FEATURE

Marine pollutants and contaminants

Michael Elliott explores marine problems, solutions and the role of the UN Decade of Ocean Science for Sustainable Development.

'The Decade aims to catalyse the human behaviour change required for the successful implementation of these solutions. Guided by the United Nations Convention on the Law of the Sea (UNCLOS), the Decade will generate the data, information and knowledge needed for more robust science-informed policies and stronger science-policy interfaces at global, regional, national and even local levels, leading to improved integrated ocean management and development of a sustainable ocean economy.'[1]

The greatest challenge of the UN Decade of Ocean Science for Sustainable Development is to enable science to help create: 'clean, healthy, safe, productive, biologically diverse marine and coastal environments, managed to meet the long-term needs of people and nature'.[2] This article considers the scale of the problem to be tackled by the Ocean Decade with regard to contamination and pollution as indicated in the first of its 10 challenges: understanding and mapping land and sea-based sources of pollutants and contaminants and their potential impacts on human health and ocean ecosystems. Challenge 1 then leads to Outcome 1: 'a clean ocean where sources of pollution are identified and reduced or removed'. Most importantly, both the natural and social sciences are required in order to address this Challenge and deliver this Outcome.

The Ocean Decade should promote science to tackle the one big challenge facing our oceans: 'how to protect and maintain the marine ecology while at the same time enable the oceans to create the ecosystem services which can be used to provide the goods and benefits required by society'[3] – i.e. the sustainability in the Ocean Decade's full title. For example, suitable waves, tides, sediments, etc. will create the right conditions for

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▲ Figure 1. Industrial discharge from a petrochemical plant. (© Mike Elliott)

the marine microbes, plants, invertebrates and higher animals. These physical and biological structures and processes can then ensure the oceans provide ecosystem services, such as sustainable populations, recycling and storing carbon and nutrients and pleasant seascapes, to name but a few. Following this, human capital and complementary assets (money, energy, skills and time) can then be used to obtain societal goods and benefits (for food, recreation, clean air and water, etc.).[4]

MARINE CONTAMINATION AND POLLUTION

It is important to distinguish between contamination, which is the presence of a human-derived material in the environment, and pollution, which is the biological effect of those contaminants which, if unchecked, will reduce the health of one or more levels of biological organisation, from the cell to the ecosystem. There are various types of contaminants and pollutants – materials, which can be 'large' or small solids, dissolved substances or energy. They can be 'unnatural' materials, such as synthetic chemicals, for which organisms have not evolved coping mechanisms, or they can be 'natural' materials in 'unnatural quantities' that exceed the assimilative capacity of the oceans to be stored, sequestered, detoxified or degraded.

Classically, pollution concerns have focused on microorganisms (e.g. from sewage) and agro- and industrial chemicals (**Figure 1**), such as heavy metals, organohalogens, radionuclides and phosphate compounds. However, increasingly they include macro- and microplastics (**Figure 2**), sediment (from erosion or seabed disturbance), gases (CO_2), energy (light, noise and vibration[5]) and macroorganisms such as non-native species[6] – all of which can cause ecological damage. Indeed, if large structures (such as wind turbines, bridges, oil and gas rigs) are placed in the sea then they also meet the above definitions for contaminants and pollutants – they undoubtedly disturb the marine system and are demonstrated or assumed to harm nature and the way we use the seas. This can be, for example, by changing the habitat and hydrodynamics, inputting or resuspending contaminants in the bed sediments, affecting food chains and by preventing us from exploiting fish and shellfish. The Ocean Decade has 10 years in which to focus on the science needed to tackle all of these types of contaminants and pollutants.

The input of the materials mentioned above comes from human activities, usually on land, but also at sea. Each of those activities has a footprint and leads to pressures defined as 'the mechanism of effect', which

▲ Figure 2. Fishing, household and industrial litter washed up on the strandline. (© Mike Elliott)

are impacts both on the natural system and on humans. Those pressures and impacts also have footprints of their own, so there is the need to separate activity-footprints, pressures-footprints and effects-footprints, which may be but are often not in the same place.[7] For example, the activity-footprint of an offshore windfarm may be relatively small but it exerts pressures and effects over a larger area by affecting the migration of species, emitting noise and electromagnetic waves, and disturbing hydrographic and sediment patterns. The Ocean Decade science is needed to determine the scale of those footprints in both space and time – from a hectare to globally and from a few hours to millennia.

As indicated above, pollution implies adverse effects on one or more levels of biological organisation in the sequence from cells and tissues, through whole organisms and their populations, to communities and ecosystems.[8] Within this, environmental managers have long adopted the precautionary principle, in which it is assumed, unless proven otherwise, that human activities will have an adverse effect and that those effects, unless stopped, will be transmitted from individuals to ecosystems. For example, discharging polychlorinated biphenyls (PCBs) into the sea may generate cellular detoxification mechanisms leading to cancers and eventually whole organism, population and community effects. However, the natural marine system is complex and variable, and such complexity and variability have an ability to absorb some of the effects of stressors (what may be termed environmental homeostasis), without leading to whole-system effects.[9] All of this requires detailed science and, despite the study and management of marine pollution since the 1960s, the Ocean Decade is even more required as an impetus for fit-for-purpose, well-coordinated and well-funded science.[10]

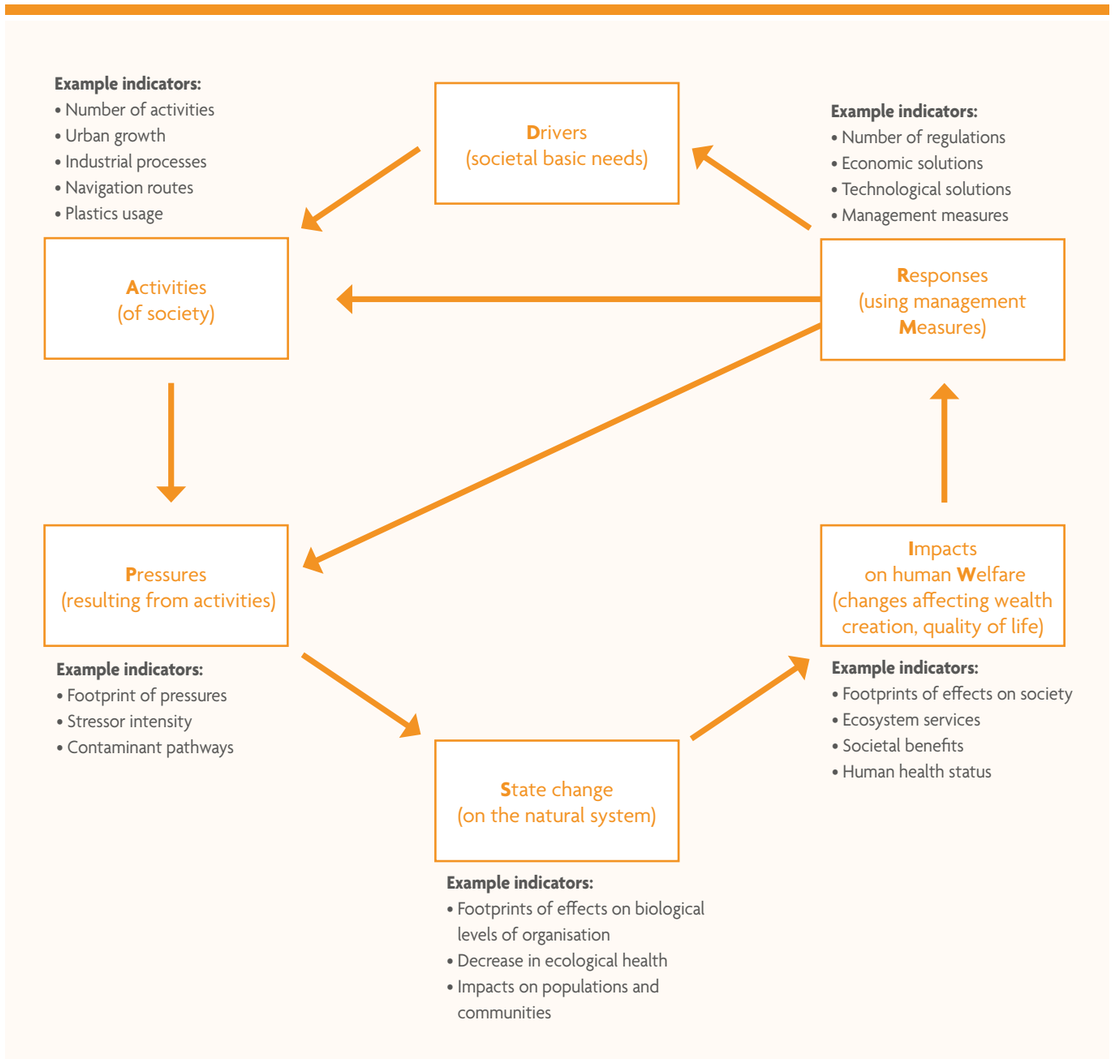
Tackling marine contamination and pollution is essentially a process of Risk Assessment and Risk Management, in which the causes and consequences need to be determined and management responses need to be enacted.[11] However, although this is the Ocean Decade, we need to know what are land-based problems, such as nutrients, plastics and industrial contaminants, and what are their synergistic, antagonistic or cumulative effects. The history of marine science for management has passed through many phases, from the first studies on oil spills (**Figure 3**) and metal pollution in the 1960s, through synthetic chemicals and an awareness today of overfishing to marine debris and the loss of habitats.[12] Hence, we have a large knowledge on which to base our management actions.

▲ **Figure 3. Pollution from shipping accidents leading to oil pollution. (© Mike Elliott)**

SCIENCE, POLICY AND MANAGEMENT

Managing and controlling the problems over the coming decade and linking these to the required science has to be underpinned by a solid causes, consequences and response approach, such as the DAPSI(W)R(M) (pronounced *dap-see-worm*) problem-solving framework[3] (**Figure 4**). In this, the **D**rivers of basic human needs, such as for food, security and clean water, are satisfied by our **A**ctivities which, in turn, result in **P**ressures. These pressures lead to **S**tate changes on the natural ecology and to **I**mpacts (on human **W**elfare) and both the ecological state changes and impacts on society need to be addressed by **R**esponses (using management **M**easures). Hence the management addresses the drivers, activities and pressures to prevent the adverse effects on the natural and human systems. Each of these elements then needs the appropriate science to create indicators (as shown in **Figure 4**) to measure and monitor the direction of trends and to determine whether or not the management measures have been successful. In the case of contaminants and pollutants, for example, urbanisation and industrialisation lead to the production, use and discharge of materials that eventually reduce the health of organisms and humans. We then need the laws, economic instruments, technological devices and societal attitudes to control the resulting problems.

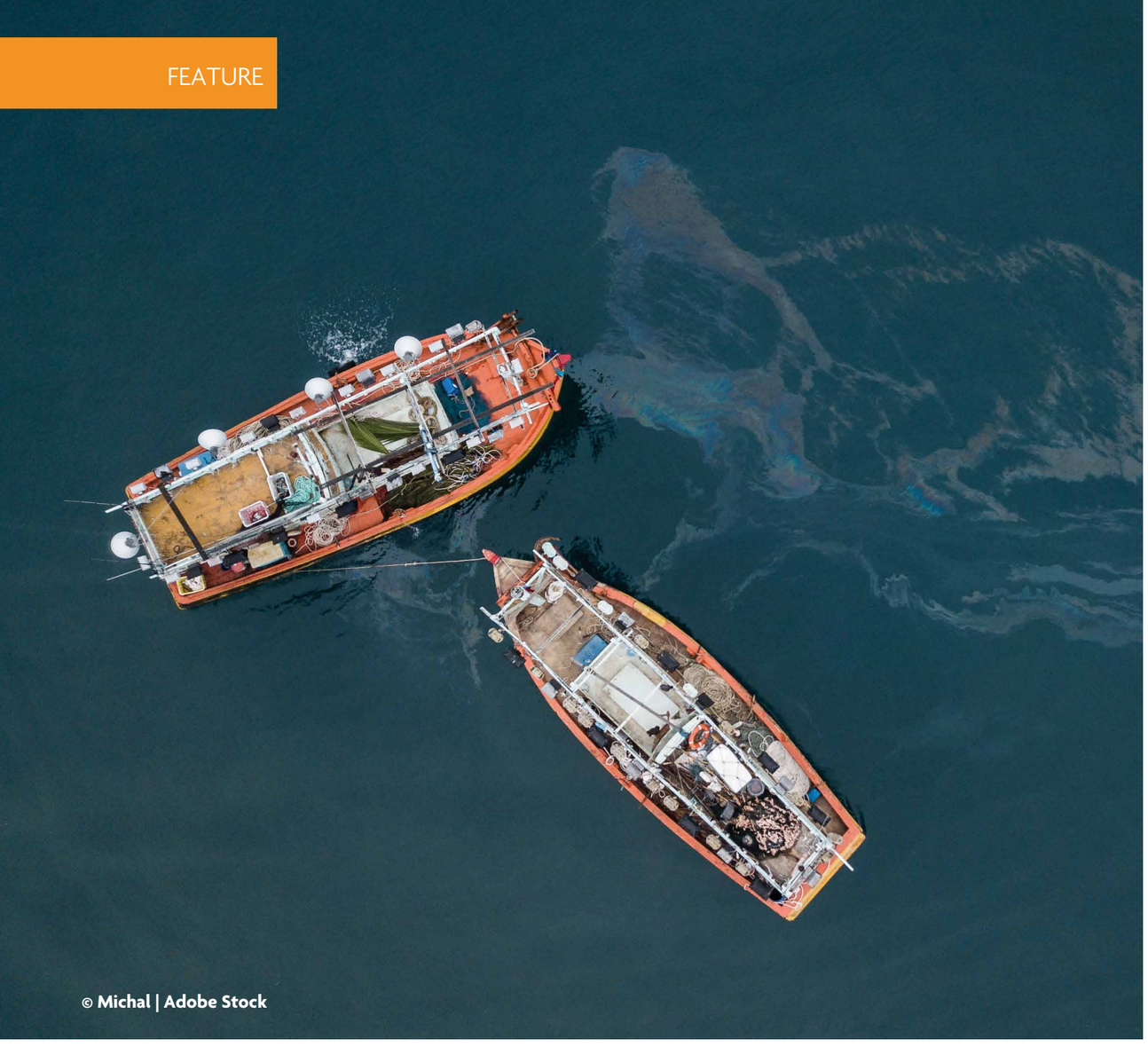
Just as the implementation plan for the Ocean Decade mentions human behaviour, the Ocean Decade needs a concerted scientific effort to understand the fate and effects of pollutants – what may be regarded as 'behaviour' at many levels. This needs interdisciplinary research that covers the physical and chemical sciences (i.e. the 'behaviour' of the physical and chemical marine system) leading to an understanding of the 'behaviour' of the contaminant in the environment. Such behaviour, in turn, leads to contaminant uptake by organisms depending on their behaviour and biological traits; for example, whether they will filter polluting particles out of the water or ingest them from sediments. Following this is the 'behaviour' of the pollutants inside organisms – whether they will be sequestered, stored, detoxified and/or excreted and whether any of these will lead to



▲ **Figure 4. The DAPSI(W)R(M) cause, consequence and response framework with indicators (modified[3]).**

them being accumulated throughout food chains, i.e. passed on to predators or progeny. As a consequence, the control, management and policy of marine pollution must be based on good science in the sequence of research – knowledge – policy – management.

The Ocean Decade is intimately linked, and over the same timescale, to the global Sustainable Development Goals (SDGs) and especially SDG 14 ('Life below water'), with its focus on the oceans. The SDG 14 targets are mostly related to wider management and fishing, and may be insufficiently quantitative to know if they are achieved by management.[13] In particular here, and notably as the first target, SDG 14 Target 14.1 has an especially ambitious (and perhaps unattainable!) target: 'By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution'. Arguably, other types of pollution are also important and, again it could be argued, that marine debris (litter) and plastics are a land-originating problem that requires land-based rather than marine solutions. At present there is an excessive effort on microplastics research but one questions whether this is looking mostly at contamination (i.e. the presence) rather than pollution *per se* (i.e. the effects).[14]



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Of increasing further concern, and as a problem exacerbated by global climate change, are biological pollutants – non-native, invasive species with a potential for ecosystem consequences.[6] This requires us to retain international maritime transport but without moving species around the globe, and of coping with the effects of one type of pollution (climate change, ocean warming, loss of ice caps, ocean acidification) exacerbating another (non-native species deposited in an area leading to ecological and economic consequences). To prevent species being moved by shipping requires control and management of ballast water; however, perhaps more insidious is the movement of non-native species with warming seas and with the opening up of sea routes through the thawing of ice caps.

SOLUTIONS FROM THE OCEAN DECADE

The Ocean Decade aims to focus on the science for healthy oceans but also gives importance to education and communication for sustainable solutions, for indicating not only obvious problems (such as litter) but also the hidden concerns such as noise and dissolved pollutants. There is the need to determine the size and context of the problem, and bring to bear the legislative, economic and technological means of controlling pollutants and contaminants. As emphasised by Outcome 1 of the Ocean Decade, 'it will be critical to fill urgent knowledge gaps and generate priority interdisciplinary and co-produced knowledge on the causes and sources of pollution and its effects on ecosystems and human health. This knowledge will underpin solutions codesigned by multiple stakeholders to eliminate pollution at the source, mitigate harmful activities, remove pollutants from the ocean, and support the transition of society into a circular economy'.[1]

Unfortunately, society still has an 'out of sight, out of mind' attitude – throwing our waste into the nearest watercourse and allowing it to be carried downstream takes it away from being a local problem. This leads to a few major river systems worldwide being the source of most plastics, eventually contributing to the huge plastics gyres in the major oceans. But in allowing contamination and pollution are we also wasting resources? The American architect and theorist Richard Buckminster Fuller commented that 'pollution is nothing but resources we're not harvesting. We allow them to disperse because we've been ignorant of their value'. This has been misquoted as 'pollution is the wrong type of materials, in the wrong place and at the wrong time'. Hence, we need a change to the mindset so that these valuable resources can be harvested in a circular economy.

In closing, it is important to return to Challenge 1 of the Ocean Decade: 'understanding and mapping land and sea-based sources of pollutants and contaminants and their potential impacts on human health and ocean ecosystems'. The understanding, monitoring and assessment are a good start but only if accompanied by management and solutions. We also have to remember that the Ocean Decade goes hand in hand with the UN Decade on Ecosystem Restoration 2021–2030, which should also include solutions for the marine environment.[15] Taken together, these give us two decades of additional effort to achieve seas restored to health.

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