OPINION

We need a global movement to transform ocean science for a better world

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The ocean is our planet's largest life-support system. It stabilizes climate; stores carbon; produces oxygen; nurtures biodiversity; directly supports human well-being through food, mineral, and energy resources; and provides cultural and recreational services. The value of the ocean economy speaks to its importance: The Organization for Economic Cooperation and Development (OECD) estimates that by 2030, $3 trillion USD will be generated annually from ocean sectors such as transportation, fishing, tourism, and energy (1). Unsustainable resource extraction, pollution, climate change, and habitat destruction are on the rise and affecting

Although improved ocean management and conservation have helped to reduce threats and restore some key ecosystems, the basic benefits that people receive from a healthy ocean are in overall decline. Image credit: © World Wildlife Fund (WWF-US)/James Morgan.

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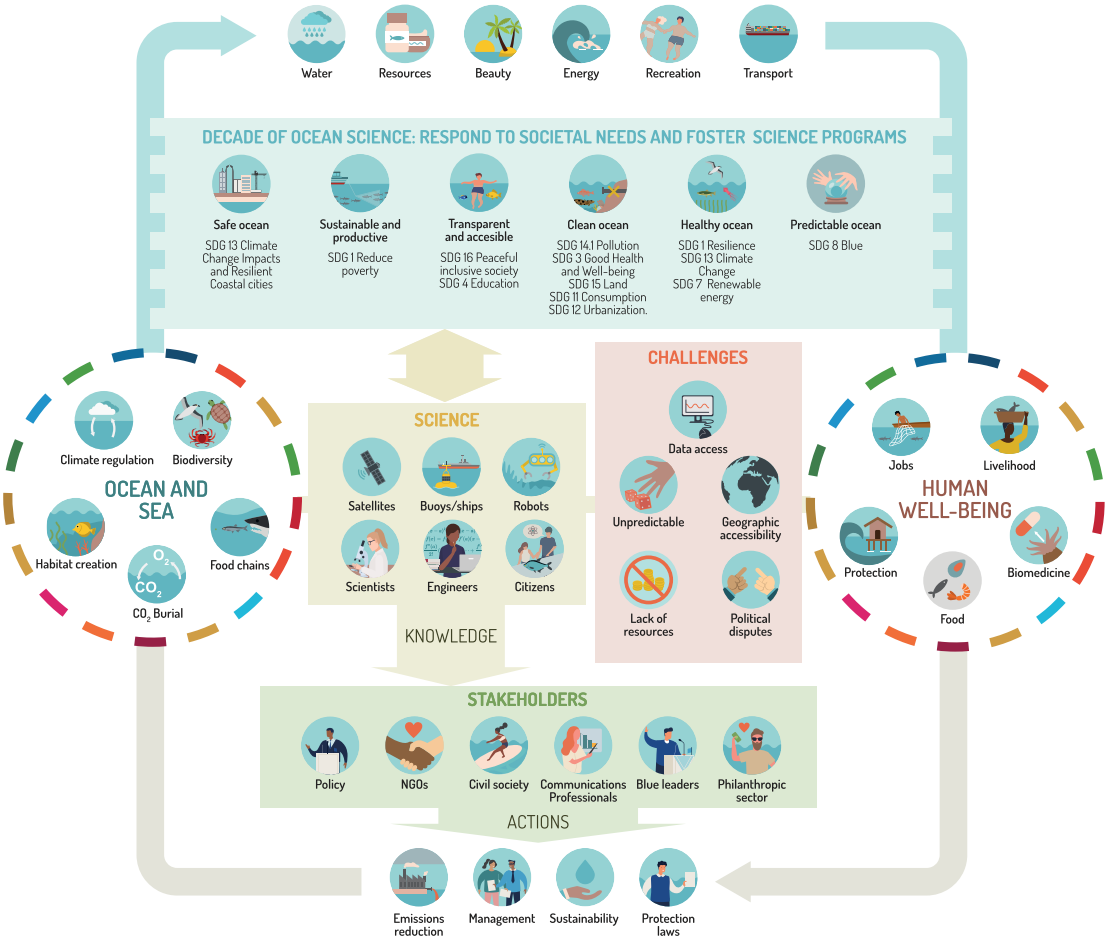

Fig. 1. The UN Decade of Ocean Science for Sustainable Development seeks to link stakeholders and researchers in hopes of catalyzing the science needed to improve ocean ecology function and human well-being. Image credit: Vanessa González-Ortiz (artist).

many parts of the world's oceans (2). The ocean is rapidly changing, and yet the ways in which these changes will play out are not yet clear.

Although improved management and conservation have helped to reduce threats and restore some key ecosystems, the basic benefits that people receive from a healthy ocean are in overall decline (3). If left unchecked, a growing and resource-hungry human population will add additional pressures on the ocean. Scientific research, experimentation, data collection, monitoring, and modeling provide the knowledge, frameworks, and evidence needed to model and explore the environmental consequences of policy and development proposals and thus to chart a sustainable future ocean.

The current scale, pace, and practice of ocean scientific discovery and observation are not keeping up with the changes in ocean and human conditions. We need fundamental changes in the way that researchers work with decision makers to co-create knowledge that will address pressing development problems. Researchers need to share their data more freely and sooner so that their work can inform decisions in near real time. Academia, government, and industry need to find new and better ways to collaborate and innovate. Huge gaps in scientific capacity and capability around the world will require that we fundamentally change the way we train and employ researchers from developing countries. Above all, we need to dramatically expand the breadth of disciplines that are directly involved in new transdisciplinary ocean research.

Accelerating Ocean Science

To catalyze this transformation, the United Nations (UN) General Assembly has called for a Decade of Ocean Science for Sustainable Development (2021–2030), "The Decade," to develop the frameworks and tools required for the sustainable development of the ocean. The aim of The Decade is to create a new movement for bringing together researchers and stakeholders from all relevant sectors to generate a new scientific process to inform policies that ensure a well-functioning, productive, resilient, and sustainable ocean (ref. 4; Fig. 1) and support the UN 2030 Agenda for Sustainable Development and associated Sustainable Development Goals (SDGs).

Roughly 40% of the world's population lives within 100 km of a coast (5). More than 600 million people currently live in low-elevation coastal zones, a number

that is expected to grow to more than a billion by 2050 (6). These coastal seas are hotspots of human–ocean interactions and are also regions where humans are at elevated risks from ocean threats (e.g., storm surges and tsunamis) and changes in the ocean conditions (e.g., sea level rise and associated coastal erosion). A sustainable coastal ocean requires an improved capacity to measure and monitor the ocean, its health, and function in coastal areas to assess the effectiveness of policy interventions, and create better forecasting and prediction to help stakeholders understand future ocean-related impacts on coastal communities, so they can better plan and regulate the human uses of coastal ecosystems.

Great progress has been made in describing, understanding, and enhancing our ability to predict changes in the ocean system (e.g., 7.). Satellites and globally operating platforms have dramatically increased our ability to measure and monitor ocean conditions (8, 9). However, we often still lack the ability to quickly get these data into the hands of decision makers in a way that is relevant and can help them sustainably manage human uses and impacts in the vast and rapidly changing global ocean.

Technical and logistical constraints, government policies, global scientific capacity and capability, lack of effective knowledge sharing, geopolitical disputes, and ongoing military conflict challenge our ability to collect and share in situ data in some parts of the world, resulting in many geographic gaps in observations. For example, measurements of ocean conditions (e.g., ocean acidity, nitrification, ecological health) are notably scarce in the Coral Triangle region of the western Pacific Ocean, the South China Sea, and coastal East Africa, all areas of high significance for potential coral reef refugia (10). These are also places where meeting the UN 2030 Agenda and associated SDGs will be critically important for growing populations, but at the same time highly challenging (11).

Many aspects of the subsurface ocean, including basic oceanographic conditions and biodiversity, are still not fully understood, including in the polar regions, the seabed, and many high seas and deep seas areas and their underlying seabeds. These resource-rich areas are the subject of rapidly developing international policy, including new treaties for the management of the high seas, new leases for seafloor mining, and proposed measures to protect biodiversity in the areas beyond national jurisdiction, that needs to be informed by good ocean knowledge, data, and science. Until these vast areas are better understood and characterized, exploitation of mineral and energy resources and efforts to manage fisheries and ocean industries will neither be properly informed nor effective in reducing impacts and risks associated with these potentially threatening uses (12, 13).

The full spectrum of benefits that humans receive from a well-functioning ocean are still poorly understood. As a result, researchers know little about the significance of biodiversity and habitat changes or loss, about whether we're approaching key tipping points, or about whether responses to ocean disasters are timely and effective.

A lack of access about ocean health data, over time, limits what we can glean about how the ocean has responded to past human pressures such as fishing, shipping, mining, and coastal agriculture and development, as well as the longer-term consequences for future sustainability. Many relevant data streams from long-term ecological research and local monitoring programs, even those made public, may not be easily found, accessed, or interpreted. Private data streams from businesses and industry—for example, those used to route ships and exploit marine resources—are never shared publicly (14, 15). The joint Academies of Sciences of the G20 countries have highlighted the need to better coordinate and integrate the collection, management, analysis, and sharing of these interdisciplinary data streams and associated knowledge that comes from the analysis of these data (15). Better means of sharing and accessing data would improve our ability to conduct interdisciplinary science on regional and global scales. Only a concerted global effort can align the many existing data networks to facilitate sustainable development.

Catalyzing Ocean Science

To nurture the ocean science needed for sustainable development, we believe that the next generation of ocean science will need to improve how we:

1. Identify and routinely measure essential variables related to the climate, ocean processes and socio-ecological systems that can serve as sentinels of ocean health,
2. In association with industry, develop new and low-cost technologies, including new sensors and new methodological approaches, to measure and monitor these ocean variables,
3. Establish new public-private partnerships in ocean observing, data distribution, and information product delivery between science, engineering, and information technology communities, and
4. Develop new tracking and prediction capacities to support integrated, multi-hazard, early warning systems, improved community preparedness, and awareness.
5. Establish innovative ways to share data, information, and knowledge amongst all stakeholders in an open, transparent, and equitable manner.
6. Advance efforts to build a "digital twin ocean" to explore, discover, and visualize current and future oceans.
7. Build science capacity and capability through new ways of training, mobilizing resources, sharing of infrastructure, and exchanging of experts and knowledge across, nations, institutions, and disciplines.

To achieve these changes, researchers need to embrace "whole earth" approaches to ocean observation, analysis, and modeling that include all relevant disciplines and people from the start to allow communities to better account and plan for the complex

and often nonlinear processes that drive ocean systems and the many pressures impacting them.

Large portions of the public are aware that pressures such as overfishing and pollution have a major impact on the ocean. But few understand the functioning of the ocean, the services it provides, or how their day-to-day activities might be impacting the ocean (16; e.g., 17). We as researchers must simplify the language we use to more clearly and openly communicate complex ocean science and sustainable development issues across cultures and languages. Researchers must actively target future generations and take into consideration the emerging technology and digital platforms used to communicate. Finally, researchers need new media allies to reach out to new communities by partnering with personalities from the business or entertainment world.

A New Era for Ocean Science

The UN Decade of Ocean Science for Sustainable Development has already embarked on a new stakeholder process that will be inclusive, participatory, and global in its approach to plan, implement, and deliver the science required for meeting the SDGs. To succeed, this process will require fundamentally new ways of bringing all ocean stakeholders together so that parties with a vested interest, from small-scale indigenous fishers to large-scale corporate leaders, can participate in a solutions-focused scientific process for generating new ocean knowledge.

Whether The Decade can achieve a transformation in ocean science will depend on the joint efforts of researchers, engineers, and scholars from all disciplines working in close collaboration with stakeholders from all sectors of the community. Although The Decade does not formally begin until 2021, the time is now for all stakeholders, including researchers, to come together to develop and sponsor these transformative events, propose new projects and partnerships, and to be part of new global community of ocean science for sustainable development. We encourage all of our colleagues to join this community at http://www.oceandecade.org, to begin to build new relationships with nonscience stakeholders, and to embrace a new era of innovation, data sharing, and scientific cocreation.

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