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PERSPECTIVE

Making the UN Ocean Decade work? The potential for, and challenges of, transdisciplinary research and real-world laboratories for building towards ocean solutions

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Abstract

1. Due to the strong interconnectedness between the ocean and our societies worldwide, improved ocean governance is essential for sustainable development in the context of the UN Ocean Decade. However, a multitude of different perspectives—ecological, societal, political, economic—and relations between these have to be understood and taken into consideration to foster transformative pathways towards marine sustainability.
2. A core challenge that we are facing is that the 'right' response to complex societal issues cannot be known beforehand as abilities to predict complex systems are limited. Consequently, societal transformation is necessarily a journey towards the unknown and therefore requires experimental approaches that must enable the involvement of everyone with stakes in the future of our marine environment and its resources.
3. A promising transdisciplinary research method that fulfils both criteria—being participatory and experimental—are real-world laboratories. Here, we discuss how real-world labs can serve as an operational framework in the context of the Ocean Decade by facilitating and guiding successful knowledge exchange at the interface of science and society. The core element of real-world labs is transdisciplinary experimentation to jointly develop potential strategies leading to

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targeted real-world interventions, essential for achieving the proposed 'Decade Outcomes'.

4. The authors specifically illustrate how deploying the concept of real-world labs can be advantageous when having to deal with multiple, overlapping challenges in the context of ocean governance and the blue economy.
5. Altogether, we offer a first major contribution to synthesizing knowledge on the potentials of marine real-world labs, considering how they act as a way of exploring options for sustainable ocean futures. Indeed, in the marine context, real-world labs are still under-explored but are a tangible way for addressing the societal challenges of working towards sustainability transformations over the coming UN Ocean Decade and beyond.

KEYWORDS

blue economy, living labs, marine conservation and biodiversity, marine socio-ecological systems, ocean governance, ocean sustainability, SDG 14, societal challenges

1 | INTRODUCING THE OCEAN DECADE

2021–2030 marks the decade dedicated to the Ocean. The 'United Nations Decade of Ocean Science for Sustainable Development' is a global effort to enact change through producing 'the science we need for the ocean we want' (Ryabinin et al., 2019; UNESCO-IOC, 2021). Literature is already emerging that takes seriously the mechanism of the Ocean Decade (as it is known in short) in leading to sustainable outcomes and meeting the aims of equality in doing so (Singh et al., 2021). It is a significant marker in attempting to instigate change for the ailing ocean. In spite of being essential to the functioning of physical, biological and societal processes, the ocean has often remained 'out of sight and mind' (Peters, 2010) resulting in a lack of societal ocean knowledge and literacy (Brennan et al., 2019; Kelly et al., 2022). Nonetheless, the marine environment is pivotal in providing oxygen, food and energy, facilitating trading and transport of goods, generating jobs and securing human health and well-being (Fleming et al., 2019; Visbeck et al., 2014). Hence, it is strongly affected through human pressures such as pollution, habitat destruction and of course climate change (Duarte, 2014; Hoegh-Guldberg & Bruno, 2010; Wittmer et al., 2021). Moreover, the blue economy, is largely unsustainable despite its aims of building sustainable growth around sectors such as fisheries, aquaculture, tourism, underwater mining and shipping (Bennett et al., 2019; Ertör & Hadjimichael, 2020; Palomares et al., 2020). These continued cumulative anthropogenic pressures endanger the health of the ocean and its ecosystems (Jouffray et al., 2020). Consequently, there is an unprecedented loss of marine biodiversity, affecting ecosystem functioning (Pörtner et al., 2021) but also public health and well-being linked to the ocean (Borja et al., 2020). In this context, sustainable ocean and coastal governance and management, pursuing integrative ecosystem-based approaches, are increasingly demanded. The Ocean Decade aims to instigate, encourage, support and develop knowledge to meet this demand.

The Ocean Decade is organized structurally through an 'Ocean Decade Action Framework' to accomplish the mission of catalysing 'transformative ocean science solutions for sustainable development, connecting people and our ocean' (UNESCO-IOC, 2021). The 'Decade Objectives' are to generate knowledge and build capacity to overcome the 10 'Decade Challenges' for example, to 'understand and beat marine pollution', 'protect and restore ecosystems and biodiversity', 'sustainably feed the global population' and 'change humanities relationship with the ocean', (UNESCO-IOC, 2021). To this end, the Ocean Decade is concerned with data and information, as much as it is with human values and well-being in protecting the oceans. It is an ambitious concept where 'Decade Actions' in the form of different programmes, projects and activities are carried out by a wide range of stakeholders, from the grassroots up, to overcome the aforementioned 'Decade Challenges' with the goal of achieving the proposed seven 'Decade Outcomes' such as a 'clean', 'healthy and resilient' as well as 'inspiring and engaging' ocean (UNESCO-IOC, 2021, see Figure 1).

Altogether, the Ocean Decade aims to be inclusive and representative in its approaches to ocean science and the building of applicable knowledge and innovations. However, to enable transformation towards more sustainable—but also more inclusive—forms of science-practice interactions and solutions is not without its challenges. What approaches can be used to produce and share science and do so in equitable and participatory ways? Continuing to establish holistic methods and frameworks to allow for multi-stakeholder collaborations and the implementation of key findings to enact change, is needed. But while capacity development is central to the work of the Ocean Decade, there is also a need to acknowledge power systems that enable certain knowledge to dominate in potential ocean futures. As Tolochko and Vadrot (2021) argue, it is still the 'usual suspects' or dominant 'players' producing marine biodiversity knowledge and sustainable solutions. Thus, there is a need to be cognisant of the 'dark sides' (risks) of transformation, for example

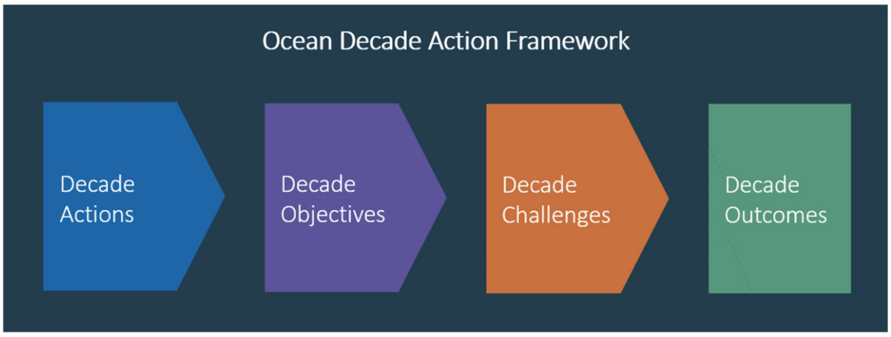

FIGURE 1 Schematic summary of the Ocean Decade Action Framework (for further details see Ocean Decade Implementation Plan, UNESCO-IOC, 2021).

'shifting the burden of response onto vulnerable parties' (for further details, see Blythe et al., 2018).

This paper provides an overview of the potentials for, and challenges of, transdisciplinary research, and under this remit, the introduction of real-world laboratories as an approach to bring together science and society in new ways to attend to the severe pressures we exert on our marine environments. Real-world laboratories have thus far been under-explored in addressing societal challenges towards ocean sustainability. However, as we go on to show, they harbour immense potential to enable knowledge exchange and production that makes possible predictions about the changing shape of the ocean (for responsive governance), an ocean that people—society in all its variegated richness and heterogeneity—can engage with and be inspired by. Accordingly, we show how real-world laboratories may be a key method developed under the umbrella of 'Ocean Decade Activities', to help meet the 'Ocean Decade Outcomes'. We pursue this aim to pitch them as a potentially highly participatory and experimental method, which can serve as a framework, for effective ocean science and achieving real-world interventions leading to the 'ocean we want'.

2 | THE SOCIETAL CHALLENGES OF PROGRESSING TOWARDS OCEAN SUSTAINABILITY

Since the ocean(s) and our societies are heavily interconnected, achieving and maintaining ocean health and sustainability to safeguard food security, people's livelihoods, health and well-being is vital (Franke et al., 2020). This means robust and rigorous research is essential in both the natural and social sciences, and across them in the form of increasing interdisciplinary and transdisciplinary approaches, that actively engage multiple stakeholders. This necessity for 'the science we need' to lead to the 'ocean we want' is core to the Ocean Decade aims. Yet, there are distinct challenges in progressing towards ocean sustainability, within and beyond this remit. Understanding these is crucial to understanding what approaches may be useful in pressing towards alternatives.

First, understandings of the imperilled oceans have been historically dominated by *natural science* perspectives. Yet, the multiple crises facing the ocean(s), as noted in our introduction, are not independent of people. People are agents of ab/use of the ocean(s) and agents of change in creating solutions to protect, conserve and restore it/them. Long-standing ocean policy work has grappled with human dimensions of changing seas, with more recent shifts under the umbrella of 'marine social science', further unravelling with greater volumes of work, the interactions between marine ecosystems *and* social systems (Bennett et al., 2019; Charles, 2012). However, to integrate different perspectives—ecological, societal, political, economic and relations between these—is key to overcome conflicting societal interests, insufficient science-policy interfaces and weak ocean governance.

Second, existing *published knowledge is unevenly distributed* around the globe (Tolochko & Vadrot, 2021). Many marine ecosystems of worldwide importance are situated in the tropics; however, literature research shows that knowledge production is not led by scientists coming from these regions, which might bring a less fitting perspective and cement unilateral dependencies (Partelow et al., 2020). An increasing body of work led by Majority World (Global South) scholars in the humanities (literature, art, post-, de- and anti-colonial thought) gives voice to perspectives beyond the west (Belhabib, 2021; Goodyear-Kaʻōpua, 2018; Hauʻofa, 1995; Hofmeyr, 2020; Underhill-Sem, 2020; Zondi, 2020) and only recently are marine social sciences engaging more in this rich work.

Third, the ocean is a *global commons*, leading to a range of nested collective dilemmas on various social, economic and geographical scales (Abhold et al., 2019; Glaser & Glaeser, 2014). In marine spaces, different jurisdictions are overlapping and social systems meet due to fluidity and multi-dimensionality (Schlüter et al., 2019; Steinberg & Peters, 2015; Van Assche et al., 2020). Emerging socio-political dilemmas can only be solved by intensive, 'equitable' interaction between the various jurisdictions as well as the fostering of societal discussion processes through which awareness for sustainable ocean governance is raised among ocean users in charge of informal, non-state governance processes.

Fourth, the strategic relevance of the ocean and its resources is the subject of global *geopolitical power relations* (e.g. at the International Seabed Authority). Social inequality and sectoral differences in negotiations of power are contributing to situations that adversely affect the incomes and nutritional situation of some countries or particular social groups. The EU fisheries partnership agreement with Mauritania, for example, has been repeatedly criticized

for supporting the country's economic and political elite, while contributing to the impoverishment of the small-scale fisheries sector (Belhabib et al., 2015; Hornidge & Keijzer, 2021).

Fifth, there is a need for greater openness in *participation* but also to listen to opinions, knowledge, ideas, visions and potential solutions for ocean futures that may not always align neatly, and may also contradict dominant desires, on how to 'save' the ocean. Belhabib argues along these lines for decolonising ocean science and ocean advocacy (Belhabib, 2021). To build knowledge partnerships for sustainable ocean governance, steps must be taken to boost the negotiating clout of coastal states in regional and multilateral blue economy debates on ecosystem conservation and job creation. Moreover, it is fundamental to imagine futures where local, traditional and indigenous knowledge is front and centre instead of merely including local knowledge within existing frameworks (that are themselves burdened with western power logics) (Brown & Peters, 2018; Hau'ofa, 2008; Turner et al., 2022; Yusoff, 2018).

Sixth, thinking about transformations for sustainable development also requires a critical discussion about *ocean sustainability and its targets*. Whose sustainability perspective counts? How are targets established, by and for whom? While certain marine system knowledge is acquired, neither jointly negotiated target knowledge (where to go), nor transformation knowledge (how to reach the new stage) exists to a sufficient degree (Pohl & Hirsch Hadorn, 2007; Wittmer et al., 2021). Moreover, transregional learning from each other's 'solutions'—to assure 'local fit' and applicability—needs to be further understood and fostered (Hornidge et al., 2020; Krause et al., 2022).

In summary, there is a range of societal challenges but also responsibilities of working towards sustainable development and 'just' transformation under projects such as the Ocean Decade. Attending the oceanic crises, as this section shows, will be a challenging endeavour due to the complex nature of the ocean (a space of commons, social dilemmas and fluidity), the manifold pressures it is facing, the lack and asymmetry in distribution of knowledge, low societal ocean literacy and insufficient ocean governance arrangements. Hence, holistic approaches, such as transdisciplinary experimental research in the form of real-world laboratories which aim not only to involve all necessary stakeholders but also to implement the achieved results, could offer gains for a successful Ocean Decade.

3 | TRANSDISCIPLINARY APPROACHES: POTENTIALS, CHALLENGES AND LESSONS LEARNED

3.1 | Transdisciplinary research and its challenges

Transdisciplinary research denotes a multitude of research approaches that abandon the traditional division of labour between science as knowledge producer and society as knowledge applicant. Instead, in transdisciplinary knowledge production, research questions, processes and products are developed *collaboratively* among researchers and broadly-defined stakeholders engaging thoughtfully with local knowledge systems and cultures (Chigbu et al., 2016; Newton & Elliott, 2016; Weiand et al., 2021). The core aspiration of transdisciplinary research is to contribute to problem solving directly in societal contexts (Cash et al., 2003; Hinkel et al., 2016; Moss et al., 2013). It is underscored by principles which include recognizing multiple ways of knowing and doing, fostering deliberation, mutual learning and trust building among actors through the creation of safe spaces in which they can express their own opinions, interests and experiences (Brandt et al., 2013; Mielke et al., 2017; Norström et al., 2020). A wide range of *participatory* methods (Callahan, 2007) implement these principles and public participation is nowadays widespread in environmental governance (e.g. see EU Public Participation Directive; Birnbaum, 2016; Quittkat & Kohler-Koch, 2013), although achieving it fully is notoriously difficult (Flannery et al., 2018).

A core element of many transdisciplinary research approaches is *experimentation* followed by reflection, as first articulated through the concepts of action research (Lewin, 1946) and reflective practitioners (Schön, 1983). The idea is that the 'right' response to complex societal issues cannot be known beforehand, as abilities to predict complex systems are limited. Hence, there is a need to first experiment, to then be able to observe, reflect and learn for next steps. Experimentation at the interface of science and society can thereby target the biophysical as well as the social realm by exploring different ecosystem management approaches and governance arrangements (Armitage et al., 2009; Folke et al., 2005).

However, the implementation of transdisciplinary approaches and real-world embedding in the actual field of research is challenged by the prevailing disciplinary mindset within scientific communities instead of inter- or transdisciplinary ways of thinking and interacting (Knapp et al., 2017), existing incentive mechanisms within the science systems (e.g. focus on scientific high-impact publications instead of community engagement) as well as the socio-political environments in which and for which the research takes place (Hornidge et al., 2011). Compared to disciplinary research, different timescales, goals and measures of success need to be acknowledged since changes in both natural and social systems take place on scales of years to decades. This results in a direct need for long-term planning, support and financing. Hence, to enable sustainable development and capture transformative effects of transdisciplinary engagements, long-term research programs (10 to 30+ years) such as the Ocean Decade are key.

It is also important to critically contextualize experimentation since it may not always be positive or transformative despite well-intended efforts from the onset. Experimentation has ethical dimensions and always holds dimensions of power (Kullman, 2013; Last, 2012; Yusoff, 2018 for critical approaches to the history of experimentation). Therefore, notions of *who* experiments, *why*, *for* and *on behalf of whom*, for *what* knowledge and *who* benefits/loses, are vital.

3.2 | Real-world laboratories: An experimental approach

In recent years, a multitude of so-called real-world experimentation approaches, such as real-world laboratories (RwLs), living labs (LLs), transition labs, transformation labs and innovations labs have emerged (Hossain et al., 2019; Huning et al., 2021). Standard definitions for the different methods do not exist, which means that terms like RwL and LL seem to be used interchangeably. However, the different definitions and variants all have a common core: they are solution-oriented, experimental and real-world laboratory research settings, attempting to accelerate transformations together with and for the society towards more sustainability (Schäpke et al., 2018). RwLs can be described as a targeted set-up of a research infrastructure or a space in which scientists and other stakeholders *jointly* invent and conduct experiments to produce knowledge for the more sustainable development of society (Schneidewind et al., 2018; WBGU—German Advisory Council on Global Change, 2016). RwLs provide a platform for knowledge exchange (instead of unidirectional knowledge transfer) between involved stakeholders that might range from representatives of the civil society, such as indigenous and local knowledge holders, to governmental organizations and businesses. The term 'real-world lab' suggests research takes place *in* the 'real' world versus research that only takes place in a research lab. This creates a problematic dichotomy as arguably lab research is also 'real'. As such, our own use appreciates this complexity, and rather, for us, RwLs refer to unique tools where research takes place in *specific spaces and environments*, i.e. in a particular socio-ecological context with communities.

According to Schäpke et al., (2018), the core characteristics of RwLs are (i) the contribution to sustainability transformation using a transdisciplinary research mode and experimental methods, (ii) the scalability and transferability of the results and (iii) scientific learning, societal learning and reflexivity. RwLs consist of three phases in which all stakeholders are involved: (i) a *co-design* phase, where problems and potential solutions are discussed and selected, (ii) a *co-production* phase, where experiments are conducted and selected real-world innovations are implemented and tested and (iii) a *co-evaluation* and adjustment phase, which consolidates the innovations (Wanner et al., 2018, see also Figure 2).

RwLs have their basis in urban research and sustainable transitions in cities (Hossain et al., 2019). However, we contend that they be considered as an experimental transdisciplinary tool for marine spaces facilitating and guiding successful knowledge exchange and science-practice interactions. To date, there is little research which deploys them in marine environments (see Section 4), yet arguably they may have much to offer, especially within the context of the Ocean Decade.

The *purpose and overall goal* of RwLs is to enable the co-development of transformative knowledge leading to potential solutions, strategies and options ready for implementation (real-world interventions) in highly participatory and 'just' ways. Consequently, marine RwLs—carefully considered, planned, implemented and reflected upon—may offer great potential in light of the Ocean Decade mission of catalysing 'transformative ocean science solutions for sustainable development, connecting people and our ocean'.

3.3 | Lessons learned: A guideline for successful real-world labs

In terrestrial settings (agricultural, development and environmental research as well as urban planning), transdisciplinary research has already gained more prominence than in marine settings (Hornidge et al., 2011; Norström et al., 2020; Ul Hassan et al., 2011, transdisciplinarity.ch/en), which allows us to extract several generalizable learnings and requirements for the possible implementation of RwLs in marine environments:

1. The process should be clearly situated within a particular context, place or issue.
2. All necessary stakeholders should be involved before the start of the project. Roles and priorities should be clarified in the transdisciplinary team from the start.
3. Substantial attention should be paid to a systematic, continuous, well-documented, transparent and reliable team interaction and communication. To avoid misunderstandings and communication problems, the coherence of the used terminology and definitions is of utmost importance.
4. Shared and meaningful goals and innovations, related to the challenge at hand, should be co-designed and clearly defined. Innovation packages should not be too complex.
5. Multiple ways of knowing, doing and communicating should be explicitly recognized. True interest and conscious investment into a culture that encourages the mutual exchange of knowledge (to overcome feelings of superiority and inferiority), fosters flat hierarchies and builds trust are needed.
6. Joint decision making during the entire process of co-development (incl. finances) is important. If only certain groups have the decision-making power, while others are supposed to follow, ownership diminishes with negative effects on the co-production of knowledge.
7. Individual and institutional level capacity development as well as team facilitation are crucial. Attention has to be paid to the facilitation being supportive without creating a dependency trap.
8. Transdisciplinary innovation development processes are time and resource intensive and require well trained, continuous local staff (incl. local language expertise). In negotiations with science donors it is crucial to raise awareness for the value of transdisciplinary forms of knowledge production and their funding requirements regarding funding phases and amounts.

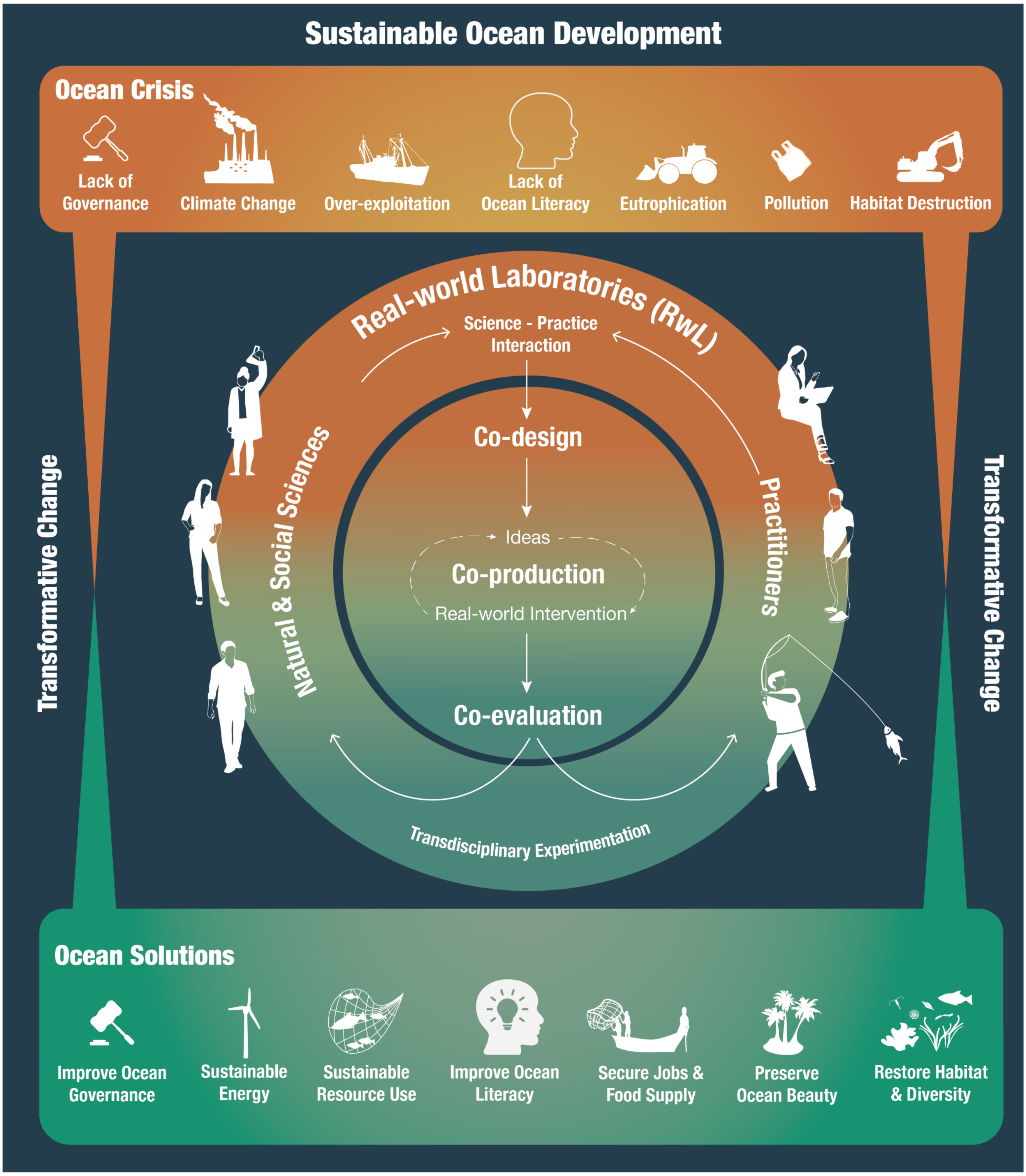

FIGURE 2 Applying the cyclical real-world lab concept (based on Wanner et al., 2018) in the context of marine sustainable development can foster transformative change leading to ocean solutions.

9. Transparency and open handling of data and information are key success factors. If the partners are not equipped with the same technologies, intercalibration is crucial (see Acri et al., 2020; Chander et al., 2013; Gissi et al., 2022).
10. The results of co-produced knowledge, the innovations, should be co-evaluated and reassessed on a regular basis to judge if they still pose 'plausible promises' for an improved situation or have lost that potential due to adjustments to stakeholder needs.

4 | WORKING TOWARDS OCEAN SUSTAINABILITY: FROM TRADITIONAL PARTICIPATORY APPROACHES TO MARINE REAL-WORLD LABS

There is a long history of participatory approaches in marine community, conservation, restoration and ecological engineering projects involving stakeholders, scientists and users, for the protection, study, management and enhancement of biodiversity (see Abelson et al., 2016; Garcia-Soto et al., 2021; Krause et al., 2020; Narayan et al., 2016; Temmerman & Kirwan, 2015; Wittmer et al., 2021 for notable but not exclusive examples). Prominent examples include the world's largest and most successful eelgrass restoration project on the Atlantic west coast (Virginia, USA) (Orth et al., 2020) and the efforts in certain Great Barrier Reef areas where science, citizens and management have been working together to reduce reef decimation by the Crown-of-Thorns starfish (GBRMPA, 2021). However, despite some success in restoring and conserving parts of ecosystems (e.g. vegetation and habitat structures) and populations of single species, developing holistic, transformative and sustainable concepts and solutions (targeting the biophysical and the social realm and their interlinkages) has proven to be very challenging due to the high complexity of human-ocean relationships (see Section 2). To address this complexity and accelerate transformations towards ocean sustainability, RwLs are a promising concept because they provide a *tangible framework* that can be used to structure science-practice interactions leading to real-world interventions (implementations) in coastal and marine socio-ecological systems. Because RwLs are spatial approaches—they take place in a specific place—they are context specific, tailored, and led by the very people impacted by change. They hence offer the potential of solutions in situ, that are crucially needed to overcome the challenges that the Ocean Decade alerts us towards. RwLs can further be distinguished from traditional participatory approaches because they are a specific *experimental* transdisciplinary research method that goes beyond stakeholder involvement alone. They facilitate the co-creation *and* co-evaluation of transformative knowledge and potential solutions, for a more sustainable development of society, in a structured manner (see Figure 2).

Even though the use of the RwL concept is not yet very common in marine and coastal settings, the number of implementations of the approach is currently increasing. One example is the project 'Gute Küste Niedersachsen' ('Good Coast Lower Saxony', Germany), which started in 2020 and investigates and promotes ecosystem-strengthening coastal protection in the specific space of the Lower Saxony North Sea coast. The 5-year project focuses on (i) how robust, multifunctional and especially ecosystem-strengthening coastal protection measures work in the long run and (ii) how they are simultaneously considered in reliable planning and approval by the responsible authorities and accepted by civil society. Both questions are to be answered in RwLs with scientists, non-scientific stakeholders and local actors on equal footing with each involved in the selection of RwL sites and the co-design of the research itself (following Mauser et al., 2013). Knowledge co-production will be ensured through regular exchange and reflection. The initial co-design process is nearly completed in this project and has shown so far that, in addition to the spatial conditions as well as ecological, legal and socio-economic dimensions, the existence of already available (research) infrastructures and preliminary scientific work is of high relevance for all parties (Zielinski et al., 2022). In this regard, it is noteworthy that coastal and ocean observatories, long-term time series and digital inventories, such as recording archives, have been in operation for decades in this area and their advanced experience (at least on the technological and operational side) can be used as a basis for the development of marine RwLs (Muelbert et al., 2019; Weller et al., 2019).

In the project 'Wissen Schafft Lebensraum' ('Knowledge Creates Living Space'), the RwL approach was used to build a network of approx. 50 stakeholders to develop the coastal region around the harbour city of Bremerhaven (Germany) into a model region for sustainable food production and supply including aquaponics (Fuchs & Krause, in prep.). Bremerhaven has a historically important fishing port however continuously declining fisheries require a structural transformation of the area. Using the RwL method enabled research in situ, in highly participatory ways. The recently completed concept phase of the project revolved around the co-definition of goals, the co-identification of stakeholders and consensus building regarding adequate communication formats to be used (e.g. focus groups). To continuously consider different stakeholder interests over the entire project period, a pre-formulation of project goals by the scientific and/or the initial stakeholder groups was avoided as this would degrade the other stakeholders to spectators.

Another example is the pilot project 'Eckernförder Bucht 2030'. The aim of this marine RwL is to contribute to the protection of biodiversity, the improvement of water quality and thus to the achievement of the EU MSFD objectives and the HELCOM Baltic Sea Action Plan ('Eckernförde Bay 2030', Germany). The area is characterized by designated nature reserves but also by high agricultural nutrient input into the sea, tourism, fishing and military presence. One of the goals of the RwL is to assess the extent to which coastal protection measures can contribute to improving the ecological situation in this specific area and in relation to stakeholder interests in this space.

While our examples so far are of sites in Germany (reflecting our authorship and expertise), examples for real-world experimentation approaches in a coastal context can also be found in the Netherlands, where the term Living Lab (LL) instead of RwL appears to be predominant. The LL 'Holwerd aan Zee', for example, is a testing ground for the sustainable development of a Wadden Sea coastal area (Zijlstra, 2019). Here, different research institutions, citizens, entrepreneurs and (non)governmental organizations are working on innovations regarding saline agriculture, flood risk management, sustainable energy production but also recreation and healthy ageing. In another Dutch consortium, over 90 public and private partners joined forces resulting in the 'Delta Plan for Biodiversity Restoration'. Apart from running the coastal LL 'B7' the consortium is set to find comparable LL standards, which are representative of all landscapes

in the Netherlands and can be translated accordingly into all possible practice situations for the maintenance of biodiversity in rural areas and extended into the marine environment in future.

Finally, the 'North Atlantic Whitefish Marine Living Lab' (2011–2014), which had two main objectives: (i) to build a branding platform for whitefish from the North Atlantic that facilitates market differentiation in terms of sustainability and consumer benefits and (ii) to demonstrate how a LL can be established in the marine sector leading to solutions that are co-created, explored and evaluated with a user-centric approach. As a result, the LL developed the application DigitalFishmonger to disseminate facts about the history of whitefish from the North Atlantic.

5 | FUTURE PERSPECTIVE: IMPLEMENTING MARINE REAL-WORLD LABS—A STEP TOWARDS REACHING THE OCEAN DECADE VISION

The vision of the Ocean Decade is, as noted at the start, 'the science we need for the ocean we want'. While the 'we' of the Ocean Decade statement can be read to homogenize society into an undifferentiated 'whole', which overlooks the differences people may have in what they 'want' the ocean to be (similar critiques are waged against the universalising tendencies of the Anthropocene as a concept, see Malhi, 2017; Yusoff, 2018), the statement could also be read conversely to be inclusive of all societies in its variegated richness. Indeed, the 'we' in the Ocean Decade vision relates to society not just to the subgroup of scientists usually producing ocean knowledge. In the spirit of engaging society, to find out what 'we want', real-world laboratories offer possibilities for being able to jointly formulate which science 'we need' for achieving what 'we want'. This iterative process between 'what we want' and 'what we can get'—in a real-world lab—can take place in various levels of society and space and hence allows us to consider spatially differentiated contexts and societal complexity. RwLs could occur in a small beach, a national jurisdiction of a certain country, or the high seas. This is what marine RwLs do—they are a potentially transformative ocean science tool to structure this iterative process, including the testing of new ways to achieve the 'ocean we want', which is necessarily a journey towards the unknown and therefore requires real-world experimentation. Marine RwLs can serve as a valuable framework for methodical guidance on how to co-develop this kind of transdisciplinary experimentation to derive sustainable ocean solutions within the scope of 'Decade Actions' and the Sustainable Development Goal 14 (SDG 14 'Life below Water'). In this regard, RwLs—attentive to the power of experimentation and to the pitfalls of participation and other socio-political challenges in marine research—may be a meaningful instrument for addressing the 'Decade Challenges' and hence reaching the 'Decade Outcomes' proposed in the Decade's implementation plan.

5.1 | The role of real-world labs in advancing ocean governance

To date, most marine management goals are static (Lambach, 2021; Peters, 2020) as they aim to achieve a certain status (e.g. the MSFD GES). However, the ocean and its ecosystems are changing constantly due to their spatial fluidity, spatial–temporal variability and environmental change (e.g. rapid turnover of biodiversity, adaptation etc.) which requires non-static, encompassing, inclusive and flexible governance that takes the dynamics of the marine realm—and the social realm—into account. While RwLs seem static (they rely on the demarcation and designation of space), they present a feasible opportunity to co-develop dynamic governance goals and frameworks due to their *cyclical* design (see Figure 2). The co-evaluation phase in particular allows for investigating their operationality and societal acceptance therefore putting research into practice. This meets the 'Decade Challenges' via ways that are acceptable/accepted by communities because they are directly involved in such developments.

Potentially one of the most interesting concepts for marine biodiversity management in RwLs is the concept of biodiversity enhancement, encompassing enhancement of species, food webs and habitats. This can involve the development and implementation of active intervention strategies to counteract anthropogenic pressures on marine ecosystems and hence slow down or prevent their further degeneration (Abelson et al., 2020). These strategies, such as the reduction of ocean plastic debris or mangrove reforestation, are often characterized by a lack of scientific knowledge transfer (Cormier-Salem & Panfili, 2016; Dharmawan et al., 2017; Rochman, 2016). Other proposed intervention strategies, such as improving coral reef resilience through assisted evolution, are facing moral and ethical concerns (Anthony et al., 2017; van Oppen et al., 2015). Given that active interventions are controversial, starting a societal dialogue on what is preferred, what is feasible, and what are the associated risks and benefits is crucial. For carrying this out, RwLs provide a suitable framework and therefore can help to work towards societal consensus by providing a democratic communication backdrop between interested parties leading to the co-development of novel governance strategies.

Altogether, RwLs hold potential to grapple with the qualities, forms and temporalities of the ocean that typically make governance approaches slippery (Steinberg & Peters, 2015). This is because a RwL creates *space* for *participatory* knowledge that allows in-depth and prolonged engagement with certain areas and stakeholders improving ocean stewardship. Ultimately, 'better' governance can arise through increased understanding of the linkages between society and areas of the sea. Certainly, many of the societal challenges associated with the ocean are large-scale and global ocean solutions require international governance. However, a prerequisite for finding wide-ranging solutions is achieving sustainable transformations on a local level hence RwLs can be part of the basis to develop global transformative pathways.

5.2 | Real-world labs as an opportunity to develop a more sustainable blue economy

Transformative change argues for a systemic paradigm shift: from 'blue growth' to a 'sustainable blue economy'. For this shift to happen, economic activities in coastal and marine areas, that have largely increased in the last decades and which are planned to be expanded even further, need to reduce their cumulative impacts on the marine environment. Value chains need to transform themselves to contribute to a circular economy, net-zero carbon emission, zero pollution, coastal resilience and sustainable food systems (Krause et al., 2022). This attends particularly to the 'Decade Challenges' of 'developing a sustainable and equitable ocean economy' and 'changing humanity's relationship with the ocean' (UNESCO-IOC, 2021). Under this lens, transdisciplinary research including cross-sector stakeholder involvement ensures that the multiple economic and social dimensions are brought together in a complementary or even reinforcing manner (Silver et al., 2015). The analysis of historical fisheries or aquaculture case-studies, for example, highlight the diversity of values and needs that different stakeholder groups may have. However, current blue growth agendas do not explicitly consider this diversity (Caswell et al., 2020). Caswell and co-authors describe 'that when the desires of only a subset of stakeholders are considered, short-term ambitions may be prioritized over long-term sustainability, and the perspectives and needs of the weakest stakeholders may be overlooked' (Caswell et al., 2020). To overcome these barriers and ensure justice and equity, the RwL approach could be particularly helpful especially to ensure a continuous knowledge exchange between scientists, fishers and governmental authorities managing fish stocks. Furthermore, RwLs provide a basis for prototype testing and validating new marine technologies and services in real-life environments as they involve Public-Private-People Partnerships in the co-creation process (Engel et al., 2020). They are also one of the most recent forms of open innovation networks integrating multiple concepts such as the transition to low-carbon economies (Evans & Karvonen, 2014). Consequently, marine RwLs provide a possible tool towards solving potential multi-use conflicts and sustainable blue economy pathways. The latter shares the idea that multifaceted economic activities and growth are not per se antithetical to ecological conservation but can be supplementary to one another (Boonstra et al., 2018).

6 | CONCLUSION

Initiatives such as the Ocean Decade may have transformative potential. However, as we have noted in this paper, transformation must be *just* (following Blythe et al., 2018) and part of this is only possible through participation. Although this is challenging to achieve, thoughtful scientific research approaches at the interface of science and society with the overall goal of real-world problem solving may be key to overcome the 'Decade Challenges' and to achieve the proposed 'Decade Outcomes'. Real-world labs are an experimental transdisciplinary research method that fulfils these criteria but are rarely implemented in the marine context. RwLs provide a tangible framework for building science-policy-practice interactions in situ thereby fostering the exchange of existing knowledge as well as the co-development of transformation knowledge and holistic marine solutions ready for implementation. More specifically, within the scope of 'Decade Actions', RwLs can act as a way of exploring and testing potential future strategies and options through *joint experimentation* leading to interventions towards much-needed change over the coming years of the Ocean Decade and beyond. RwLs transform both research and decision-making processes. Both aspects are crucial when dealing with complex challenges like advancing marine governance and sustainable blue economy strategies. Developing marine RwLs requires tailoring the respective design, time schedule and budgeting of transdisciplinary research projects to ensure a long-lasting and meaningful co-identification of possible pathways towards sustainable futures. Taken together, RwLs represent a valuable tool for the Ocean Decade mission of catalysing 'transformative ocean science solutions for sustainable development, connecting people and our ocean'.

AUTHOR CONTRIBUTIONS

The idea for this manuscript was originally developed by Helmut Hillebrand and Andrea Franke; Andrea Franke led the writing of the manuscript; Andrea Franke, Kimberley Peters and Jochen Hinkel significantly contributed to drafting the outline. All authors contributed to writing and revising the manuscript and gave final approval for its publication.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

This manuscript does not include any data.

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