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Perspective

Operationalizing Ocean Health: Toward Integrated Research on Ocean Health and Recovery to Achieve Ocean Sustainability

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https://doi.org/10.1016/j.oneear.2020.05.013

Protecting the ocean has become a major goal of international policy as human activities increasingly endanger the integrity of the ocean ecosystem, often summarized as "ocean health." By and large, efforts to protect the ocean have failed because, among other things, (1) the underlying socio-ecological pathways have not been properly considered, and (2) the concept of ocean health has been ill defined. Collectively, this prevents an adequate societal response as to how ocean ecosystems and their vital functions for human societies can be protected and restored. We review the confusion surrounding the term "ocean health" and suggest an operational ocean-health framework in line with the concept of strong sustainability. Given the accelerating degeneration of marine ecosystems, the restoration of regional ocean health will be of increasing importance. Our advocated transdisciplinary and multi-actor framework can help to advance the implementation of more active measures to restore ocean health and safeguard human health and well-being.

Introduction

Humans have interacted with the ocean since prehistoric times.[1] The ocean supplies us with essential resources such as food and energy, it is a platform for transport and trading, and most importantly, it plays a key role in securing human health and well-being, including employment and recreation.[2,3] However, the way we build our economy, our rapidly growing world population, and our unsustainable development and consumption patterns all place increasing pressures on the marine environment, e.g., through overfishing, eutrophication, and rising greenhouse gas emissions, driving ocean warming and acidification[4–6] (Figure 1). As a consequence, marine ecosystems are experiencing severe losses,[7] and basic ecosystem functions are at risk.[8,9]

Calling for a more sustainable use of our planet, the United Nations (UN) 2030 Agenda for Sustainable Development with its 17 Sustainable Development Goals (SDGs) came into action in 2015. SDG 14 (Life below Water) aims to "conserve and sustainably use the oceans, seas and marine resources for sustainable development." Among the targets are to "sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans" by 2020 and to "increase scientific knowledge … in order to improve ocean health." Yet the question of how to operationalize these targets remains open.[11] Furthermore, the UN has proclaimed the "Decade of Ocean Science for Sustainable Development" and the "Decade on Ecosystem Restoration" (both 2021–2030) to support "efforts to reverse the cycle of decline in ocean health and gather ocean stakeholders worldwide" and the "momentum for restoring our natural environment" by emphasizing that "adaptation strategies and science-informed policy responses to global change are urgently needed." The call to implement extensive actions to restore ocean health has recently been substantiated by various scientists.[12,13]

Even though plenty of scientific descriptions of ocean and ecosystem health exist,[14–16] agreeing on a common definition, let alone an operational framework for assessing ocean health,

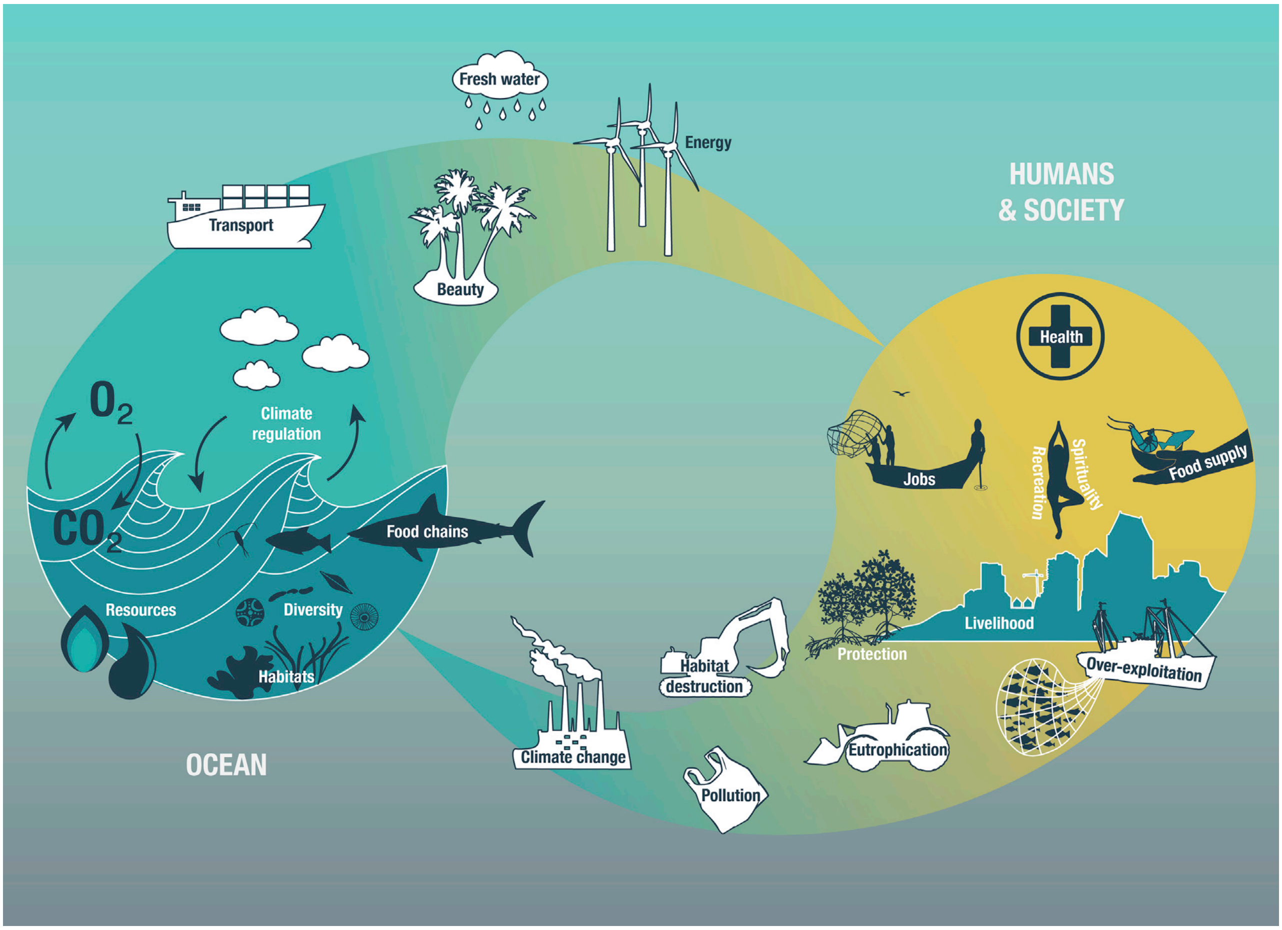


Figure 1. Interdependence Between the Ocean and Humankind
The ocean and human societies are strongly interconnected. Humans benefit from numerous services provided by the ocean; hence, human health, well-being, and wealth strongly depend on a healthy ocean. However, various human activities have adverse impacts on the marine environment, calling for a more sustainable use of the ocean (inspired by Ocean Atlas[10]).

continues to be a challenging task.[17–19] Therefore, it is essential to not only add another definition but also conceptualize the metaphorical term "ocean health" in order to adequately address the question of how we can assess, secure, and improve ocean health and the associated benefits for human health and well-being.

Moreover, SDG 14 requires that pressures and degradation be reversed; hence, merely sustaining and conserving the current state is no longer an acceptable goal. The ambition cannot be to avoid trespassing beyond planetary boundaries,[20,21] defined as "boundaries for anthropogenic perturbation of critical Earth-system processes [that delineate] the risk that anthropogenic activities could inadvertently drive the Earth system to a much less hospitable state."[20] The goal should be to maintain a healthy planet[22] and an ocean that can support the abundance and diversity of (marine) life, delivers a wealth of ecosystem services and benefits, and supports human health and well-being within planetary and ocean boundaries.[23]

The most widely used measure for ocean health, the Ocean Health Index (OHI),[24] evaluates progress toward a suite of key societal goals representing the benefits and services people expect a healthy ocean to provide. Whereas the OHI has been widely used and found to be useful for the purpose it was designed for, there is scope to provide more encompassing metrics of ocean health to emphasize that people value nature for ethical and aesthetic reasons given that nature has its own intrinsic value.[25,26] Yet, current frameworks only partially capture the broader social components of our interrelation with the ocean. Addressing this interrelation adequately requires a profound, holistic understanding of marine ecosystems and their complex interdependencies with human societies. This, in turn, calls for an integration of human health and well-being, environmental ethics, ocean governance, and the natural and social sciences in a more encompassing framework of ocean health.

Because an arbitrary definition of ocean health will not solve the problem,[18] we stand in need of a theoretically informed ocean-health conceptualization that (1) integrates normative values and goals and (2) addresses open epistemic pathways for the operationalization of a broader ocean-health framework considering the ocean as a social-ecological system.

In order to find feasible solutions that counteract the ongoing degradation of the ocean, we need a clear ocean-health concept (beyond a mere ocean-health definition) to develop an operational ocean-health framework.

We advocate for a truly transdisciplinary and cross-sector research approach that integrates not only different scientific disciplines from both natural and social sciences but also civil society, marine workers and industries, governments, non-governmental organizations (NGOs), and local and indigenous communities: all those who interact with the ocean and also contribute to formulating the collective aspiration for a healthy ocean. Moreover, rapidly advancing pressures, feedback mechanisms, and lags in ecosystem recovery require the consideration of potentially controversial strategies such as active ecosystem intervention to restore ocean health.[27]

The purpose of this Perspective is to highlight the need to (1) provide a conceptual and simultaneously operational ocean-health framework that integrates the links between ocean and human health and (2) address potential solutions and obstacles to sustain and restore a healthy and productive ocean for future generations through advancing approaches for a broad transdisciplinary integration of marine sciences.

Ocean Health: The Need for Operationalization

Securing a healthy marine environment recently became a priority of (inter)national political agendas (e.g., UN SDG 14) given that most actors agree that the key to sustaining the ocean's productivity and its benefits to humankind is to keep the marine realm in a healthy condition. Although the term "ocean health" is widely used by different stakeholders (ranging from the general public to scientists, politicians, and NGOs), its specific meaning can differ considerably among these actors.[17] This can lead to misunderstandings, ultimately hampering effective actions to secure and maintain marine ecosystem functioning and services.

So far, there has been no consensus on a universal ocean-health definition, which is crucially needed for sustainable ocean development. This does not come as a surprise because ocean health can be regarded as a metaphor.[28] According to common "health" definitions, the concept of health applies to organisms and not to ecosystems, let alone the vast entity we name "ocean," because they can be neither completely healthy nor sick. Hence, we follow the "classical" criticism[29] and wish to avoid all Clementsian suggestions of ecosystems as "superorganisms." Critical arguments against the literal understanding of ecosystem health were discussed in the 1995 Special Issue in Environmental Values. It was argued that "ecosystem health" is a metaphorical and hybrid concept composed of facts and values.[30–32] Hence, we see the metaphor "ocean health" as a pre-analytic vision of the state of the ocean as being "good." This state of goodness must be specified, scientifically and ethically, and should be reached through ocean governance integrating empirical and normative aspects.

Several comprehensive tools for evaluating ocean health have been developed over the years.[14,33] Yet, efforts to examine the complex links between ocean and human health are still rare, and approaches to integrating human aspects beyond livelihoods and jobs (i.e., health and well-being) into ocean-health definitions and assessments are often missing. A well-known assessment tool is the OHI, which measures progress toward a suite of key societal goals representing the benefits and services people expect healthy oceans to provide, e.g., food provision, carbon storage, and biodiversity.[24,34] However, the OHI is based on the weak sustainability concept,[35] and because SDG 14 is implicitly based on the concept of strong sustainability,[36] the OHI framework can be further refined.

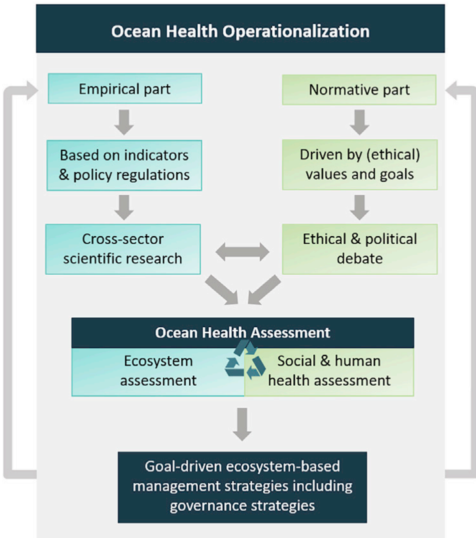
The debate between the two competing concepts of weak and strong sustainability refers to the issue of whether stocks and funds of natural capital can be substituted with human capital. Proponents of "weak sustainability" assume a high degree of substitutability between capital stocks. Proponents of "strong sustainability" claim that the decisive features of natural capital, including the flow of ecosystem services that they provide, limit the degree of its substitutability[37] because natural capital is essential for human welfare. Thus, the concept of strong sustainability adopts a "constant natural capital rule," which makes the preservation and restoration of natural capital stocks mandatory at different scales.[38] The concepts of the "safe minimum standard" and the "precautionary principle" support a reasonable decision in favor of strong sustainability.[39] Recent assessments of the ocean's contributions to human well-being and climate-change mitigation[40] are perfectly in line with strong sustainability.

Our aim is to provide both a conceptual and an operational framework for evaluating ocean health by integrating ethical values, human health and well-being, and traditional marine ecosystem services. This will ultimately enable us to inform policymakers and give reality- and evidence-based advice for integrated ecosystem-based management (EBM, including specific targets) to enable recovery of degraded marine ecosystems to sustain a healthy ocean (according to SDG 14).

Accordingly, we propose following Neumann et al.,[36] who interpret the ocean-health metaphor as analogous to the famous idea of health in Aldo Leopold's principle for an ecologically inspired "land ethic." Leopold argues that all actions affecting land-use systems should respect the "stability, integrity, and beauty" of land.[41] This principle can be expanded to marine systems. Thus, we propose a conceptual update and reframing for ocean health by translating (1) stability into resilience, (2) integrity into productivity, and (3) beauty into diversity. Given this interpretation, we define the ocean as "healthy" if and only if it is resilient, productive, and diverse.

This conceptual definition attempts to bridge the gap between the pre-analytical and holistic "ocean-health" metaphor and the descriptors, criteria, and indicators used in the EU Marine Strategy Framework Directive (MSFD) to specify a "good environmental status" (GES) of marine waters (for further details on GES, see Borja et al.[42]). Resilience, productivity, and diversity are the essential requirements for a good status and serve as focal points for an integrated assessment of marine systems, correlating services and societal values. Therefore, they connect the metaphor "ocean health" to both ecological science and environmental ethics without falling prey to a naturalistic fallacy confusing facts and values. This allows us to open routes for specification and quantification on the side of marine sciences as well as disputes about ocean governance on the side of policy making.

Our definition of ocean health is in accordance with the concept of strong sustainability discussed above,[36] i.e., that the economic, social, and environmental capital are complementary, but not interchangeable, and can be applied to different parts of the ocean. As a scientific concept, it fulfills the requirement to allow an operationalization given that resilience, productivity, and



The 7-Step Ocean Health Management Framework		
I	**Normative values & goals**	Integrating normative values and goals is crucial and linked to ethical and political debates. They are defined as specific targets, obligations and thresholds.
II	**Indicator-based empirical measurements**	Set of socio-ecological, operational ocean health and human health indicators (incl. thresholds) complementing each other and suitable for the given boundaries.
III	**Diagnostic tools and communication**	Transparent, open-access ecosystem monitoring and assessment tools; ethical and political dialogue towards consensus building.
IV	**Ocean health assessment**	Holistic understanding of ocean ecosystems and their complex interdependencies with human societies.
IV a	**Social & human health assessments**	Qualitative social and biomedical research on public health, human health and well-being, resiliency, policies, power structures, and human-ocean and coastal use practices.
IV b	**Ecosystem assessment**	Long-term data series of basic environmental variables and other indicators or proxies for key ecosystem components and processes.
V	**Ecosystem-based management strategies**	Holicstic set of targeted empiric and normative measures for ocean health management; consider active intervention as management approaches.
VI	**Governance strategies**	Evaluate governance architecture, identify potential governance strategies and implement EBM plans into political agendas.
VII	**Continuous adaptation**	Steps (I) to (VI) have to be continuously adapted in response to environmental and societal changes.

Figure 2. Operational Ocean-Health Management Framework
The proposed operational ocean-health management framework is based on a holistic socio-ecological, as well as strong sustainability, concept. The framework integrates both empirical and normative aspects into ecosystem-based management and considers different epistemologies and ontologies.

diversity can be measured either directly or via indicators. Measures for ecological productivity and diversity are, however, more advanced than for resilience. We define the concept of "resilience" as the ability of ecosystems to recover from perturbations and to return to a former trajectory rather than to a specific referential state.[43] If a trajectory is taken as a point of reference, resilience has no single direct measure. At a high theoretical level, Niesen et al.[43] propose measuring resilience in terms of pattern complexity, supporting response to disturbances.

In order to assess ocean health according to our definition, we argue that a holistic socio-ecological framework that encompasses not only empirical but also normative and political aspects is needed (Figure 2).

For a sound empirical foundation, scientific observations and the acquisition of local and global data are essential. These data should comprise operational indicators that can serve as proxies for the state of marine ecosystems (i.e., resilience, productivity, and diversity). Moreover, social-science-based assessments of the policies, values of stakeholders, and power structures (as well as ocean and coastal use practices influencing ocean health) are required, and these could help us to understand anthropogenic drivers of ecosystem change.

The normative part involves ethical and political debates for identifying a common moral ground, value judgments, and finally, specific goals. The specification of common values could reduce the current institutional fragmentation of existing ocean-health governance and inter-sectoral contestations. The value of resilience is a kind of insurance because a resilient ecosystem has the ability to recover from disturbances and therefore remains functional into the future.[44] The value of productivity can be evaluated in terms of providing and regulating ecosystem services. With respect to diversity, one can rely on the Convention on Biological Diversity (CBD),[45] which identifies different values of biodiversity, and furthermore on environmental ethics, which has contributed to biodiversity ethics.[46,47]

In general, normative values must be specified. International law can be supportive in this regard: the interpretation and implementation of the CBD by states, and their subsequent practice, are, for example, mechanisms for achieving the specification of normative values. Here, we propose an analogy to natural science: just as concepts must be open for quantitative measurements as well as for qualitative evaluations, normative values must be open for specification in terms of targets, obligations, and thresholds. Moreover, in order to be applicable in different world regions and at multiple scales, they should be able to incorporate knowledge on the basis of different ontological and epistemological assumptions. This means that the law can no longer be static; rather, it should encourage and enable adaptive management. A normative UN SDG 14 target, for example, is to "conserve at least 10% of coastal and marine areas" by 2020, whereas the concept of planetary boundaries is an example of normative thresholds.[20]

Hence, an integrated ocean-health assessment, including empirical and normative parts, would be the ideal basis for adaptive EBM strategies (such as DAPSI(W)R(M); see Elliot et al.[48]) given that it takes both specific environmental conditions and regionally differing values into account (Figure 2, left). To evaluate and regain ocean health, our operational ocean-health management framework (further developed after Harvey et al.[49] and Levin et al.[50]) encompasses seven steps, as illustrated to the right of Figure 2.

The last step of continuous adaptation is crucial because marine ecosystems and their use are constantly changing, which requires flexible management strategies and sound stewardship.[50] An integrated approach is needed to ensure that the different SMART (specific, measurable, achievable, realistic, and time bound) and hence operational indicators can be evaluated in relation to each other, thus allowing the determination of realistic threshold values.[11] To systematically obtain quantitative and qualitative information about the health status of our ocean, regular and thorough monitoring and evaluation, such as long-term data series (including, e.g., temperature, oxygen, pH, and species composition), are essential.[51] Tools for determining the health of marine ecosystems by integrating data from various ecosystem components remain scarce.[23]

Because we are dealing with complex systems, the further development of models, software, statistical tools, and advanced data science methods (e.g., artificial intelligence and machine learning) is crucial for analyses of marine data. The development of transparent, open-access ecosystem monitoring and assessment tools, which include the interactions between the health of both ecosystems and humans, should be prioritized because they will enable us to identify and re-evaluate indicator thresholds. In particular, these tools will facilitate the process of evidence-based decision making because they will help reveal the inevitable trade-offs between human and ecosystem health during ocean-health assessments, which form the basis for EBM and governance strategies.

Future Research Perspectives to Restore Ocean Health

The proposed operational framework for ocean health (Figure 2) could form a basis for novel ocean governance that integrates normative and empirical values and the links between the ocean and human health. This, in turn, will provide the foundation for comprehensive efforts to establish socio-ecological pathways that help to sustain and restore healthy and productive marine ecosystems.

Mapping socio-ecological pathways that resolve the trade-offs between ocean use and the provision of ocean-derived benefits for future generations is one of the grand challenges of society. Providing solutions for the complex human-ocean system will require the crossing of disciplinary boundaries to facilitate a transition from multi- and interdisciplinary[52] to fully transdisciplinary and cross-sector[53] work, which is key to identifying research priorities for achieving ocean health and sustainability.[54]

Insights from "transition research" could be helpful in analyzing how we could move to a new paradigm of treating ocean health more holistically through research, governance, and technological innovations toward an integrated cross-sector implementation. Given the large number of actors and stakeholders as well as existing path dependencies, moving to a new paradigm might not be achieved by small or incremental changes within the existing regime of our socio-ecological system. Instead, it will most likely need more comprehensive, potentially non-linear transitory processes to reach a new dynamic equilibrium. Such non-linearities are inherent to large-scale disruptive changes studied by transition research.[55]

The starting point of many transition discourses within social science and outside the academic community is "the notion that the contemporary ecological and social crises are inseparable from the model of social life that has become dominant over the past few centuries."[56] In particular, research in the field of sustainability transitions describes that large-scale disruptive societal changes might be necessary for solving major societal challenges over longer time horizons.[55] Important questions for a step forward are those raised by Braun:[57] "... from where, by whom, and in what ways transformations towards a just and livable planet should be generated."

Only over time do new developments and innovations prove to be successful (or not) and form a part of the new equilibrium (or not). Actual change is more likely to occur as more actors from different fields and institutions join and work together to foster change. Consequently, it is even more important to accompany and politicize the transition with in-depth research focusing on the societal root causes of environmental change and not only on symptoms such as habitat loss[58] and to develop suitable and socially just governance schemes and participatory decision-making processes.

Transition research and transformative politics are per se highly uncertain fields. In this context, experimental approaches are gaining ground in the sciences.[59] This can include ecosystem restoration and governance experiments, as well as bottom-up attempts that pursue alternatives to our current development models.[56] Additional lessons might be learned from biosphere reserves and the Man and Biosphere Programme. Biosphere reserves have been developed as networked sites for mutual learning for a transformation toward sustainability.[60] Many of the biosphere reserves existed on paper only ("paper parks"); however, recent large-scale comparative studies have shown that successful reserves are those that have included all relevant stakeholders, had sufficient financial resources, and had clear governance structures.[61]

For such participatory processes that account for the interrelationship between marine ecosystem health and human health and well-being, different stakeholders representing societal actors, public health experts, representatives of various scientific disciplines, policymakers, NGOs, industrial partners, and indigenous people need to be involved in pushing the transition toward a more sustainable use, framing transdisciplinary research questions, and implementing solutions. Newton and Elliot[62] provide a typology of marine stakeholders based on the Driver-Pressure-State-Impact-Response Framework, and this could be beneficial for designing participatory processes. It includes six stakeholder types (extractors, inputters, beneficiaries, affectees, regulators, and influencers) and suggests the weighting of actors according to their relevance for the solution of a specific environmental problem or conflict.

A transdisciplinary and multi-actor framework is also indispensable for the implementation of more active measures to restore ecosystem health.[63] The ongoing and still accelerating degeneration of marine ecosystems not only requires the reduction of anthropogenic pressures but also necessitates active intervention strategies that need a societal consensus given that they are often controversial and elicit moral and ethical concerns.

A case in point is current attempts by coral reef ecologists to move conservation efforts to the next phase by implementing "assisted evolution" approaches.[64] A number of methods—ranging from maintaining the genetic potential of resident populations (which is probably uncontroversial) to the selective breeding of corals to the genetic editing of coral genotypes in order to make them more resilient to thermal stress—have been proposed. Proponents of more controversial conservation measures substantiate their willingness to release genetically engineered coral species into the wild with the enormous costs of losing vast coral reef areas permanently through recurrent bleaching events.[64,65]

This example illustrates that a societal dialogue is a key ingredient in formulating societal consensus as to which risks and trade-offs involved in coastal management and conservation should be allowed. At the same time, the example highlights the necessity to include environmental ethicists in these discussions and research. Ethicists have reflected upon the values implied within ecological restoration, and they can shed light on conflicts likely to arise from active interference in marine systems.

Other active interventions in marine ecosystems to counteract anthropogenic impacts have little or no scientific basis, consultation, or formal evaluation (e.g., various attempts to remove plastics from the ocean[66]) but often garner huge public attention. Although there are examples of successful active ecosystem intervention, such as large-scale mangrove reforestation,[67] many more have been suggested but not implemented. Reasons for withholding implementation range from scientific uncertainties (e.g., in large-scale ocean fertilization) to public resistance (e.g., artificial evolution) to a lack of funding.

Although active ecosystem intervention and restoration backed by scientific evidence is rather new in marine systems (successful examples are primarily limited to estuaries and coastal systems), it is in the standard conservation toolbox of terrestrial ecologists.[68] One reason why the (open) ocean is lagging behind is possibly that the scale of marine ecosystems and their connectivity challenge the transfer of existing terrestrial ecosystem restoration strategies into the marine environment. There could also be a perception that most of the ocean is still wilderness, which has recently been thoroughly refuted.[69] The conceptual knowledge transfer of terrestrial restoration strategies is an immediate and easy-to-realize focus of future ocean conservation research. For example, in anticipation of climate change, reforestation with appropriate tree seedling genotypes is commonplace (but sometimes controversial) in terrestrial forestry, whereas analogous practices are absent and controversial in marine systems, where climate velocities are even faster than on land.[70]

Another important issue is a change in the mindset of the scientific community, which often hesitates to implement solutions while documenting and investigating the deterioration of marine ecosystems in detail. Advancing the co-design of research questions with diverse stakeholders will help to define goals of restorative and active intervention and develop appropriate implementation measures. Practical experience is needed for learning how to successfully operationalize and implement ocean management strategies that integrate environmental, social, cultural, health, and ethical aspects. Transdisciplinary, solution-oriented case studies (management experiments) integrating empirical and normative parts should thus be a future priority. This integrated strategy would allow us to address and potentially overcome conflicting societal interests and to identify common values.

Eventually, fostering transdisciplinary research and the co-design of research questions could establish new meta-disciplines that might serve as excellent communication tools for bringing together stakeholders, researchers, affected communities, and industrial partners. An excellent example is the meta-discipline "ocean and human health," which connects diverse scientific communities of the natural and social sciences with public health and biomedical sciences.[2,71]

Together, transdisciplinary and cross-sector approaches can interlink (1) the operationalization of ocean health, (2) active science-based ecosystem recovery strategies, and (3) the meta-discipline "ocean and human health" and therefore help to facilitate a sustainable use and management of the ocean (Figure 3).

To facilitate strong cooperation and better communication between all partners and knowledge systems, transdisciplinary training and new funding schemes—particularly those that account for different timescales, goals, and measures of success than those of current disciplinary projects—are crucially needed. Engaging the next generation will require a change in the present structure of mostly disciplinary-focused curricula, for example, through the establishment of more transdisciplinary master and PhD programs that teach students not only the language of multiple disciplines but also how to work solution oriented across disciplines and how to cooperate with different communities, stakeholders, and practitioners.[72]

Moreover, to address current and future security issues and prevent civil unrest, more research is needed in the areas of environmental ethics and ocean governance. Shortcomings of the existing ocean governance architecture—from the local to the global level—have been highlighted by numerous researchers.[12,73] Negative consequences of organizational fragmentation, particularly the primarily sectoral ordering, are institutional conflicts, increasing costs due to organizational duplications, competing claims of (spatial) authority, and overall inefficiency.[74–76]

However, more comprehensive governance initiatives, such as the 2007 Integrated Maritime Policy of the EU, have begun to emerge. Although their implementation has been shown to be challenging,[77,78] innovative elements such as maritime spatial planning, the ecosystem approach, and the ten tenets of sustainable management[79] still offer a considerable window of opportunity for more integrated political approaches of future ocean-health governance to improve the implementation of political solutions.

Conclusion

We show here that a refined definition of ocean health can overcome previous limitations of ocean-health concepts. Although our ocean-health framework integrates normative and empirical aspects aligned with the idea of "strong sustainability," we show that an operationalization is possible and highly warranted. At the same time, we emphasize and include the interdependencies and synergies of "health" concepts and issues among the human and ocean spheres. An improved ocean-health operationalization through an explicit definition of the associated attributes of resilience, productivity, and diversity will ultimately provide the foundation for more active measures that restore ocean health. If we are to achieve this, a societal consensus needs to be assured via a transdisciplinary and multi-actor framework to advance the overall policy goals encapsulated in SDG 14 (Life below Water) jointly with SDG 3 (Good Health and Well-Being).

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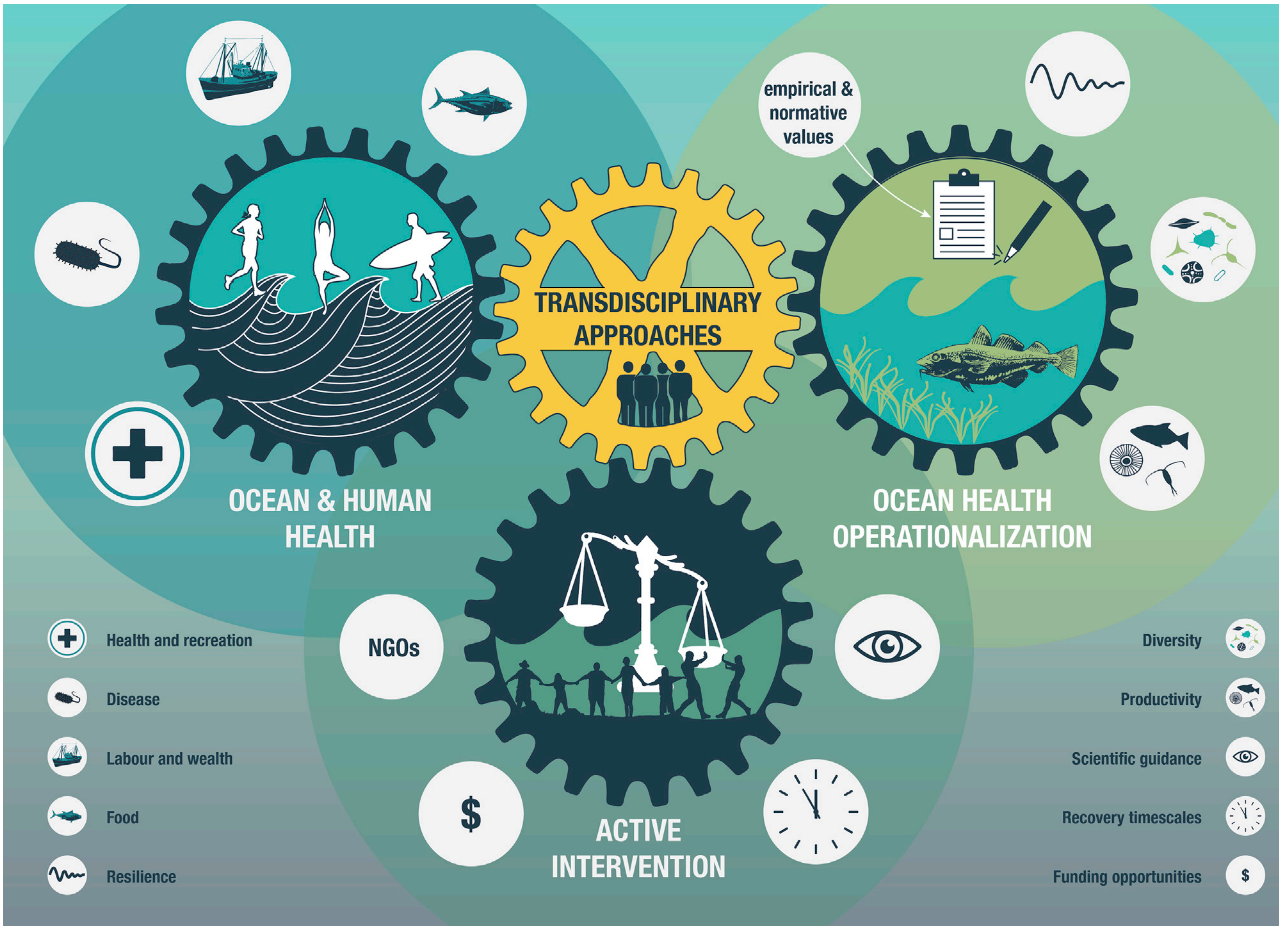

Figure 3. A Transdisciplinary Framework Integrating Ocean and Human Health and Ocean-Health and Recovery Research
The proposed framework interlinks the meta-discipline of ocean and human health, the operationalization of ocean health, and active science-based ecosystem recovery strategies through transdisciplinary, cross-sector approaches and stakeholder involvement and thus forms a basis to safeguard ocean sustainability and human well-being.

ACKNOWLEDGMENTS

This Perspective is based on the results of the workshop "Integrated Science for Future Ocean Health and Recovery," financed by the Cluster of Excellence "The Future Ocean." The workshop took place on June 7, 2018, in Kiel, Germany. The authors acknowledge the funding of travel grants and workshop organization by the Cluster of Excellence and especially the support of its speakers, Profs. Dr. Martin Visbeck, Dr. Ralph Schneider, and Dr. Nele Matz-Lück. Furthermore, the authors thank all participants of the workshop for their contributions and Susanne Landis (@scienstration) for the graphic design. L.E.F. acknowledges funding from the European Union's Horizon 2020 Research and Innovation Programme under grants 774567 (H2020 SOPHIE Project) and 666773 (H2020 BlueHealth Project) and from the UK's Global Challenges Research Fund via the United Kingdom Research and Innovation under grant NE/P021107/1 to the Blue Communities project. T.B. acknowledges funding from the European Union's Horizon 2020 Research and Innovation Programme under grant 820989 (project COMFORT, "Our common future ocean in the Earth system—quantifying coupled cycles of carbon, oxygen, and nutrients for determining and achieving safe operating spaces with respect to tipping points"). C.B. acknowledges funding from the Kiel Marine Science Centre for Interdisciplinary Marine Science at Kiel University. C.M.D. was funded by the King Abdullah University of Science and Technology.

AUTHOR CONTRIBUTIONS

A.F., E.P., and T.B. conceptualized the overall manuscript with expertise and feedback from all authors. A.F., E.P., K.O., L.E.F., and C.S. wrote the original draft. T.B., C.M.D., A.A., T.B.H.R., C.B., J.H., U.K.-G., J.D., A.K., E.v.D., M.W., M.S., R.K., L.C., and D.K. contributed to the writing and editing of the manuscript. All authors reviewed, edited, and approved the manuscript. A.E. and U.H. acquired the funding.

DECLARATION OF INTERESTS

C.M.D. serves as a member of the advisory board of the Red Sea Development Company.

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