconnected changes occurring in the ocean also demand coordinated and global responses to sustain and strengthen our capacities for monitoring and understanding these changes. Sustained and enhanced ocean observation systems are critical for filling data gaps, particularly in polar and under-monitored regions, and for providing more accurate, real-time information on, for example, ocean warming, acidification, and sea level rise. Expanding these systems, alongside advancements in improved data integration, dissemination, and modelling, will empower decision-makers with the evidence-based and digital knowledge necessary to support sustainable ocean stewardship and to safeguard and protect the ocean. With more comprehensive, timely, and accessible ocean data, we can better address the triple planetary crisis and strengthen the resilience of marine life, ensuring that the ocean can continue to fulfil its vital role in sustaining life on Earth.

As we face increasing and compound impacts of ocean change, the need for high-resolution, evidence-based information becomes even more urgent. While global indicators provide essential insights into overarching trends, uncertainties highlight the importance of strengthening regional and local monitoring systems, forecasts, early warning systems, and downscaled projections. The scientific community must take a more proactive role in ensuring that data products derived from observations and models, along with the indicators based on them, are accompanied by robust uncertainty frameworks. These frameworks should be grounded in scientific principles and methodologies to accurately quantify and communicate the uncertainties inherent in these indicators. This is crucial for enhancing the reliability of the data and indicators, making them more actionable for decision-makers. By incorporating well-informed uncertainty analyses into data products, we can provide policymakers with clearer, more reliable guidance, enabling more effective planning and adaptive management strategies in response to ocean change.

Code availability. All codes are available upon request.

Data availability. All data used are available, and their sources are listed in the Supplement.

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