

PERSPECTIVE OPEN



An evolution towards scientific consensus for a sustainable ocean future

Françoise Gaill^{1,2✉}, Tanya Brodie Rudolph^{3✉}, Lara Lebleu¹, Denis Allemand⁴, Robert Blasiak^{5,6}, William W. L. Cheung⁷, Joachim Claudet⁸, Leopoldo Cavaleri Gerhardinger⁹, Nadine Le Bris¹⁰, Lisa Levin¹¹, Hans- Otto Pörtner¹², Martin Visbeck¹³, Anna Zivian¹⁴, Pierre Bahurel¹⁵, Laurent Bopp¹⁶, Chris Bowler¹⁷, Frédérique Chlous¹⁸, Philippe Cury¹⁹, Didier Gascuel²⁰, Sylvie Goyet²¹, Nathalie Hilmi⁴, Frédéric Ménard²², Fiorenza Micheli²³, Lauren Mullineaux²⁴, Rémi Parmentier²⁵, Marie-Alexandrine Sicre²⁶, Sabrina Speich¹⁶, Olivier Thébaud²⁷, Torsten Thiele²⁸, Martha Bowler¹, Philippe Charvis²⁹, Raphael Cuvelier¹, François Houllier³⁰, Sarah Palazot¹, Francis Staub³¹ and Olivier Poivre d'Arvor³²

The ocean has recently taken centre stage in the global geopolitical landscape. Despite rising challenges to the effectiveness of multilateralism, attention to ocean issues appears as an opportunity to co-create pathways to ocean sustainability at multiple levels. The ocean science community, however, is not sufficiently well organised to advance these pathways and provide policy input. The Intergovernmental Panel on Climate Change and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services demonstrate how knowledge consensus and integration have been instrumental in charting global pathways and eliciting commitments to address, respectively, climate change and biodiversity loss. An equally impactful global platform with a thematic focus on ocean sustainability is needed. Here we introduce the International Panel for Ocean Sustainability (IPOS) as a coordinating mechanism to integrate knowledge systems to forge a bridge across ocean science-policy divides collectively. The IPOS will enrich the global policy debate in the Ocean Decade and support a shift toward ocean sustainability.

npj Ocean Sustainability (2022)1:7; <https://doi.org/10.1038/s44183-022-00007-1>

INTRODUCTION

The ocean is increasingly understood as essential for achieving sustainable development, including climate and biodiversity goals^{1–9}. This is reflected in a growing consensus that the prosperity and well-being of humanity depend on a healthy ocean^{1,10,11}. Neither climate nor biodiversity threats can be resolved without including ocean solutions^{12,13}, with the ocean harbouring its specific biodiversity and influence over land, economies, and human well-being. Scientists warn that the ocean is approaching physical, chemical, and ecological tipping points that will trigger the collapse of the key climate and life support roles it provides^{14–17}. As a result, there is a need for science-based, solution-oriented advice on sustainability that considers the interconnectivity of all biosphere components and processes, including the ocean, climate, biodiversity, and human society. Effects from these interactions require contextualisation within the socioeconomic systems in which they occur, at multiple levels and scales. These effects also need to be continuously monitored and assessed before feeding into the science-policy interface on an ongoing basis, as change is experienced and adaptive responses evolve.

Human interactions with the ocean (and other parts of the biosphere) need to be managed under a social contract that requires cohesive collective effort^{18–21}. Navigating a shift in current economic and social systems towards ocean stewardship will require enhanced connectivity and transdisciplinary collaboration across knowledge systems, from Indigenous Peoples and Local Communities (IPLC) to natural sciences to social sciences^{5,19,22}. Global knowledge co-production to support the assessment and management of ocean commons^{6,19} requires multi-level collaboration across the entire social-ecological system. This whole-of-ocean approach calls for a culture of cooperation among scientists, ocean actors, and users for environmentally sustainable and socially equitable ocean protection and use by each individual and society as a whole²³.

This Perspective suggests that legitimate, salient, and credible evidence-based policy recommendations arising from an international platform on ocean sustainability would facilitate transitions towards sustainability. In order to achieve this, we further introduce an idea to establish a coordination mechanism for the aggregation of different types of knowledge that will require

¹Ocean & Climate Platform, Paris, France. ²National Center for Scientific Research, Institute of Ecology and Environment (INEE), Paris, France. ³Centre for Sustainability Transitions, University of Stellenbosch, Stellenbosch, South Africa. ⁴Centre Scientifique de Monaco, Monaco, Monaco. ⁵Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden. ⁶Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo, Japan. ⁷Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, Canada. ⁸National Center for Scientific Research, Université PSL, CRILOBE, CNRS-EPHE-UPVD, Paris, France. ⁹Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Barcelona, Spain. ¹⁰Sorbonne University, National Center for Scientific Research, Sorbonne, France. ¹¹Center for Marine Biodiversity and Conservation, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, USA. ¹²Integrative Ecophysiology, Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany. ¹³GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany. ¹⁴Ocean Conservancy, Santa Cruz, CA, USA. ¹⁵Mercator Ocean International, Toulouse, France. ¹⁶LMD/IPSL, Ecole Normale Supérieure/PSL University, Paris, France. ¹⁷Institut de Biologie de l'Ecole Normale Supérieure (IBENS), ENS, CNRS, INSERM, Université PSL, Paris, France. ¹⁸National Museum of Natural History, Paris, France. ¹⁹MARBEQ, IRD, Sète, France. ²⁰Pôle Halieutique, Mer et Littoral, Institut Agro, Rennes, France. ²¹Fondation Prince Albert II de Monaco, Monaco, Monaco. ²²Aix Marseille Université, Université de Toulon, CNRS, IRD, MIO, Marseille, France. ²³Hopkins Marine Station and Stanford Center for Ocean Solutions, Stanford University, Pacific Grove, CA, USA. ²⁴Woods Hole Oceanographic Institution, Woods Hole, MA, USA. ²⁵The Varda Group, Madrid, Spain. ²⁶LOCEAN, Sorbonne Université, Paris, France. ²⁷AMURE, IFREMER, Plouzané, France. ²⁸Institute for Advanced Sustainability Studies (IASS), Potsdam, Germany. ²⁹IRD, Marseille, France. ³⁰IFREMER, Paris, France. ³¹International Coral Reef Initiative, Oakland, USA. ³²Ministry for Europe and Foreign Affairs, Paris, France. ✉email: fgaill@ocean-climate.org; tanya@enviromer.co.za

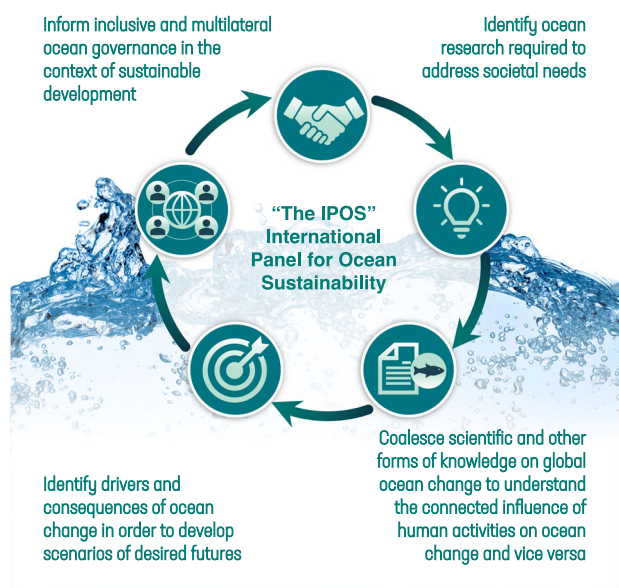


Fig. 1 **Introducing the IPOS.** The potential roles of the IPOS in centralising past, existing and future science and knowledge to support ocean sustainability.

Box 1 Potential structure and framing for the IPOS

Different options exist regarding the structure of the IPOS, which must be guided by lessons learnt from other global environmental assessment panels^{33,79}. The IPOS is envisaged as a coordination mechanism grounded in integrated scientific knowledge (and other types of knowledge), and, like IPBES, represents a wide scope of actors. Similarly, the scope of IPOS is broader than that of an intergovernmental platform. A natural evolution of current assessments of climate change and biodiversity would possibly favour an intergovernmental approach. Despite common and specific developments still required in current global assessments^{79,80} (see Fig. 2), both the IPCC and IPBES have been effective^{52,79,80}. However, given the urgency to address critical ocean priorities^{31,37,81,82}, an international panel may (in the shorter term at least) offer the benefits of speed, flexibility, and autonomy. During the 2022 UN Ocean Conference, the European Union (EU) identified a number of key priorities regarding international ocean governance⁸³. The eighth key priority pertained to 'build up ocean knowledge by creating an intergovernmental science-policy interface for ocean sustainability, aiming at establishing an Intergovernmental Panel for Ocean Sustainability (IPOS), promoting ocean diplomacy and literacy'⁸³. This recommendation could be read as implicitly acknowledging the necessity of a staged approach for the evolution of the IPOS. A more flexible and autonomous approach at the outset would enable agility so that the IPOS could direct its collective knowledge resources to address particular priority issues. Examples of effective and thematically focused international groupings include the science-industry initiative Seafood Business for Ocean Stewardship (SeaBOS)⁸⁴ and a series of collaborative workshops headed by the International Atomic Energy Agency's Ocean Acidification International Coordination Centre⁴². A combination of elements from both framings (international and intergovernmental) would potentially provide IPOS with needed agility (international), as well as authority and continuity (intergovernmental). Nevertheless, the priority should be to strengthen a focus on the ocean in the global arena.

development as the project takes root. Now more than ever, charting a pathway for our future ocean must be guided by coordinated, synthesised, and transdisciplinary ocean science. This endeavour must be anchored in the United Nations (UN) Sustainable Development Goal (SDG) 14, which is central to achieving the 2030 Agenda for Sustainable Development²⁴.

COHESIVE GOVERNANCE BASED ON SCIENTIFIC CONSENSUS: INTRODUCING THE INTERNATIONAL PANEL FOR OCEAN SUSTAINABILITY

Ocean governance faces the challenge of responding to the ocean's multiple dynamics, complexities, scales and diversities as a

system-to-be-governed. Fragmentation within this system is heightened by asymmetries in power and knowledge accessibility amongst ocean actors and users, which limit consensus-based solutions for the ocean^{6,25}.

The foundations and pathways towards integrated and ecosystem-based visions for ocean governance must be built through legitimate, salient²⁵, and credible interactions among ocean scientists, decision-makers and citizens at large²⁶. Pluralised interventions that respond to the complexity, nonlinearity, and unpredictability of the ocean system could then support consensus-based decisions^{14–17,27,28}. The first cross-pollination of climate change and biodiversity science, found in the Workshop Report²⁹ by the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), heralded a new era of coordinated development of science and knowledge. However, synergies between strategies for climate, biodiversity, ocean health, social equity, and human well-being are yet to be fully realised in assessments and incorporated in ocean management and policy^{6,30,31}.

To build a comprehensive ocean narrative, we propose the establishment of an International Panel for Ocean Sustainability (IPOS) (Fig. 1 and Box 1). Acting as a platform to integrate global ocean knowledge systems to inform management and policy, this panel will offer a transdisciplinary architecture, cross-cutting between scientific panels and processes, such as the IPCC, IPBES, World Ocean Assessment (WOA), and others. The objective is to accelerate the use of the best available knowledge on the past, present, and (alternative) future(s) of the ocean. The IPOS will provide a mechanism to mobilise and synthesise existing and emerging knowledge to paint a global picture of the evolution of the state of the ocean and inform efforts to achieve ocean stewardship. Such a mechanism will avoid duplicated efforts in collectively building an ocean narrative, and will provide the best possible scientific foundation as a keystone for future ocean governance²⁵ (see Fig. 1).

As a coordinating panel, the IPOS can build upon ongoing but often disparate global efforts to leverage the scaling up of mutually positive outcomes^{32–34}. For instance, the IPOS could highlight the consideration of ocean knowledge in negotiations and policy recommendations developed under the UN Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD). By partnering with the powerful mission and networking capacities of the Ocean Knowledge Action Network (Ocean KAN) by Future Earth, the IPOS could also accelerate connection with worldwide marine learning networks³⁵, advance stakeholder engagement informed by social sciences, and pilot novel communication and networking approach in knowledge co-creation and synthesis³⁶.

COORDINATING SCIENCE TO SHAPE OCEAN ACTION

For both climate and biodiversity topics, the IPCC and IPBES have proved effective in distilling and repackaging knowledge to inform decision-making and influence political agendas, providing a foundation from which to catalyse linkages between knowledge and action^{32,33,37–39}. However, an equally impactful global platform with a thematic focus on the ocean does not exist. The ocean scientific community remains too often entangled in research silos (Fig. 2)⁵. As a result, qualitative and quantitative knowledge exchange across sectors, disciplines, institutions, and high- and low-income countries is hampered, despite shared international targets such as the UN SDGs³⁸. Also, alternate forms of knowledge on, and relationships with the ocean, must be part of developed solutions. For instance, deep knowledge is held by IPLC and small-scale fisheries communities as traditional custodians of coastal and ocean spaces⁴⁰. Improved articulation and communication between non-scientists and the scientific community is, therefore,

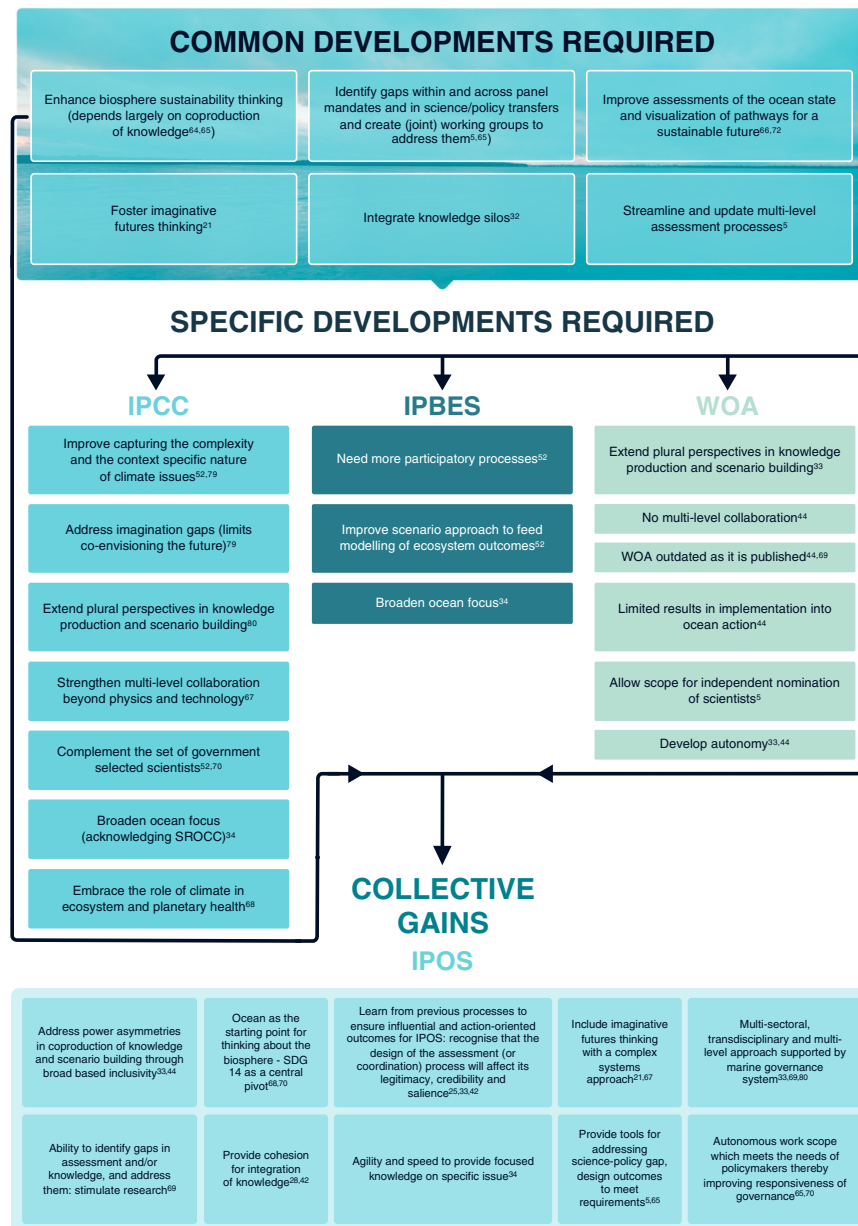


Fig. 2 A comparative literature review of the developments required in current assessment bodies, illustrating the rationale for the IPOS. Common developments required in current international assessment bodies could be leveraged through collaboration, resulting in collective gains for the biosphere. Strengthening a sustainable transition must rely on integrated and deliberative ocean science that involves all stakeholders in defining common goals and supports cohesive efforts to build ocean policy that protects ecosystems and communities alike.

necessary to determine the policies required to mitigate and adapt to the rising effects of multiple stressors on the ocean⁴¹.

Despite growing recognition of the need for greater trans- and interdisciplinarity in ocean science, progress to achieve this has been slow^{32,35,42}. Only in the last decade has the ocean been formally included in the climate agenda. In 2015, the Because the Ocean initiative³⁹ was launched at the Conference of the Parties of the UNFCCC (COP) in Paris. In 2019, after the release of the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate¹⁶, the first Ocean and Climate Change Dialogue was mandated by COP 25, and held in December 2020⁴³. Also in 2020, the High-Level Panel for a Sustainable Ocean Economy addressed the need to transition to a sustainable ocean economy using transdisciplinary advisory networks to facilitate the dialogue with science, while recognising the ocean's role in providing benefits for humanity and solutions for climate change⁸. However, despite

almost a century of marine assessments^{32,33,44} and the global momentum on ocean discussions, we are yet to use the full transdisciplinary potential of knowledge systems from IPLC, natural sciences and social sciences.

There is, thus, an urgent need for the development of an international organisation with 'a global technical mandate and global coverage with the legitimacy and authority to speak with one voice on behalf of the ocean[s]'³¹. The IPOS is, consequently, the next logical step in the historical evolution of global marine assessments. Moreover, the UN Decade of Ocean Science for Sustainable Development (2021–2030) (Ocean Decade)²⁴ sets the stage for IPOS by providing an overarching focus on collaborative ocean solutions.

The IPOS can be instrumental in (1) providing guidance and cross-scale linkages, (2) piloting emerging concepts and frameworks, and (3) building on and incentivising longer-term

Table 1. Overarching motivations for the establishment of the IPOS and some of the potential outcomes of an ocean-focused knowledge-based synergistic panel to improve ocean governance.

Potential motivations for the IPOS	Possible outcomes of IPOS
Responsiveness	<ul style="list-style-type: none"> • Mobilise siloed knowledge into transdisciplinary ocean science • Develop networked knowledge-to-action pathways scenarios for policymakers to navigate a fragmented governance and management landscape
Cohesion	<ul style="list-style-type: none"> • Build on previous marine assessments • Continually assess past, present and future oceans state in collaboration with ocean data platforms (for example, Global Fishing Watch and Ocean Data Platform) or link up with Marine Life 2030 and the Global Ocean Observing System • Articulate common goals for humanity in line with the United Nations Decade of Ocean Science for Sustainable Development and establish Sustainable Development Goal 14 as central in the 2030 Agenda • Provide guidance (standards) and incentives for integrated and long-term transdisciplinary research
Inclusivity	<ul style="list-style-type: none"> • Facilitate knowledge co-production with Indigenous Peoples and Local Communities, i.e. envisioning of ocean sustainability pathways reflecting cultural diversity • Build an international panel inclusive of global ocean users and actors • Produce information relevant to a range of target audiences and their needs • Ensure principles of intergenerational justice and support the inclusion of youth • Highlight principles of justice and equity for vulnerable communities
Coordination	<ul style="list-style-type: none"> • Complement and support existing scientific platforms (such as the Intergovernmental Panel on Climate Change, the Intergovernmental Science-Policy Panel on Biodiversity and Ecosystem Services and the World Ocean Assessment) and scientific bodies (such as the International Council for the Exploration of the Sea and the North Pacific Marine Science Organisation) to provide consensus for scenario development • Coalesce ocean sustainability and stewardship efforts by assisting existing institutions such as the Intergovernmental Ocean Commission, Ocean Knowledge Action Network and the High-Level Panel for a Sustainable Ocean Economy
Innovation	<ul style="list-style-type: none"> • Drive innovation through multi-stakeholder engagement and tools to share available data e.g. Digital Ocean Twin • Develop future scenarios and sustainability transition pathways to inform anticipatory policymaking • Pilot novel co-created solutions by engaging with diverse knowledge holders
Value	<ul style="list-style-type: none"> • Build awareness of the value of nature and the cost of inaction and support natural capital accounting • Support inclusion of ocean commitments in Nationally Determined Contributions • Develop finance and market-based mechanisms to support ocean sustainability • Advance the uptake of plural valuation approaches of the ocean's contributions to people in the interfaces of ocean science and policy

transdisciplinary ocean research programmes to scale their impacts at global levels (Fig. 2). This would facilitate autonomous, decentralised ocean knowledge co-production at policy interfaces where problems and opportunities emerge, hence improving the responsiveness of governance regimes. This vision might be achieved through the creative combination of applications in networked knowledge-to-action^{35,45,46}, the co-design of ocean scenarios and pathways⁴⁷, and the use of plural valuation⁴⁸. Integrated and deliberative (e.g. through dialogic learning)⁴⁹ transdisciplinary methods can assess the ocean's contribution to people, including socio-ecological pressures, risks and conflicts⁴⁹. These methods can also promote ocean sustainability transition experiments in innovation labs⁵⁰ to support collective action in order to transform existing governance systems⁵¹. The IPOS could help to address a major gap faced by global environmental assessments, where scenarios are most often developed at the global level by scientists—with currently limited resolution for regionally or locally imagined outcomes to play a role, and thereby become more salient in global assessments⁵². A more independent IPOS could also foster a 'critical turn' in how sustainable ocean governance is implemented⁵³. For example, the IPOS could provide opportunities to inform the redesign and transformation of governance regimes through transdisciplinary practice, develop strategies to empower stakeholders, induce change towards more integrated ocean policies, and equitably mitigate conflict in marine governance⁵⁴.

A central ocean sustainability panel will provide opportunities to achieve collective gains, as set out in Fig. 2—which also presents a comparative analysis of IPOS, IPCC, IPBES and WOA. From a holistic perspective, the IPOS would assist the Intergovernmental Oceanographic Commission of UNESCO to facilitate the implementation of a global, integrated and fit-for-purpose observing system. It would provide the information needed for robust understanding, monitoring, predicting and projecting the state of the ocean, across requirements and scales (from global to local), in alignment with the Global Ocean Observing System⁵⁵. Innovative digital tools that use observation and advanced modelling (from the open ocean to coastal areas, from physics to biology⁵⁵) can be integrated into a digital twin of the ocean (an open source of combined ocean observations, artificial intelligence, and advanced modelling providing a consistent, high-resolution, multi-dimensional and near real-time virtual representation of the ocean)^{56,57}. The latter would contribute to the assessment of the ocean state and ocean scenarios in light of management options.

In alignment with a global shift in mindsets towards sharing knowledge on open source platforms^{58,59}, we anticipate that experts across disciplines will contribute to task forces and projects within the IPOS, as has been the case with other initiatives such as the Ocean KAN and IPBES. Increasingly, researchers are acknowledging the need for humility^{47,60}, imagination^{47,52} and vision^{6,61,62} to embrace not only a diversity

of knowledge systems and communities⁶², but also the values upon which a just and sustainable future can be co-created⁶³. In this vein, the overarching motivations for the IPOS have the potential to deliver outcomes to help ocean citizens to better envision and navigate pathways for a sustainable ocean future (see Table 1).

Future scenarios for a sustainable ocean

While urgent action needs to be reliably informed about *past* and *ongoing* ocean changes, policymaking also requires a consideration of *future* ocean changes to be sustainable^{64–69}. While modelling and scenario-building underpin the IPCC and IPBES reports, projections have not been as central in WOA reports^{33,70,71}. The IPOS could support ocean scenarios based on available data and projections to adapt the implementation of new or existing policies (Fig. 1 and Table 1). These scenarios will need to consider the compelling need for transdisciplinarity in ocean science^{72,73} and assess the viability of a range of potential options to account for both the trade-offs and synergies that will likely occur.

The success of global knowledge- and science-led future scenarios will depend on the input—and even leadership—from communities directly impacted by ocean change in local visioning exercises and co-conception, as they can provide the feedback necessary to define a framework of issues to be solved in future scenarios (Table 1). To promote and ensure that scenarios are linked to solutions, the IPOS can work in coordination with the UN Ocean Decade Programme 'Global Ecosystem for Ocean Solutions (GEOS)' and other Ocean Decade communities of practice focused on implementation and scaling of actions.

The IPOS can advance the implementation of future methods, thus creating spaces where visions of alternative pathways can inspire collective actions⁶². Integrating social learning and interactive strategies into scenario building (e.g. through artistic expression, serious games, and visioning of networked transformation/transition pathways) will not only secure credibility but also accelerate the pace of discovery and research advances, thereby stimulating a deeper sense of stewardship and engagement to foster transformative policymaking⁶³.

The need for innovative visions for the future of ocean management must fuel novel management and financing frameworks alongside scientific projections^{71,74}. The emergence of anticipatory governance (i.e. governing in the present to adapt to or shape uncertain futures)⁷⁵ could generate new forward-looking decisions and policies to facilitate sustainable future scenarios identified by the IPOS (Fig. 2). Anticipatory governance adopts a systems approach that combines capacities for forecasting and foresighting, visioning, and collaborative and participatory processes⁴⁶, to anticipate and respond to the challenges that come with rapid and unpredictable change. Innovations that emerge can contribute to sustainable transitions, not only in ocean management and governance but also across all components of the biosphere¹⁹.

If a wide consensus is established (e.g. via IPOS facilitation), generating sufficient credibility and legitimacy (Fig. 2), innovative processes to demonstrate global stewardship could be developed to hold parties accountable to their ocean sustainability commitments and objectives¹⁹.

CONCLUSION

The ocean plays a pivotal role in the climate system, food security, human health and well-being, biodiversity conservation, and the global economy^{76,77}. Given that one of humanity's major challenges is to support and enhance capacity for dealing with the unexpected while taking into account injustice and rising inequality⁷⁸, an integrated and inclusive scientific perspective on

ocean science is required to chart possible future pathways. Decisions will need to be made in shorter time frames, under greater stress, and with less certainty. For this, scientific foundations are needed to support flexible and dynamic policies, which can adapt as the ocean and its communities change. A timely opportunity exists now to augment current global environmental assessments with a focus on ocean sustainability and to build on lessons learnt (see ref. 33). The IPOS has the potential to reshape and coalesce knowledge to advance consensus on ocean status, promote collaboration and social learning between societal, political, and expert communities, guide policymakers in navigating future trade-offs, support sustainable ocean use, and inform the design of adaptive and anticipatory governance responses.

DATA AVAILABILITY

No new data were generated during this study.

Received: 7 March 2022; Accepted: 7 November 2022;

Published online: 21 December 2022

REFERENCES

1. IPCC. In *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (IPCC, 2019).
2. IOC-UNESCO. *Global Ocean Science Report 2020-Charting Capacity for Ocean Sustainability* (UNESCO Publishing, 2020).
3. Sala, E. et al. Protecting the global ocean for biodiversity, food and climate. *Nature* **592**, 397–402 (2021).
4. Boyce, D. G., Lotze, H. K., Tittensor, D. P., Carozza, D. A. & Worm, B. Future ocean biomass losses may widen socioeconomic equity gaps. *Nat. Commun.* **11**, 1–11 (2020).
5. Foundation Prince Albert II of Monaco. "Which Knowledge for Which Sustainable Ocean Governance?" in *Livre de restitution de la Monaco Ocean Week 2021* (2021).
6. Swilling, M. et al. *The Ocean Transition: What to learn from System Transitions* (World Resources Institute, 2020).
7. OECD. *The Ocean Economy in 2016* (OECD Publishing, 2016).
8. High Level Panel for a Sustainable Ocean Economy. *Transformations for a Sustainable Ocean Economy – a vision for Protection, Production and Prosperity* (2020).
9. Landrigan, P. J. et al. Human health and ocean pollution. *Ann. Global Health* **86**, 151 (2020).
10. OECD. *Development Co-operation Report 2016: the Sustainable Development Goals as Business Opportunities* (OECD Publishing, 2016).
11. OECD. *Development Co-operation Report 2020: Learning from Crises, Building Resilience* (OECD Publishing, 2020).
12. Hoegh-Guldberg, O. et al. *The Ocean as a Solution to Climate Change: Five Opportunities for Action*. (World Resources Institute, 2019).
13. Gattuso, J. P. et al. Ocean solutions to address climate change and its effects on marine ecosystems. *Front. Mar. Sci.* **5**, 337 (2018).
14. Heinze, C. et al. The quiet crossing of ocean tipping points. *Proc. Natl Acad. Sci. USA* **118**, e2008478118 (2021).
15. IPBES. *Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (eds. Brondizio, E. S., Settele, J., Díaz, S. & Ngo, H. T.) (IPBES Secretariat, 2019).
16. IPCC. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (IPCC, 2019).
17. Nash, K. L. et al. Planetary boundaries for a blue planet. *Nat. Ecol. Evol.* **1**, 1625–1634 (2017).
18. UN General Assembly. *General Assembly Resolution Declaration of Principles Governing the Seabed and Ocean Floor. A/RES/25/2749*. (1970).
19. Brodie Rudolph, T. et al. A transition to sustainable ocean governance. *Nat. Commun.* **11**, 1–14 (2020).
20. Claudet, J., Amon, D. J. & Blasiak, R. Opinion: transformational opportunities for an equitable ocean commons. *Proc. Natl Acad. Sci. USA* **118**, e2117033118 (2021).
21. Laffoley, D. et al. Evolving the narrative for protecting a rapidly changing ocean, post- COVID-19. *Aquatic Conserv.* **31**, 1512–1534 (2021).
22. Folke, C. et al. Our future in the Anthropocene biosphere. *Ambio* **50**, 834–869 (2021).
23. Bennett, N. J. et al. Towards a sustainable and equitable blue economy. *Nat. Sustain.* **2**, 991–993 (2019).

24. United Nations General Assembly. *Oceans and the law of the sea A/RES/72/73* (5 December 2017).
25. De Santo, E. M. et al. Protecting biodiversity in areas beyond national jurisdiction: an earth system governance perspective. *Earth Syst. Governance* **2**, 100029 (2019).
26. Röckmann, C., van Leeuwen, J., Goldsborough, D., Kraan, M. & Piet, G. The interaction triangle as a tool for understanding stakeholder interactions in marine ecosystem based management. *Mar. Pol.* **52**, 155–162 (2015).
27. Kotzé, L. J. Fragmentation revisited in the context of global environmental law and governance. *SALJ* **131**, 548–582 (2014).
28. Claudet, J. et al. A roadmap for using the UN decade of ocean science for sustainable development in support of science, policy, and action. *One Earth* **2**, 34–42 (2020).
29. Pörtner, H. O. et al. *IPBES-IPCC Co-sponsored Workshop Report on Biodiversity and Climate Change* (IPBES and IPCC, 2021).
30. Picourt, L. et al. *Swimming the Talk: How to Strengthen Collaboration and Synergies between the Climate and Biodiversity Conventions?* (Ocean & Climate Platform, 2021).
31. Valdes, L. The UN architecture for ocean science knowledge and governance. Chapter 18. In *Handbook on the Economics and Management of Sustainable Oceans* (eds. Paulo A.L.D. Nunes, P.A.L.D., Svensson, L. E. & Markandya, A. (Edward Elgar Publishing, 2017).
32. Valdés, L., Mees, J. & Enevoldsen, H. International organizations supporting ocean science. In *IOC-UNESCO, Global Ocean Science Report—The current status of ocean science around the world* (eds. Valdés, L. et al.) 146–169 (UNESCO, 2017).
33. Fawkes, K., Ferse, S., Scheffers, A. & Cummins, V. Learning from experience: what the emerging global marine assessment community can learn from the social processes of other global environmental assessments. *Anthropocene Coasts* **4**, 87–114 (2021).
34. Tessnow-von Wysocki, I. & Vadrot, A. B. M. The voice of science on marine biodiversity negotiations: a systematic literature review. *Front. Mar. Sci.* **7**, 614282 (2020).
35. Dalton, K. et al. Marine-related learning networks: shifting the paradigm toward collaborative ocean governance. *Front. Mar. Sci.* **7**, 1–16 (2020).
36. Gerbara, M. F. Understanding international bricolage. What drives behaviour change towards sustainable land use in the Eastern Amazon? *Int. J. Commons* **13**, 1 (2019).
37. Jabbour, J. & Flachsland, C. 40 years of global environmental assessments: a retrospective analysis. *Environ. Sci. Policy* **77**, 193–202 (2017).
38. Messerli, P. et al. Expansion of sustainability science needed for the SDGs. *Nat. Sustain.* **2**, 10, 892–894 (2019).
39. The Because the Ocean Initiative. Ocean for climate – Ocean-related measures in climate strategies (Nationally determined contributions, national adaptation plans, adaptation communications and national policy frameworks) (2019).
40. Vieross, M. K. et al. Considering indigenous peoples and local communities in the governance of the global ocean commons. *Mar. Pol.* **119**, 104039 (2020).
41. Halpern, B. et al. Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nat. Commun.* **6**, 1–7 (2015).
42. Watson-Wright, W., & Valdes, J.L. Fragmented Governance of Our One Global Ocean. In *The Future of Ocean Governance and Capacity Development - Essays in Honor of Elisabeth Mann Borgese (1918–2002)* 16–22 (Brill, Nijhoff, 2019).
43. United Nations Framework Convention on Climate Change. *Chile Madrid Time for Action. FCCC/CO/2019/13.Add.1 Decision 1/CP* (2020).
44. Fawkes, K. & Cummins, V. Beneath the surface of the first world ocean assessment: an investigation into the global process' support for sustainable development. *Front. Mar. Sci.* **6**, 612 (2019).
45. Bayliss-Brown, G., Cavaleri Gerhardinger, L. & Starger, C. Networked knowledge to action in support of ocean sustainability. *Coast. Manage.* **4**, 4, 235–237 (2020).
46. Gerhardinger, L. C., Holzkämper, E., de Andrade, M. M., Corrêa, M. R. & Turra, A. Envisioning ocean governability transformations through network-based marine spatial planning. *Marit. Stud.* **21**, 1, 131–152 (2022).
47. Wyborn, C. et al. Imagining transformative biodiversity futures. *Nat. Sustain.* **3**, 670–672 (2021).
48. Jacobs, S. et al. Use your power for good: plural valuation of nature – the Oaxaca statement. *Glob. Sustain.* **3**, e8 (2020).
49. Herbst, D. F., Gerhardinger, L. C., Vila-Nova, D. A., de Carvalho, F. G. & Hanazaki, N. Integrated and deliberative multidimensional assessment of a subtropical coastal-marine ecosystem (Babitonga bay, Brazil). *Ocean Coast. Manag.* **196**, 105279 (2020).
50. McCrory, G., Holmén, J., Schöpke, N. & Holmberg, J. Sustainability-oriented labs in transitions: an empirically grounded typology. *Environ. Innov. Soc. Transit.* **43**, 99–117 (2022).
51. Gerhardinger, L. C., Andrade, M. M. de, Corrêa, M. R., & Turra, A. Crafting a sustainability transition experiment for the Brazilian blue economy. *Mar. Pol.* **120**, 104157 (2020).
52. Pereira, L., Sitas, N., Ravera, F., Jimenez-Aceituno, A. & Merrie, A. Building capacities for transformative change towards sustainability: imagination in Inter-governmental Science-Policy Processes. *Elem. Sci. Anth* **7**, 35 (2019).
53. Flannery, W., Toonen, H., Jay, S. & Vince, J. A critical turn in marine spatial planning. *Marit. Stud.* **1987**, 223–228 (2020).
54. Clarke, J. & Flannery, W. The post-political nature of marine spatial planning and modalities for its re-politicisation. *J. Envir. Policy Plan.* **22**, 2, 170–183 (2020).
55. von Schuckmann, K. et al. Copernicus marine service ocean state report 5th issue. *J. Oper. Oceanogr.* **14**, 1–185 (2021).
56. Mercator International. Digital twin of the ocean. <https://www.mercator-ocean.eu/en/digital-twin-ocean/> (2022).
57. Geomar. Digital twin ocean. <https://www.geomar.de/en/research/irf/digital-twin-ocean> (2022).
58. Creative Commons. <https://creativecommons.org/licenses/> (2022).
59. Orchid. Connecting research and researchers. <https://orcid.org/#:~:text=ORCID%20provides%20a%20persistent%20digital,%2C%20peer%20review%2C%20and%20more> (2022).
60. Jasanoff, S. Technologies of humility. *Nature* **450**, 33 (2007).
61. Pörtner, H.-O. et al. Technical summary. In *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (eds Pörtner, H.-O. et al.) (Cambridge Univ. Press, 2022).
62. Pereira, L. M., Hichert, T., Hamann, M., Preiser, R. & Biggs, R. Using futures methods to create transformative spaces: visions of a good anthropocene in Southern Africa. *Ecol. Soc.* **23**, 1, <https://doi.org/10.5751/ES-09907-230119> (2018).
63. TWI2050 Report. *Transformations to Achieve the Sustainable Development Goals. Report prepared by World in 2050 Initiative*. International Institute for Applied Systems Analysis (IIASA). www.twi2050.org (2018).
64. Mitchell, R. B., Clark, W. C., Cash, D. W., & Dickson, N. M. *Global Environmental Assessments: Information and Influence* (MIT Press, 2016).
65. Norström, A. V. et al. Principles for knowledge co-production in sustainability research. *Nat. Sustain.* **3**, 182–190 (2020).
66. Galland, G., Harrould-Kolieb, E. & Herr, D. The ocean and climate change policy. *Clim. Pol.* **12**, 6, 764–771 (2012).
67. Pereira, L. M. et al. Developing multiscale and integrative nature–people scenarios using the nature futures framework. *People Nat.* **2**, 1172–1195 (2020).
68. Evans, K. et al. Transferring complex scientific knowledge to useable products for society: the role of the global integrated ocean assessment and challenges in the effective delivery of ocean knowledge. *Front. Environ. Sci.* **9**, 626532 (2021).
69. United Nations Ocean Conference. An international panel for ocean sustainability side event. (2022).
70. Foundation Prince Albert II of Monaco. “Why an IPOS” in Livre de restitution de la Monaco Ocean Week 2022 (2022).
71. Convention on Biodiversity. Open ended working group on the post 2020 global biodiversity framework. 3rd meeting. *First Draft of the post-2020 global biodiversity framework* (2021).
72. Sitas, N. et al. Exploring the usefulness of scenario archetypes in science-policy processes: experience across IPBES assessments. *Ecol. Soc.* **24**, 35 (2019).
73. Laffoley, D. et al. The forgotten ocean: why COP26 must call for vastly greater ambition and urgency to address ocean change. *Aquatic Conserv.* **32**, 1–12 (2021).
74. Martin, M. A. et al. Ten new insights in climate science 2021: a horizon scan. *Glob. Sustain.* **4**, 1–20 (2021).
75. Poli, R. Anticipation: what about turning the human and social sciences upside down? *Futures* **64**, 15–18 (2014).
76. Dasgupta, P. *The Economics of Biodiversity: The Dasgupta Review* (HM Treasury, 2021).
77. Sumaila, U. R. et al. Financing a sustainable ocean economy. *Nat. Commun.* **12**, 3259 (2021).
78. Muiderman, K., Gupta, A., Vervoort, J. & Biermann, F. Four approaches to anticipatory climate governance: different conceptions of the future and implications for the present. *WIREs Clim. Change* **11**, e673 (2020).
79. Obermeister, N. Local knowledge, global ambitions: IPBES and the advent of multi-scale models and scenarios. *Sustain. Sci.* **14**, 843–856 (2019).
80. Vadrot, A., Rankovic, A., Lapeyre, R., Aubert, P. & Laurans, Y. Why are social sciences and humanities needed in the worlds of IPBES? A systematic review of the literature. *Innovation* **31**, 578–5100 (2018).
81. Edenhofer, O. & Kowarsch, M. Cartography of pathways: a new model for environmental policy assessments. *Enviro.Sci.Policy* **51**, 56–64 (2015).
82. Kowarsch, M. et al. An road map for global assessments. *Nat. Clim. Change* **7**, 379–382 (2017).
83. European Commission Press Release. *International Ocean Governance: EU's Contribution for Setting the Course of a Blue Planet*. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3742 (2022).
84. Seafood Business for Ocean Stewardship (SeaBOS). <http://www.seabos.org/> (2022).

ACKNOWLEDGEMENTS

The authors thank the Ocean & Climate Platform, specifically Loreley Picourt, Anaïs Deprez and Marine Lecerf; the National Center for Scientific Research, and specifically

the Institute of Ecology and Environment; and the Centre Scientifique de Monaco. The authors also thank Virginie Tassin Campanella for her input on legal mechanisms of ocean governance and Frédérique Viard for her comments on this manuscript, as well as anonymous reviewers for their insightful comments on an earlier version of this manuscript.

AUTHOR CONTRIBUTIONS

F.G. and T.B.R. co-conceived the idea; F.G., T.B.R. and L.L. wrote the initial draft of this manuscript. D.A., R.B., W.W.L.C., J.C., H.-O.P., L.C.G., N.L.B., L.L., M.V. and A.Z. brought major elements to the discussion. M.B. and S.P. put together the core literature for the conception of the paper. P.B., L.B., C.B., F.C., P.C., D.G., S.G., N.H., F.M., F.M., L.M., R.P., M.-A.S., S.S., O.T., T.T., P.C., R.C., F. H., F.S. and O.P.d.A. have been involved in discussing the IPOS initiative and have reviewed and commented on the manuscript.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s44183-022-00007-1>.

Correspondence and requests for materials should be addressed to Françoise Gaill or Tanya Brodie Rudolph.

Reprints and permission information is available at <http://www.nature.com/reprints>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2022