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PERSPECTIVE OPEN

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An evolution towards scientific consensus for a sustainable ocean future

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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.

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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 whole[23].

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

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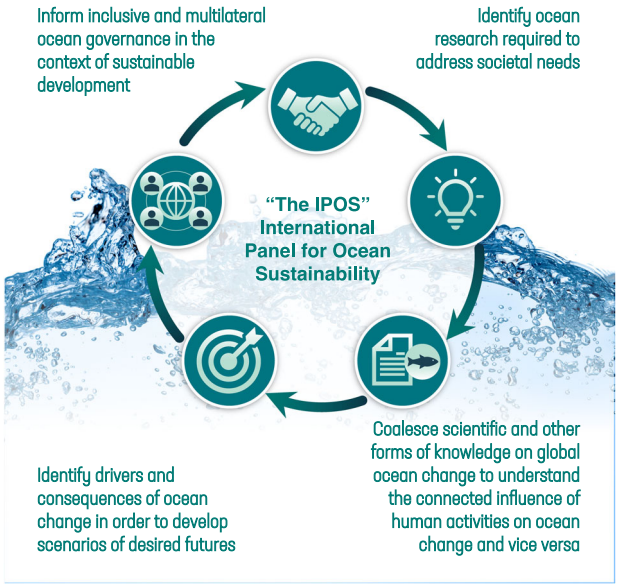

Fig. 1 Introducing the IPOS. The potential roles of the IPOS in centralising past, existing and future science and knowledge to support ocean sustainability.

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 governance[83]. 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 Centre[42]. 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 endevour must be anchored in the United Nations (UN) Sustainable Development Goal (SDG) 14, which is central to achieving the 2030 Agenda for Sustainable Development[24].

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, salient[25], and credible interactions among ocean scientists, decision-makers and citizens at large[26]. 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 Report[29] 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 synthetise 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 governance[25] (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 networks[35], advance stakeholder engagement informed by social sciences, and pilot novel communication and networking approach in knowledge co-creation and synthesis[36].

COORDINATING SCIENCE TO SHAPE OCEAN ACTION

For both climate and biodiversity topics, the IPCC and IPBES have proved effective in distiling 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 SDGs[38]. 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 spaces[40]. Improved articulation and communication between non-scientists and the scientific community is, therefore,

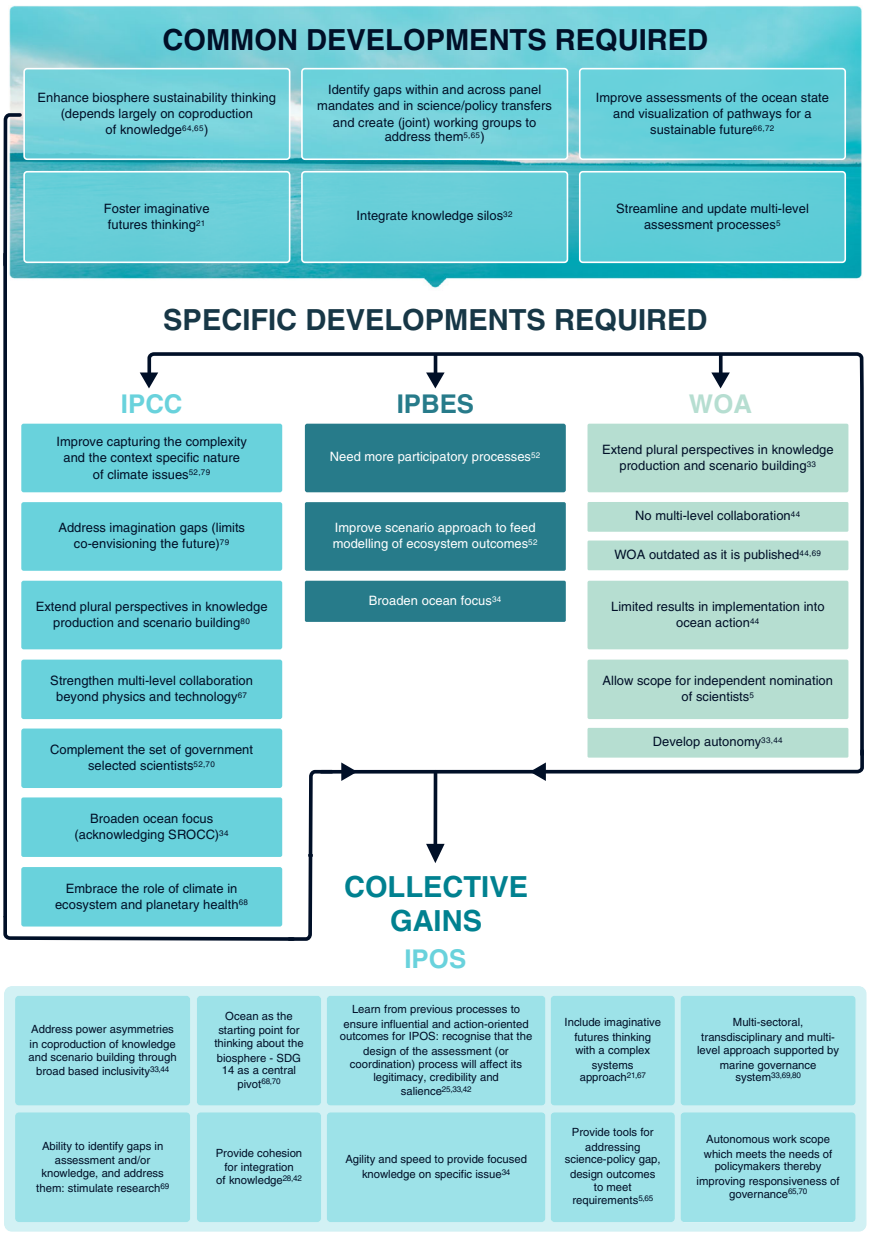

Fig. 2 A comparative literature review of the developments required in current assessment bodies, illustrating the rationale for the IPOS. Common developments required in current international assessment bodies could be leveraged through collaboration, resulting in collective gains for the biosphere. 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 ocean[41].

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 initiative[39] 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 Climate[16], the first Ocean and Climate Change Dialogue was mandated by COP 25, and held in December 2020[43]. 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 change[8]. 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	• 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	• 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	• 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	• 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	• 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	• 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 pathways[47], and the use of plural valuation[48]. 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 conflicts[49]. These methods can also promote ocean sustainability transition experiments in innovation labs[50] to support collective action in order to transform existing governance systems[51]. 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 assessments[52]. A more independent IPOS could also foster a 'critical turn' in how sustainable ocean governance is implemented[53]. 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 governance[54].

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 System[55]. Innovative digital tools that use observation and advanced modelling (from the open ocean to coastal areas, from physics to biology[55]) 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 communities[62], but also the values upon which a just and sustainable future can be co-created[63]. 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 actions[62]. 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 policymaking[63].

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 processes[46], 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 biosphere[19].

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 objectives[19].

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 inequality[78], 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.

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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.

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