Back to Blue

An initiative of
Economist Impact and The Nippon Foundation

THE ZERO-POLLUTION OCEAN

A call to close the evidence gap

ECONOMIST IMPACT

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THE CRITICAL NEED FOR MARINE POLLUTION DATA

Back to Blue, an initiative of Economist Impact and The Nippon Foundation, is launching a global call to action to close the marine pollution data gap

Pollution caused by human activity accumulates in the seas. Yet poor and inaccessible data means building a coherent and holistic picture of marine pollution is impossible. Plastic pollution garners headlines, but a plethora of other chemicals and contaminants—mostly unseen—are likely doing as much, if not greater, harm to ecosystems, marine life and human health. On this score society knows frighteningly little: there has been no comprehensive global effort to harmonise, collate, analyse and interpret data to build a holistic picture of marine pollution and its impacts.

Chemicals and other contaminants reduce biodiversity and damage the marine ecosystem. Ocean pollution is an economic problem too, damaging fisheries, reefs and coastal environments. A zero-pollution ocean is critical to achieving global climate-change and biodiversity targets, yet it will only be possible if policymakers, business leaders and investors have access to sufficient evidence to evaluate the scope, scale and impact of marine pollution and to take action.

Back to Blue has published a discussion paper, *The Zero-Pollution Ocean: A call to close the evidence gap*, and calls on all individuals including scientists, activists, policymakers, investors and business leaders to join the conversation about how to spearhead a co-ordinated global response to marine pollution.

Why a zero-pollution ocean?

- Restore marine biodiversity
- Conserve ecosystems
- Safeguard human health
- Preserve healthy fisheries
- Protect coastal communities
- Boost carbon sequestration

"DUE TO THE LACK OF DATA, WE'RE NOT EVEN ABLE TO GIVE A SIMPLE ONE-PAGE SYNTHESIS OF THE GLOBAL STATUS OF OCEAN POLLUTANTS."

Henrik Enevoldsen
Head of ocean science section
at the Intergovernmental
Oceanographic Commission of UNESCO

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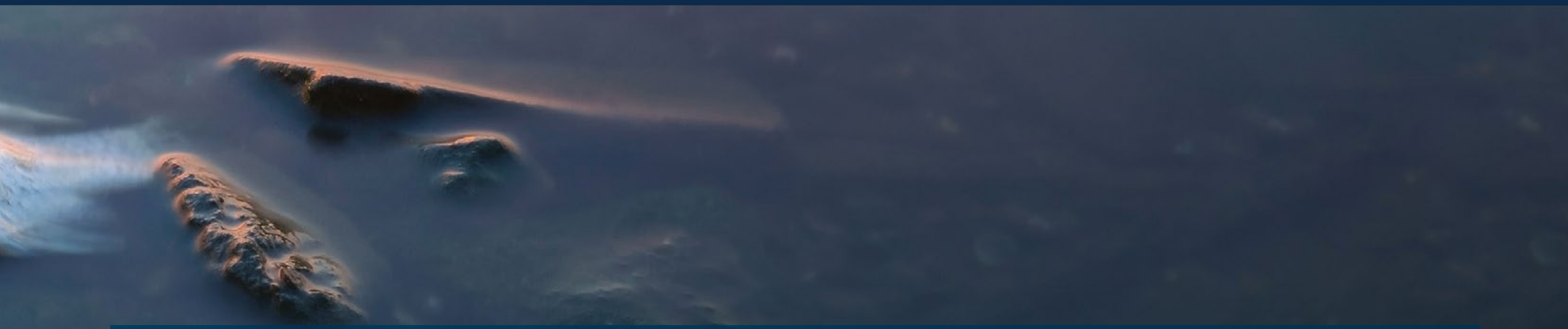
Intergovernmental Oceanographic Commission



Back to Blue's recommendations:

That marine pollution—beyond plastic—be central to the agenda at the 2025 UN Ocean Conference and other major meetings, such as the United Nations Environment Assembly in 2024, with a view to raising awareness and spurring action among policymakers.

That the UN Ocean Decade framework be used to foster effective collaboration among the various agencies that collect and hold data and other resources relevant to understanding marine pollution, including (but not limited to) UN agencies, national government agencies, universities, scientific organisations and the private sector.

That a strategic plan be developed by 2025, setting out the pathway to building a comprehensive global understanding of marine pollution. This process must incorporate the widest possible range of actors from the UN system, national governments, scientific agencies, universities, NGOs and the private sector, including the technology industry.

That a diverse group of projects and initiatives—including Back to Blue—work collaboratively with scientists to raise awareness and use existing marine pollution data to inform policymakers, business leaders and the broader public.

Join the conversation

Back to Blue invites all stakeholders, including UN and government agencies, universities, scientific bodies, civil-society groups, business, investors and individuals to share their views. With your permission, we will publish submissions on our website.

Your submission can contain any information that you think is relevant. We particularly draw your attention to the following questions:

- Is there a genuine need for a global effort to address marine pollution data gaps? Why or why not?
- What would it take to support and build on existing global data-collection initiatives, governance bodies and frameworks to develop a comprehensive picture of marine pollution?
- Which organisations need to be involved to ensure success?
- How could existing bodies and frameworks be expanded not only to store data but also to communicate it to the public and decision-makers in a way that produces meaningful change?

To learn more about marine pollution, download the discussion paper, make a submission or comment on how to close the marine pollution data gap, visit **backtoblueinitiative.com/take-action-on-ocean-pollution/** or scan the QR code.

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Key points

- Pollution severely impacts the ocean's health. Yet poor and inaccessible data mean that it is impossible to build a coherent and holistic picture of marine pollution.
- There has been no comprehensive global effort to harmonise, collate, analyse and interpret such data to build a holistic picture of marine pollution.
- This discussion paper aims to catalyse a co-ordinated global response to marine pollution. This will require building a thorough picture of the existing data and an understanding of the science needed to fill the evidence gaps.
- This paper calls for closer collaboration between UN bodies and other stakeholders to build a more comprehensive understanding of marine pollution to spark action by policymakers. The UN Ocean Decade provides the ideal framework to support enhanced collaboration.
- UN bodies and scientific and non-government organisations (NGOs) must work collaboratively to raise awareness about marine pollution and use data analysis and storytelling to engage policymakers, business leaders and the public.
- Back to Blue is calling for submissions on the most effective way to catalyse a co-ordinated global response to marine pollution. Our objective is to engage with stakeholders in the ocean community to co-design a roadmap, as part of the UN Ocean Decade, by 2025. This roadmap will set out the pathway to an inclusive and collaborative solution to global ocean pollution monitoring and data governance by 2030.

Make a submission in response to this discussion paper at backtoblueinitiative.com/take-action-on-ocean-pollution.

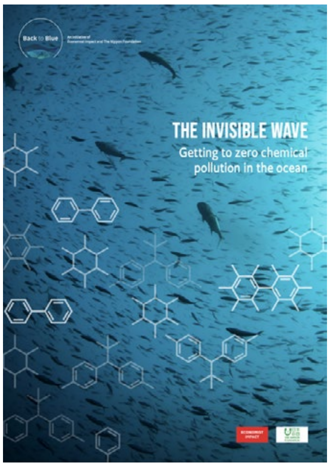
Submissions close on April 30th, 2023.

Introduction

Pollution caused by human activity accumulates in the seas: this much we know. Yet quantifying the range and scale of ocean pollution, discerning how various pollutants interact and move around the ocean, and explaining anthropogenic pollution's impact on the ocean is a much more difficult task. On the question of what impact pollution—in its most holistic sense—has on the ocean's health, we know frighteningly little.

Economist Impact and The Nippon Foundation launched Back to Blue in 2021 with this question in mind. Our mission is to shape and support progress towards having zero pollution in the ocean and healthy seas, as they are essential to human wellbeing and prosperity. We define pollution broadly, recognising that while plastic waste is a significant issue for ocean health, it is not the only (or even the most important) source of pollution. Plastic pollution garners headlines, but a plethora of other chemicals and contaminants—mostly unseen—are likely doing as much, if not greater, harm.

We know little about this wider, invisible group of chemicals, contaminants and pollutants. The global scientific community's understanding of how pollution impacts ocean health is so poor that when the UNESCO Intergovernmental Oceanographic Commission (IOC) published its pilot *State of the Ocean Report in 2022,* it was unable to prepare a simple one-page synthesis of the global status of ocean pollutants owing to a lack of available data, says Henrik Enevoldsen, head of centre and programme manager at the Intergovernmental Oceanographic Commission and one of the report's lead authors.



The Invisible Wave: Back to Blue's major research report on marine chemical pollution

In 2022 Back to Blue published *The Invisible Wave,* a major study on marine chemical pollution — and its findings were sobering. This discussion paper builds on that work, drawing upon its interviews and research. In interviewing a diverse range of policymakers, scientists, business leaders, investors and activists, we heard a wide range of responses, but almost every person told us a version of the following:

- Almost all marine pollution is invisible. Macroplastics have garnered an enormous amount of attention precisely because they are visible. Nutrient pollution, which can result in so-called dead zones, areas where the oxygen has plummeted, is also well understood. Yet decision-makers in both the public and private sectors and the general public remain largely unaware of other types of marine pollution. Microplastics, industrial chemicals, urban and river runoff, pollution from the shipping and offshore drilling industries, sewage, air pollution, pharmaceutical contamination, and more collectively make up an invisible wave of pollution in our ocean.

- The invisible nature of marine pollution is an obstacle for those who want action. Leaders in government and business are unlikely to recognise the value in tackling marine pollution if they can't see it and don't understand it. Voters and consumers are unlikely to put pressure on their elected representatives and make purchasing decisions with a view to stopping marine pollution if they don't know it exists.

- Yet making the invisible *visible* is easier said than done. The scientific body of knowledge about marine pollution is largely fragmented and scattered. We may know about the impact of one chemical on a local estuarine environment or how a single heavy metal affects one type of marine organism. But we know very little about the wider scope and scale of marine chemical pollution, much less its cumulative impact and the impact of combinations of chemicals and pollutants on marine organisms and ecosystems, and more broadly on ocean health and function. This is particularly true in the open and deep ocean.

The aim of this discussion paper is not to provide a comprehensive survey of the available data on marine pollution. Instead, it explores pathways for improved data collection, collaboration and communication. The hope is that it will spark a conversation among scientists, research funders, policymakers, investors and business leaders about how to close the gap on marine pollution data collection, collaboration and communication.

The positive news is that chemicals are under greater scrutiny for their impact on environmental and human health and the industry's role in climate change. Long considered an essential yet hard-to-abate sector, a new and urgent narrative is developing about the transition to less toxic, greener chemicals and an industry that must free itself from fossil fuels. The UN Environment Programme (UNEP) cites pollution as the third anthropogenic challenge after climate change and biodiversity loss[1], while an emerging regulatory rigour on chemicals in China[2] and the EU[3] suggests that governments are taking notice too.

Yet the transition will only be successful if policymakers, business leaders and investors have access to sufficient evidence to evaluate the scope, scale and impact of chemical pollution and to take action. This applies as much to freshwater (and land) as to the ocean; empirical data on how these systems are aligned and integrated as a single hydrological system will be critical.

The Challenge: Understand and beat marine pollution

In 2022 the UNESCO Intergovernmental Oceanographic Commission published its pilot *State of the Ocean Report*. It lists ten challenges for the ocean. Challenge number one is to "understand and beat marine pollution." On this topic, the report finds that:

- "There is indisputable evidence of the continued, widespread and unabated increase of land pollution in the ocean."
- "Despite the global significance of ocean pollution, observations remain limited, geographically and thematically, being mainly concentrated at the ocean surface and in coastal areas."
- "Very little is known about other types of pollution except … nitrogen, phosphorus and plastic pollutants."
- "In order to be able to support actions against ocean pollution and enable the meaningful use of existing and emerging legally binding instruments on ocean conservation, **a more resourced and systematic approach to observations and synthesis of ocean pollution is urgently required."**

The State of the Ocean Report, UNESCO, pg. 8[4]

Part 1: The current state of ocean data collection and dissemination

What is ocean pollution?

Perhaps the most difficult hurdle to overcome in building a complete picture of ocean pollution is the complexity of the problem. There is no single measurement of pollution; building a better understanding requires assembling a painstaking layer cake of data points. Determining *how* to measure pollution is just as important as determining *what* to measure.

Chapter 1 of The Invisible Wave listed several categories of pollutants that harm or potentially harm the marine environment.

- Persistent organic pollutants
- Toxic metals
- Excess nutrients
- Pesticides
- Plastics
- Pharmaceuticals
- Radioactive substances
- Oil
- Household and consumer chemicals
- Pseudo-persistent chemicals
- Other chemicals including some of the approximately 300,000 chemicals in use with unknown effects

There is no firm scientific agreement about which of these groups of pollutants are the most harmful to the marine environment or which should be the most urgent policy priority. Measuring pollution in the ocean is complex. Contaminants disperse and dilute differently. Some accumulate in estuarine and coastal areas. Tracking and assessing pollutants in the open or deep ocean is even more difficult.

The complication doesn't end there. Atmospheric pollution, the way various pollutants mix and combine in seawater, the role of climate change and ocean acidification in amplifying the effects of contaminants, and the toxicity of many chemicals are all often unknown. Scientists understand more about legacy chemicals such as DDT. Yet 'contaminants of emerging concern,'[5] such as some pharmaceuticals and personal care products, may pose new and less well-understood threats.

We know this: an unseen, unknown (and potentially unknowable) number of pollutants are entering the ocean. Mostly, this is because of human activity, much of it on land and in freshwater. These pollutants, collectively, are highly likely to be having a detrimental effect on the ocean's health.

The interviewees for this discussion paper and *The Invisible Wave* did, almost universally, share one further caution. We may not know as much about marine pollution as we would like. But we do already know enough to realise that we need to act—now.

Who collects ocean data?

National and intergovernmental data sources

Oceanographic data outline physical measurements, including salinity, temperature and currents. These are primarily collected through scientific observations and remote-sensing devices. Water quality assessments have long been a major data source, particularly for nutrients.

Fifty-seven national governments fund and operate oceanographic data centres or repositories.[6] Their scale, scope and focus vary significantly. Unsurprisingly, large and wealthy countries with long coastlines have the most sophisticated oceanographic data collection and monitoring systems. The US' National Oceanic and Atmospheric Administration (NOAA), China's National Marine Data and Information Service, the Japanese Oceanographic Data Centre, and the European Marine Observation and Data Network (EMODnet) are a few examples. Some governments conduct routine monitoring of chemical contaminants in the marine environment.

National governments administer these agencies independently, and Eighty national governments are members of the International Oceanographic Data and Information Exchange, a programme established by the IOC to facilitate "the exchange of oceanographic data and information" between IOC member states.[7]

Government agencies such as defence departments, space agencies, meteorological agencies and commerce departments also often collect and store oceanographic data. The US Navy provides oceanographic and meteorological data to US and coalition forces, for example.[8] The European Space Agency is using an inactive earth-observing satellite, Envisat, to map changes in the ocean's surface temperature, phytoplankton distribution, water sediment and pollution.[9] Private sector businesses from industries such as shipping, fisheries, offshore drilling and offshore renewables also collect data to aid their commercial operations.

Several international and regional organisations maintain ocean databases too. Examples include the OECD Sustainable Ocean Economy database,[10] the UNEP World Conservation Monitoring Centre's Ocean Data Viewer,[11] and NOAA's World Ocean Database.[12] These cover a wide range of oceanographic data.

UN agencies and programmes such as UNEP and its regional seas programmes, the Group of Experts on the Scientific Aspects of Marine Environmental Protection, the Food and Agriculture Organisation (FAO), and the Secretariats of the Basel, Rotterdam and Stockholm conventions collect or use data on marine pollution too.

Non-government data sources

Civil society is another important source of data collection, analysis and dissemination. Large-scale philanthropic projects such as Seabed2030 (a collaborative project of GEBCO and The Nippon Foundation, which is jointly part of Back to Blue alongside Economist Impact), which aims to produce a definitive map of the world ocean floor,[13] and REV Ocean, which conducts research cruises,[14] provide a platform for scientists to collect and analyse data and understand the impact of pollution on ocean health. Land-based projects, such as the International Network on Soil Pollution by the FAO[15] collect data on

Figure 1: Oceanographic Data Repositories

Repository	Description
Australian Ocean Data Centre Joint Facility (AODCJF) http://portal.aodn.org.au/aodn/	Australia's designated National Oceanographic Data Centre, created in 1964 and based in Tasmania. The AODCJF is a joint venture between six Australian government marine data agencies.
Banco Nacional de Datos Oceanográficos (BNDO) http://www.mar.mil.br/dhn/chm/ oceanografia/bndo.html	Brazil's designated National Oceanographic Data Centre, created in 1994 and based in Rio de Janeiro. The BNDO is supervised by the Brazilian government's Centro de Hidrografia da Marinha (CHM)
British Oceanographic Data Centre (BODC) http://www.bodc.ac.uk/	The United Kingdom's designated National Oceanographic Data Centre, created in 1969 and based in Liverpool. The BODC is funded by the National Environment Research Council (NERC).
Centro Argentino de Datos Oceanográficos, Servicio de Hidrografia Naval http://www.hidro.gov.ar	Argentina's designated National Oceanographic Data Centre, created in 1974 and coordinated by the naval hydrographic service of the Argentine Ministry of Defence, Buenos Aires.
Centro Nacional de Datos Oceanográficos do México (CeNDO) http://cendo.ens.uabc.mx/	Mexico's designated National Oceanographic Data Centre, created in 2011 and based at the Autonomous University of Baja California, Campus Ensenada (UABC).
European Marine Observation and Data Network (EMODnet) http://www.emodnet.eu/	An Ostend-based consortium of over 100 organizations making marine data available to the public, created in 2009 by the European Commission's Directorate- General for Maritime Affairs and Fisheries (DG MARE).
Geological and Geophysical Data (Geo-Seas) http://www.geo-seas.eu/	A Nottingham-based initiative of the European Commission's Research Infrastructures programme (20092013) which continues to offer data and services to the public. Steered by the project coordinator NERCBGS (the Natural Environment Research Council and the British Geological Survey) and the technical coordinator MARIS BV (Marine Information Service, the Hague, Netherlands), Geo-Seas brings together 26 data centres located in 17 European maritime nations.
Integrated Marine Observing System (IMOS) http://imos.org.au/home.html	An initiative led by the University of Tasmania in partnership with ten other academic institutions, created in 2007 and supported under the Australian government's National Collaborative Research Infrastructure Strategy (NCRIS).
JERICO http://www.jerico-fp7.eu/datatool/	A consortium of 27 partners created in 2011 and coordinated by the Institut français de recherche pour l'exploitation de la mer (Ifremer).
MyOcean www.myocean.eu/	A consortium of 59 partners in 28 countries created in 2009 and directed by Mercator Océan (Ifremer).
National Oceanic and Atmospheric Administration (NOAA) http://www.nodc.noaa.gov	The United States' designated National Oceanographic Data Centre, created in 1961 and based in Silver Spring, Maryland.
Ocean Data Portal (ODP) http://www.oceandataportal.org/	A portal created in 2013 by the International Oceanographic Data and Information Exchange (IODE) programme of UNESCO's Intergovernmental Oceanographic Commission (IOC-UNESCO) through the network of National Oceanographic Data Centres.
Rolling Deck to Repository (R2R) http://www.rvdata.us/	A programme created in 2008 and coordinated by the University-National Oceanographic Laboratory System (UNOLS) at the University of Rhode Island Graduate School of Oceanography.
SeaDataNet http://www.seadatanet.org/Data-Access	A consortium of 49 partners in 35 countries, created in 2004 and coordinated by the Institut français de recherche pour l'exploitation de la mer (Ifremer) in Brest, Brittany; technical coordination by MARIS BV (Marine Information Service, the Hague, Netherlands).

Source: Silva, Fabiano Couto Corrêa da, Ernest Abadal, and Enrique Wulff. 2017. "Oceanographic Data Repositories: An Analysis of the International Situation" Publications 5, no. 2: 8. https://doi.org/10.3390/publications5020008[16]

hydrosphere pollution. Hub Ocean's digital tool, Ocean Data Platform, enables better data sharing and aims to create economic incentives for doing so.[17] Citizen science projects, such as The Ocean Conservancy's TIDES (Trash Information and Data for Education and Solutions), enable individuals and local communities to upload observational data to a centralised portal.[18]

Several not-for-profit oceanographic centres and research institutes collect and analyse data, such as the Woods Hole Oceanographic Institute and Schmidt Ocean Institute.[19] Universities also play an important role in collecting and understanding data about the ocean. Academic journals such as *Environmental Pollution*,[20] *Marine Pollution Bulletin*[21] and *Frontiers in Marine Science*[22] routinely publish studies on pollution, while the American Chemistry Society's CAS Content Collection collates all available data about chemicals, aggregating information from thousands of academic journals.[23]

Data from land and freshwater-based sources

Scientists increasingly understand the inextricable connection between the earth's fresh and saltwater systems. As *The Invisible Wave* notes, around 80% of ocean pollution comes from land-based sources. Many estuarine environments are well researched, says Elsie Sunderland, Gordon McKay professor of environmental chemistry at Harvard University.

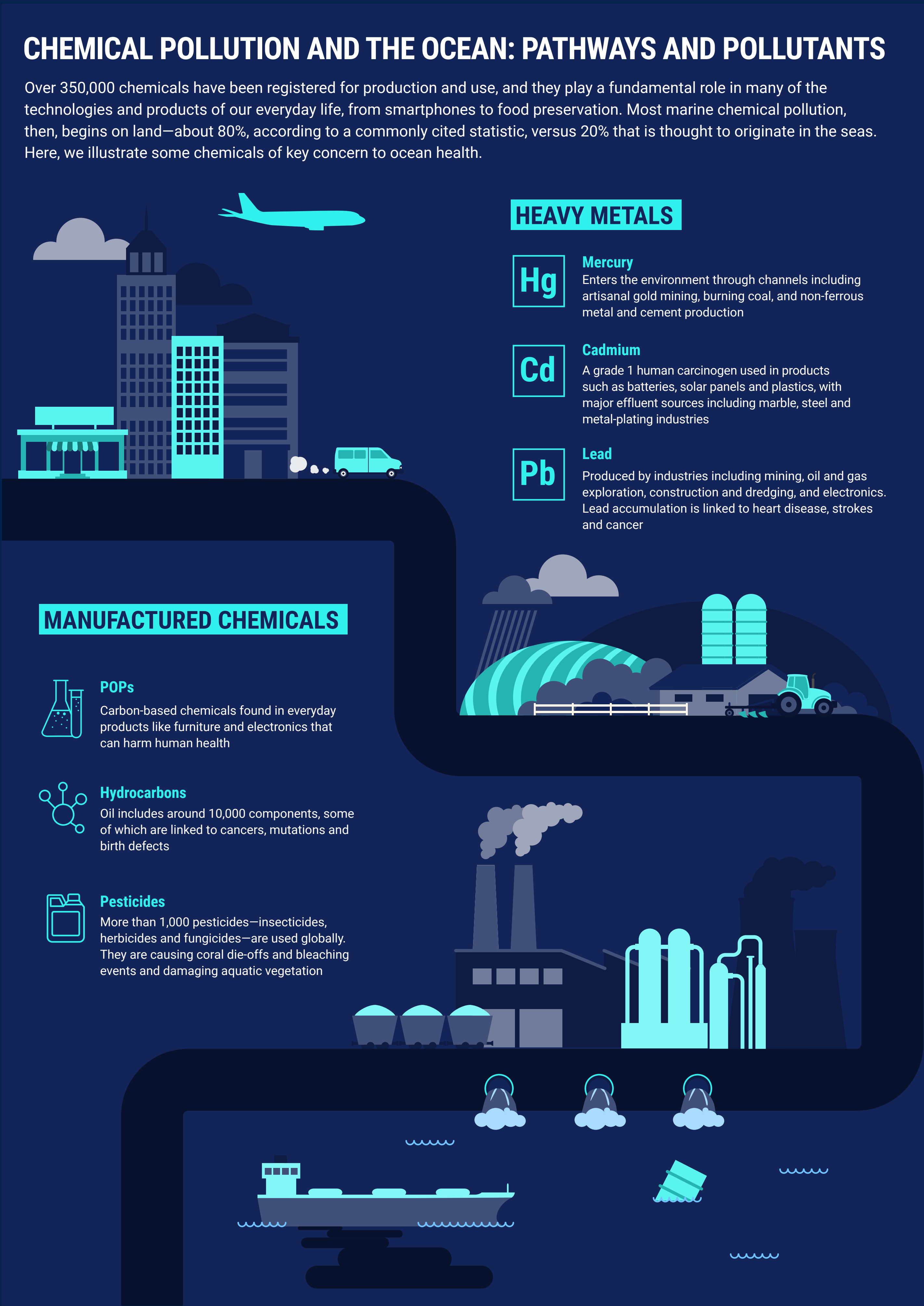
These studies can provide a useful starting point for understanding the role of the hydrological system—which encompasses both fresh and saltwater—on ocean pollution.

UNEP's Global Chemicals Outlook II focuses on the sound management of chemicals and waste on land, in freshwater and in the ocean.[24] In the future, a stronger science-policy interface on chemicals and waste should enable further data sharing and collaboration, provide an assessment of existing data, and identify critical data and knowledge gaps.[25]

Several databases focus on ocean pollution that comes from land-based sources, including the Water Information System for Europe (WISE Marine)[26] and the Information Platform for Chemical Monitoring (IPCHEM).[27] Ocean Watch,[28] created by the World Resource Institute, is an effective data visualisation tool, demonstrating the impact that land-based pollution has on ocean health. The Global Estuaries Monitoring Programme[29] is a global network that monitors environmental pollutants at the interface of fresh and seawater ecosystems as well as on land.

Our lack of knowledge about the impact of pollution on the marine environment comes partly from a failure to knit together data about land-based pollution with ocean-based measurements. An interface between freshwater, saltwater and soil data is needed in order to provide a holistic view of ocean health.

Figure 2: Pathways and Pollutants



Source: The Invisible Wave, pg. 24

Mind the gap

Despite a wealth of oceanographic data being collected, only a small slice relates to marine pollution. The data that are collected tend to focus on specific pollutants. There is simply not enough information to clearly understand the scale, nature and impact of pollution on the ocean. "The data gaps are enormous," says Bethanie Carney Almroth, associate professor in marine ecotoxicology at the University of Gothenburg in Sweden. This tip of the iceberg indicates a much larger problem below the surface.

Information about pollution is available for just 67 of the world's 13,674 marine protected areas, according to a 2017 study published in *Environmental Pollution.* Despite this, "more than 80% of the areas studied exhibited evidence of contamination at potentially toxic concentrations," the study's authors concluded.[30] Even in the parts of the ocean that scientists and policymakers deem most vulnerable, information about the scale and impact of pollution is minimal.

Where pollution data are collected, they most often relate to macroplastics or excess nutrients. This has not always been the case: government policy priorities, funding availability and changing research priorities mean the attention scientists give to various pollutants ebbs and flows over time. Not long ago, persistent organic pollutants and pharmaceuticals received the bulk of academic attention. Now, microplastics are a popular subject, says Geoff MacFarlane, a marine ecotoxicologist at Australia's University of Newcastle and an associate editor of the Marine Pollution Bulletin. Being less visible, chemical pollution "has been given lower attention", says Marina Lipizer, a scientist at Italy's Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, a conclusion that the findings of *The Invisible Wave* support.

As a result, the impact that the vast majority of the 350,000 or so chemicals in circulation[31] have on ocean health remains understudied or wholly ignored. Adding to the challenge is the fact that "the chemicals we are studying are the ones we expect to find because they are the ones we are looking for," says Ms Carney Almroth. Monitoring

Mind the gap: what we don't know about marine pollution

1. **The scale gap.** Scientists have local knowledge but are unable to draw conclusions about wider ocean ecosystems.
2. **The FAIRness gaps.** Datasets fail to adhere to the FAIR principles: Findability, Accessibility, Interoperability and Reuse of digital assets.
3. **The geography gap.** We know a lot about some parts of the ocean, and almost nothing about others.
4. **The long-term monitoring gap.** Point-in-time studies make it difficult to discern trends.

for the presence of 'emerging contaminants of concern', chemicals that may be adverse to human or environmental health but are not yet regulated, is largely absent.

The ocean pollution data gap exists not just in the scientific literature but at the national and international levels too. National marine and oceanographic datasets overwhelmingly include physical oceanographic measurements such as temperature, salinity and currents. Pollution data typically account for a small portion of what national data centres collect, if they collect it at all.[32]

The scale gap

One particular challenge when studying the effects of pollution in the marine environment is that chemicals' properties react to changes in temperature or salinity and when other chemicals are present. This means that, while scientists may have data on the effects of a particular chemical in a specific part of the ocean, they cannot necessarily be used to draw conclusions about how that chemical will affect ecosystems elsewhere or if other pollutants are present.

Compounding this problem is the fact that scientific studies are often small-scale and narrowly focused. Financial and logistical obstacles mean it is "impractical to sample everywhere."[33] "It's predominantly people working in their own little bubble," says Mr MacFarlane. We may have a clear picture of some types of pollution in some parts of the ocean, but it is not enough to draw large-scale conclusions about the overall impact of pollution on ocean health.

The FAIRness gap

Another problem is that much of the data about marine pollution is not made publicly or easily available. Data do not always adhere to the FAIR Guiding Principles for scientific data management and stewardship: findability, accessibility, interoperability and reusability of data.[34] Datasets that do exist are often inconsistent. National data repositories "differ in terms of architecture and the organisational level of the content they offer."[35]

"Despite several existing legislations, there is still a large heterogeneity among countries concerning what is being measured and how, depending on the major sources of pollution," explains Ms Lipizer. "But there are not yet consolidated harmonised methodologies. In some cases, data are not comparable, because they are measured in different ways and with different approaches."

"There is a really huge need to harmonise what different countries do in terms of monitoring protocols, analytical proficiency and quality control of data," Ms Lipizer adds. She has found inconsistencies in data collection, labelling and in the quality of instruments among EU countries. It is probably safe to assume that these inconsistencies are far greater at a global level.

Even when data are available, they are not always usable. Data governance standards mean that large data-collecting bodies such as the OECD cannot always use data collected through academic studies, says Ms Carney Almroth. Datasets often lack metadata tags that contain critical information on geography, and the type and quality of data, which makes them difficult to use. Adding metadata is a resource-intensive process, says Jonathan Baines, ocean data manager of the Sustainable Ocean Initiative and project lead of Ocean Watch at the World Resource Institute. Yet it is important in closing the information gap between scientists and the average person, he believes. Improving metadata use is an integral component of the FAIR Guiding Principles.[36]

There are other obstacles to data accessibility too. The US Navy, for example, holds a large amount of classified ocean data. Offshore industries collect data for operational or compliance purposes; often these are not made available due to commercial sensitivities.[37]

The geography gap

Another significant challenge is that existing and accessible data on marine pollution are unevenly spread. Most studies focus on littoral or shallow nearshore areas. Sheltered bays and estuaries are also often well studied because they provide a naturally 'enclosed' area to examine. Very few studies examine the open ocean or very deep water. "Marine contaminants are usually measured by national or regional authorities, which focus mainly on coastal areas," says Ms Lipizer. "We have very little information on the deep seas." In terms of marine pollution, macroplastics are arguably the most studied type, yet even here, research has tended, with some important exceptions, to focus on floating or stranded litter.[38]

Among coastal regions, the vast majority of research and monitoring is conducted in or by large and wealthy countries. We know substantially less about marine pollution in the parts of the ocean around developing countries. Language barriers and less well-developed scientific networks compound this north-south divide. "We still have lots of gaps," says Kenneth Leung, chair professor of environmental toxicology and chemistry at City University of Hong Kong and director of China's State Key Laboratory of Marine Pollution. He says that most developing countries typically don't have the funding and technical capacity to maintain state-run monitoring centres and analyse the data, which means that "the most studied areas in the world are still in America, Europe and China".

Marta Verier, an assistant professor at Indiana University in the US who specialises in environmental chemistry, agrees. "There's a lot of data in Europe, in North America, maybe some in Australia, but the rest of the world—it's really not well covered."

The long-term monitoring gap

The type of data and how they are collected also contribute to our lack of big-picture knowledge about marine pollution. The methods for collecting marine pollution data are typically time- and resource-intensive and often expensive.[39] Scientists use boats to collect physical samples or study rivers to measure pollution before it enters the sea.[40] Laboratory experiments replicate conditions in the ocean, says Mr MacFarlane.

Physical oceanographic data (on salinity or temperature, for example) tend to be collected continuously over time using sensors or other monitoring equipment. This enables scientists to observe long-term trends, build forecasting models—and sound the alarm about potential environmental threats. Pollution data, by contrast, tend to be collected as part of short-term 'moment-in-time' studies, making it very difficult to observe trends.[41] There is no major historical dataset for the long-term monitoring of contaminants as a result, says Mr MacFarlane.

Even the US' NOAA, one of the world's most well-funded and sophisticated oceanographic centres, focuses largely on incident-related ocean pollution monitoring, for example, following a natural disaster or an industrial accident such as the Deepwater Horizon spill. "There's not a lot going on in terms of routine monitoring of chemical ocean pollution," says Eric Kihn, director of the National Centers for Environmental Information's Center for Coasts, Oceans and Geophysics (a part of NOAA). "If we want to map [ocean pollution across] the whole world, then we have to capture data by active monitoring," says Mr Leung.

Technology creating waves

While traditional methods of collecting data on ocean pollution have been expensive and cumbersome, new and emerging technologies provide the opportunity to make building a comprehensive global picture of marine pollution an increasingly feasible and affordable ambition. Satellites, remote sensors, unmanned vessels, machine learning and digital platforms enabling seamless collaboration across the globe are radically changing the way national ocean data centres, UN agencies and scientists can collect data about marine pollution and understand its effects on ocean health.

Observing platforms are still mostly being used to collect physical oceanographic measurements but have immense potential for monitoring marine pollution.[42] These systems include "autonomous underwater vehicles, profiling floats, gliders, drifters, volunteer measurements from ships, and sensing nodes with cable networks."[43] Remote systems can provide real-time or near real-time data, which is almost impossible with traditional scientific data collection methods.

Technology underpins collaborative efforts such as the Global Ocean Monitoring System, led by the IOC, which focuses on developing tools and technology for ocean observation. Another is the Global Environment Monitoring System for the Ocean and Coasts Programme, led by UNEP, bringing together observation, monitoring and modelling for ocean policymaking. These programmes demonstrate how remote monitoring systems can be used to create large-scale databases.[44]

"The biggest thing to happen [in ocean data collection] is uncrewed systems," says NOAA's Mr Kihn. These autonomous and unmanned vessels allow scientists to take more risks and explore more remote locations, he explains. They can operate from shore-based facilities for long periods. Uncrewed vessels use less fuel, and therefore have a smaller carbon footprint, and, critically, are likely to be much cheaper to operate than conventionally crewed vessels, says Jamie McMichael-Phillips, director of The Nippon Foundation-GEBCO Seabed 2030 Project.[45]

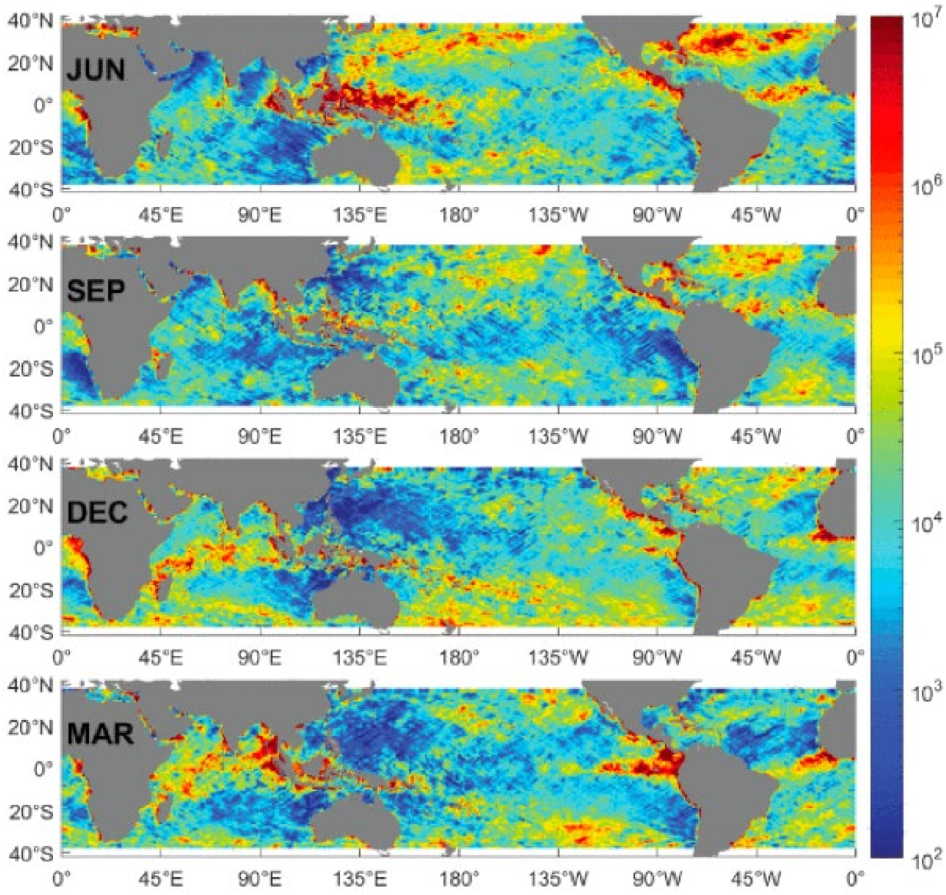
Artificial intelligence

Remote monitoring systems and uncrewed vessels can generate an enormous amount of data; artificial intelligence (AI) has the potential to analyse and make sense of it. Already, AI is being used to further our understanding of marine litter, such as plastics.[46] AI-powered plastic waste detection systems combine machine learning, satellite images and drone technology to allow for autonomous and real-time data collection.[47] This technique has significant advantages over traditional detection methods, which often involve using fishing boats to survey plastic debris across relatively small areas, usually along the shoreline and coastal waters. Another application, being used by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Microsoft uses AI to understand how plastic from rivers and storm drains will behave as it enters the ocean.[48]

Case study: Using satellite data to measure ocean microplastics[49]

Researchers at The University of Michigan[50] apply data from NASA's Cyclone Global Navigation Satellite System to estimate the presence of microplastics in the ocean by measuring the surface's roughness with satellite-borne radars that calculate wind conditions. The research team, led by Chris Ruf, professor of climate and space sciences at the University of Michigan, has found that anomalies in the expected roughness of the surface are "highly correlated with ocean microplastic concentrations." This technique allows Mr Ruf and his colleagues to collect near real-time data on microplastic movement through the global ocean.

Figure 3: Monitoring microplastic pollution in the ocean



Source: M. C. Evans and C. S. Ruf, "Toward the Detection and Imaging of Ocean Microplastics With a Spaceborne Radar," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-9, 2022, Art no. 4202709, doi: 10.1109/TGRS.2021.3081691.

Case study: Citizen science tech

Gone are the days of scientists asking study participants to fill out exhaustive paper surveys. Now, citizen scientists—members of the public who contribute to scientific research— can access a plethora of user-friendly mobile phone apps. The Marine Debris Tracker[51] and The Ocean CleanUp[52] are just two examples of apps that enable beachgoers, sailors and interested individuals to easily upload data on plastic waste. These projects serve a dual purpose, contributing to both data collection and awareness-raising.

Other types of data crowdsourcing, transformed by technology, can be extremely powerful too, says Mr Kihn. NOAA measures the earth's magnetic fields through thousands of volunteers who share the data from the magnetometer built into their iPhones. Businesses and other organisations can take part as well: sensors attached to commercial shipping vessels can provide an enormous amount of data.[53] One key example is the Volvo Ocean Race's partnership with NOAA, in which crews collect microplastic samples from their yachts throughout the race journey.[54]

Stop, collaborate and listen

Technology is not only reshaping the way that marine pollution data can be collected but also how it can be used and communicated too. HUB Ocean's Ocean Data Platform,[55] an open-source tool that is still under development (as of early 2023), will include data from sources such as NOAA's World Ocean Database and World Ocean Atlas, GEBCO's Bathymetry Data, and EMODnet. The project aims to "encourage scientific collaboration, industry transparency and regulatory power."

Also in beta, the World Resource Institute's Ocean Watch[56] is a user-friendly online portal that provides "digestible and reliable" data tools to help policymakers make evidence-based decisions about ocean policy and understand how various policy levers impact ocean health. "[Ocean Watch is a] platform that tries to make the issue accessible to the people who need to manage it," says Mr Baines, the project's lead.

One theme that interviewees for this report raised repeatedly is the lack of engagement between stakeholder groups on marine chemical pollution: industry leaders do not talk to policymakers, who do not talk to investors, who do not talk to scientists.

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Seabed 2030: a case study in collaboration

"Seabed 2030's mission is to accelerate and inspire mapping of the world's ocean floor by the year 2030," says Jamie McMichael-Phillips, who is the project's director. Seabed 2030 does not directly collect bathymetry data (which measures the depth of the seabed) itself but rather convenes partner organisations and then collates the resulting available data to form the best possible picture of the sea floor.

Seabed 2030's partner organisations come in all shapes and sizes. Data collectors can be "individual contributors, academia, industry or private philanthropists or consortia," says Mr McMichael-Phillips. Partners support the project in a variety of different ways, from mapping and collection to promotion.[57] Seabed 2030 has four regional data centres that compile bathymetric data and a global centre responsible for developing an annual data 'grid'.

Digital platforms such as these, as well as ambitious projects such as the Digital Ocean Twin[58] and Healthy Rivers, Healthy Ocean, led by the Global Water Partnership,[59] will be critical in the effort to build a comprehensive global picture of ocean pollution. Yet large-scale technology-led solutions rely heavily on collaboration. With marine pollution data, such collaboration often appears small-scale or absent altogether.

In other areas of oceanography, collaborative efforts are much more advanced. There is "a lot of co-ordination between agencies and between countries about how to [collect data] and how to validate products so that they can be shared on the national level. There's really next to none of that [with marine pollution]," explains Mr Ruf. "There aren't centralised co-ordinating bodies the way there are with a lot of other standards."

Even within Europe, with sophisticated institutional structures such as the Marine Strategy Framework Directive in place, "there is still a lot of work to do in terms of harmonisation and collaboration. It's still in the starting phase," says Ms Lipizer. In other parts of the world, particularly the global south, barriers to effective collaboration—financial, language and otherwise—are substantially higher.

One potential solution is to follow the example of GenBank and the World Register of Marine Species (WoRMS), in which scientists are required to input their research data. For WoRMS, this well-established database enables scientists to evaluate the global marine biodiversity situation, and analyse trends in biodiversity change, says Mr Leung.

The UN Ocean Decade (UNOD) is an important collaboration platform that connects key science, industry and government stakeholders through initiatives and a common framework. UNOD has identified ten 'Ocean Decade Challenges' to be tackled for collective impact. Challenge one aims to "understand and beat marine pollution," including through mapping land- and sea-based pollutants and their impacts on the environment and human health.[60] Scientists and other stakeholders are invited to submit 'Ocean Decade Actions' for official endorsement. These actions could provide an important avenue for greater cooperation around marine pollution data collection, sharing and analysis. For example, The Global Estuaries Monitoring (GEM) Programme, an endorsed decade action, aims to measure more priority chemical pollutants in global urbanised estuaries.

Part 2: Towards a comprehensive understanding of ocean pollution

National governments, UN bodies, universities, corporations and other scientific projects all collect data about the ocean as well as the pollutants on land and in freshwater that are likely to end up in the ocean, as part one of this paper has discussed. A (small) portion of these data relate directly to marine pollution. Yet, while researching this paper and *The Invisible Wave*, we have not identified any comprehensive global effort to harmonise, collate, analyse or interpret those data to build a holistic picture of marine pollution.

This does not mean that we should delay acting to address marine pollution. Interviewees repeatedly stressed that the data does not need to be perfect to be useful. We can draw 'good enough' conclusions from 'good enough' information. "[The project] doesn't have to be comprehensive" to be effective, says Miriam Diamond, an environmental chemist and a professor at the University of Toronto.

In mid-2022 the IOC published its pilot *State of the Oceans Report*,[61] with the aim of "succinctly compil[ing] the most current knowledge on the state of the ocean.[62] Yet, as noted in the introduction of this paper, the authors realised that "we're not even able to give a simple one-page synthesis of the global status of ocean pollutants," says Mr Enevoldsen.

The case for a global, collaborative effort

The need for a more comprehensive collaborative effort to monitor, assess and ultimately to underpin large-scale action to address marine pollution is clear. The objectives and purpose of such an effort should be:

1. **To make use of what we already know**

   A collated overview of ocean pollution data does not currently exist. We need to utilise the existing data to inform action.

2. **To know what we don't know**

   There are significant gaps in the collection, collaboration and synthesis of ocean pollution data. This makes it impossible to form a holistic, evidence-based understanding of the impact that pollution has on ocean health.

   An important imperative in building a comprehensive, data-driven understanding of ocean pollution is to pinpoint the gaps and plug them. "Mapping where we have data and where we do not have data can be very powerful," says Zhanyun Wang, senior scientist at Empa-Swiss Laboratories for Materials Science and Technology.

3. **To advocate for greater collaboration, transparency, interoperability and useability**

   Pollution data often exist but are either not publicly available or readily usable. An important role of a global ocean pollution monitoring and data governance collaboration would be to work with public and private sector actors to facilitate greater data sharing.

   Much of the data that are publicly available lack metadata or are not useful due to differences in labelling and collection methods. It will be important to create harmonised standards and tools to foster future data collection and sharing, where feasible, and to meaningfully knit together and analyse disparate data from a multitude of sources.

   There is no need to replicate the work that many organisations are already doing. But there is a need to 'take stock' of existing efforts and foster collaboration.

4. **To raise awareness about the ocean pollution crisis**

   The impact of plastics on the ocean is now well known, but, as *The Invisible Wave* found, awareness about other types of pollution among decision-makers and the broader public is poor. Building a comprehensive picture of ocean pollution is daunting and perhaps even impossible. Yet even an incomplete sketch of the impact of contaminants on the marine environment will be a powerful tool to reach a broader audience.

   A database alone is not enough. What is needed is a concerted and collaborative effort to use the data that do exist to tell a story to policymakers, business leaders and individuals about marine pollution. "The stumbling block with these projects is always that you can put out infinite amounts of data, but if there's no clear why or usage for it, it's just a lot of data," says Susan Ruffo, senior advisor for ocean and climate at the UN Foundation.

5. **To catalyse change**

   The ultimate purpose of building a comprehensive global understanding of marine pollution is to drive action: to use empirical evidence to persuade and guide policymakers, business leaders, investors, voters and consumers to tackle the growing threat of pollution to ocean health.

   A lack of data is often used as an excuse for inaction. And while there is much work to do to build a comprehensive global map of marine pollution, there is also a lot we already know. A critical aim will be to encourage immediate action in areas where there is already sufficient evidence. "It will be very helpful to show how much data we have on the science side in contrast to the actual action taken," says Mr Wang.

A call to action

While *The Invisible Wave* was an attempt to review the current state of knowledge about marine pollution, this discussion paper aims to spark a discussion about the current state of data collection, collaboration and communication as it relates to our understanding of the impact of pollution on ocean health.

Over the course of 2023, we plan to convene stakeholders in the ocean community to co-design a process for building a comprehensive, collaborative, global understanding of marine pollution. Over the first months of the year, we will seek submissions in response to this discussion paper, asking:

- Is there a genuine need for a global effort to address marine pollution data gaps? Why or why not?
- What would it take to support and build upon existing global data collection and governance bodies and frameworks to develop a comprehensive picture of marine pollution?
- Which organisations need to be involved to ensure success?
- How could existing bodies and frameworks be expanded to not just warehouse data but also to usefully communicate it to the public and decision-makers in a way that drives meaningful change?

In addition to these questions, we propose a series of recommendations, or calls to action, for the global ocean pollution data community to coalesce behind:

1. That marine pollution—beyond plastic—be central to the agenda at the 2025 UN Ocean Conference and other key meetings such as the UN Environment Assembly in 2024, with a view to raising awareness and catalysing action among policymakers.
2. That the UNOD framework be used to foster effective collaboration between the various agencies that collect and hold data and other resources relevant to understanding marine pollution, including (but not limited to), UN agencies, national government agencies, universities and scientific organisations, and the private sector.
3. A roadmap, by 2025, which sets out the pathway to building a comprehensive global understanding of marine pollution. This process must incorporate the widest possible range of actors from the UN system, national governments, scientific agencies, universities, NGOs and the private sector, including technology companies.[59]
4. For a diverse group of projects and initiatives, including Back to Blue, to work collaboratively with scientists to raise awareness and use existing marine pollution data to tell the story to policymakers, business leaders and the broader public.

In publishing *The Invisible Wave*, we set out to spark a global conversation about marine pollution in its broadest sense. Our (unashamedly ambitious) goal is to have a transformational impact on knowledge and awareness of marine pollution. In so doing, we hope to catalyse—and contribute to shaping—a co-ordinated global response to marine pollution.

Make a submission in response to this discussion paper at backtoblueinitiative.com/take-action-on-ocean-pollution.

Submissions close on April 30th, 2023.

Interviewees

We would like to thank the following interviewees for sharing their time and expertise. Any errors remain our own:

Name	Role	Institute
Francesco Tubiello	senior officer and team leader of environmental statistics	Food and Agriculture Organisation of the UN
Kenneth Leung	chair professor of environmental toxicology and chemistry, director of State Key Laboratory of Marine Pollution	City University of Hong Kong
Zhanyun Wang	senior scientist	Empa-Swiss Laboratories for Materials Science and Technology
Tom Redd	operations manager	HUB Ocean
Marta Venier	environmental chemist	Indiana University
Henrik Enevoldsen	head of ocean science section a.i.	Intergovernmental Oceanographic Commission of UNESCO
Therese Karlsson	science and technical advisor	International Pollutants Elimination Network
Matteo Vinci	marine litter data manager for EMODnet Chemistry	National Institute of Oceanography and Experimental Geophysics
Marina Lipizer	scientist	National Institute of Oceanography and of Applied Geophysics
Eric Kihn	director of the National Centers for Environmental Information's (NCEI) Oceanographic and Geophysical Science and Services Division	NOAA

Jamie McMichael-Phillips	director	Seabed2030
Susan Ruffo	senior advisor for ocean and climate	UN Foundation
Bethanie Carney Almroth	associate professor and researcher of ecotoxicology and zoophysiology	University of Gothenburg
Chris Ruf	professor of climate and space sciences	University of Michigan
Geoff MacFarlane	marine ecotoxicologist, professor and associate editor of the Marine Pollution Bulletin	University of Newcastle
Miriam Diamond	environmental chemist and a professor	University of Toronto
Jonathan Baines	ocean data manager of the Sustainable Ocean Initiative and project lead of Ocean Watch	World Resources Institute

Much of this report was based on research and interviews conducted by Back to Blue for The Invisible Wave, an in-depth examination of marine chemical pollution published in 2022. To download the full report, the executive summary or individual chapters, visit: backtoblueinitiative.com/the-invisible-wave-getting-to-zero-chemical-pollution-whitepaper/

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