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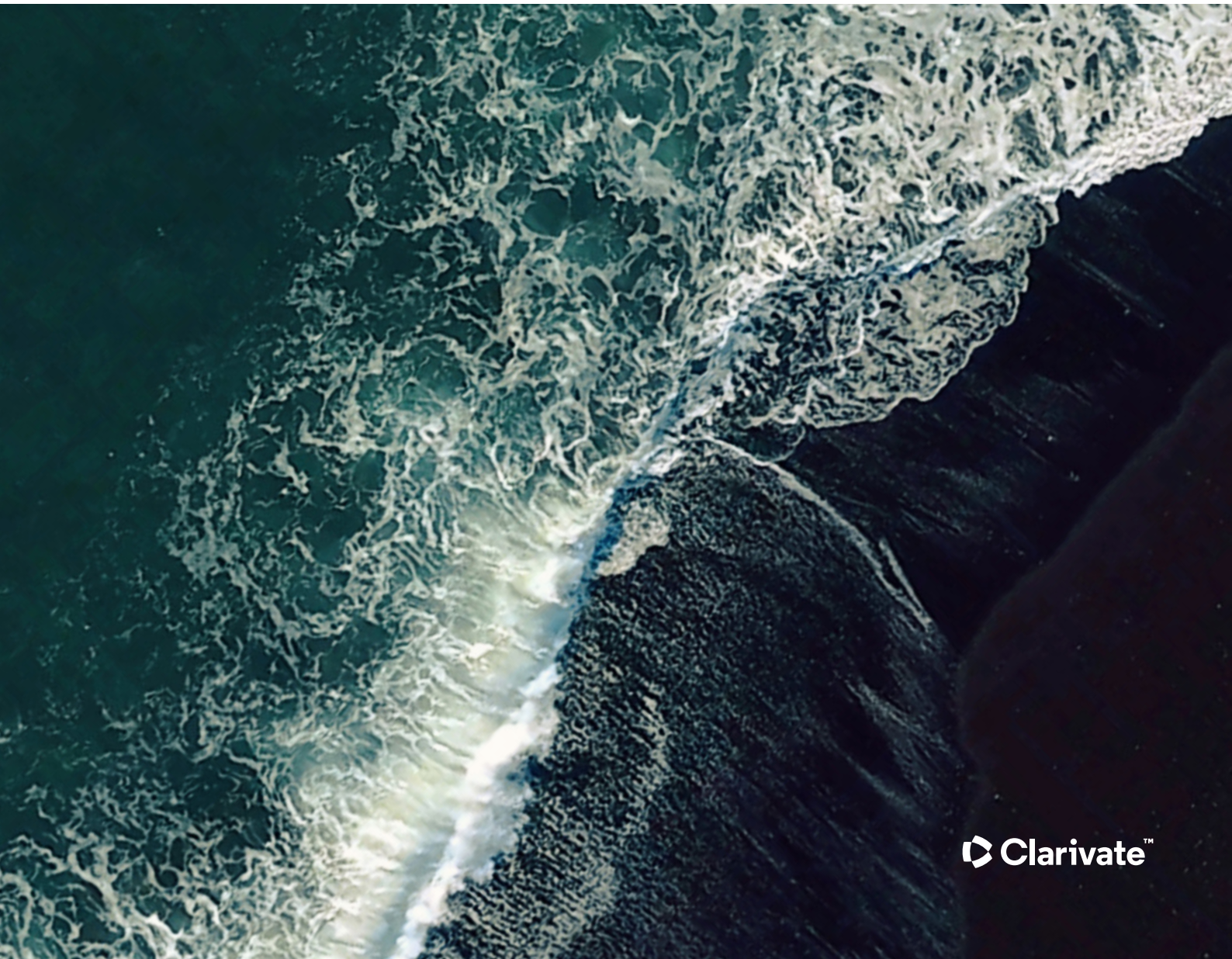
Global Research Report

Ocean science: sustainability concerns add urgency for research

Ross Potter and Brodie Pearson



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About the Institute for Scientific Information

The Institute for Scientific Information (ISI) at Clarivate™ has pioneered the organization of the world's research information for more than half a century. Today it remains committed to promoting integrity in research while improving the retrieval, interpretation and utility of scientific information.

It maintains the knowledge corpus upon which the Web of Science™ index and related information and analytical content and services are built. It disseminates that knowledge externally through events, conferences and publications while conducting primary research to sustain, extend and improve the knowledge base. For more information, please visit www.clarivate.com/webofsciencegroup/solutions/isi-institute-for-scientific-information/.

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Cover image: Cold ocean waves washing down the black sand beach in Iceland.

Photographer: Luka Lajst

Executive summary

- This analysis of ocean science represents our first report with a topical focus in a decade. Given the multi-disciplinary nature of the field, we use a hybrid approach including journal-based definitions (Web of Science subject categories), article-level clustering (InCites Benchmarking & Analytics™ Citation Topics) and custom, targeted keyword search criteria to evaluate ocean science research between 2000 and 2020.

- We give special attention to the five main ocean basins (Arctic, Atlantic, Indian, Pacific and Southern), revealing insights into the geographical distribution of both ocean science and the researchers.

- We collected nearly three quarters of a million ocean science-related documents and, separately, identified just over 100,000 with a specific ocean basin focus. The two most prominent Web of Science subject categories within the large corpus were Marine Freshwater Biology and Geosciences, Multidisciplinary (both 16%). The most prominent Meso level Citation Topics, based on an article-level classification, for the smaller selection on oceans basins were Marine Biology (35%) and Oceanography, Meteorology and Atmospheric Sciences (25%).

- Ocean science research output has increased threefold over the period, a greater increase than the total volume of Web of Science (two and a half times). Ocean basin research has also increased threefold for all oceans, except the Pacific, whose publication output has increased fourfold mainly due to the rise of Chinese research in the region (Figure 1).

- Two differing analyses drawing on Citation Topics data illustrate the astonishing growth of microplastics research, an upsurge in output reminiscent of the excitement and activity of high-temperature superconductivity in the late 1980s, or CRISPR (i.e., gene editing) during the last decade. This growth, pronounced since 2015, may be related to the introduction of the United Nations' Sustainable Development Goals (SDGs) in 2015. Growth in other Citation Topics such as Climate Change may also be associated with the targets of SDGs.

- The U.S. share of ocean basins research is in line with its overall world share. However, its dominance in the early 21st century – as well as the contributions of other G7 members – has been eroded by a rapid rise in research output from Mainland China (Figure 5). Some countries have clear foci for their ocean basin research: Russia in the Arctic; India and Iran in the Indian Ocean; Mainland China in the Pacific (Table 2).

- Ocean research is globally connected and, crucially, also includes significant collaboration with island nations and territories at the literal forefront of ocean science (e.g., New Caledonia, Bermuda). However, sub-Saharan African contributions, apart from those of South Africa, are minimal. External partnerships are likely required to build or operate the necessary infrastructure for ocean science research. Achieving the SDGs may drive such partnerships (Figure 6).

- Institutional output in all ocean basins is led by national academies (e.g., Russian, Chinese) or research institutes (e.g., U.S. National Oceanic and Atmospheric Administration [NOAA], British Antarctic Survey), illustrating the highly specialized nature of ocean science and likely reflecting its infrastructure-reliant nature (Table 3).

Introduction

Earth's oceans cover approximately 70% of its surface and ultimately reach a depth of ~11 km in the Mariana Trench in the Pacific Ocean. (Mt. Everest, for comparison, reaches a height of "only" ~9 km.) Most of the life on Earth is in its oceans, whether it is the fish that provide sustenance to coastal communities, or the plant life that supplies much of the air that we breathe (at least 50% of photosynthesis happens in the ocean). The oceans also mediate how Earth's climate changes, for example, by exchanging immense amounts of thermal energy and gasses, such as carbon dioxide and oxygen, with the atmosphere, or through the impact that ocean conditions have on the fate of polar ice (this ice reflects many of the sun's warming rays back to space and provides essential habitats).

The oceans are also central to the rapidly growing Blue Economy, which supports tens of millions of jobs in fishing, tourism, transport etc., and has a GDP of trillions of dollars. To ensure that growth of the Blue Economy is sustainable, we must understand the changing oceans, as well as the chemistry and biology of the ecosystems contained within.

Achieving the necessary balance – addressing the damages wrought by climate change and other consequences of human activity, while maintaining the accessibility of fisheries and other essential components of the Blue Economy – will likely be a central imperative, which must be informed by extensive and accurate ocean science.

"How inappropriate to call this planet Earth when it is quite clearly Ocean."

Attributed to Arthur C. Clarke

For tens of millennia, humans have used sub-regions of the ocean for navigation and sustenance. However, understanding the global ocean has proved to be more challenging because it requires information about the vast and deep ocean at various places and times. As a field of study, modern ocean science was created a little more than 100 years ago, subsequent to the growing number of oceangoing ships and the development of vessels that could explore previously inaccessible polar regions, allowing global surface data collection. This study was later complemented by the development of techniques to look below the ocean surface, such as sound waves and submersible instruments. These tools allowed the measurement of bathymetry and sub-surface water, providing discoveries spanning from the existence of life in the deep ocean to the movement of continents over millions of years.

Ocean sciences have continued to grow in the last 50 years, with two particularly significant advancements. First, computer models were developed that simulate the physical, chemical, biological and geological processes in the ocean. These models are used to isolate and understand processes that are challenging to observe, to generate data about complex systems and to predict the future state of the ocean, atmosphere and other coupled components of the Earth system.

Second, satellites have been launched that can remotely observe the ocean surface, allowing the global measurements of various properties, ranging from the temperature and motion of surface water to the amount of near-surface chlorophyll (a proxy for small plant life).

The evolution of traditional ocean science fields (biological, chemical, geological, and physical) has been paralleled by growth in the Blue Economy and acceleration of changes in climate and ocean systems. The intersection between these areas motivates the current UN Decade of Ocean Science (UNDOS)[1] announced in 2017 by the UN General Assembly and projected to run through 2030, with the mission of ensuring sustainable ocean development using transformative ocean science.

Specifically, the target outcomes of UNDOS include an ocean that is clean, resilient, productive, safe and predictable, as well as open and equitable access to data, information and technology. These UNDOS outcomes require a global community of ocean scientists to work together to quantify the global oceans, in addition to developing region-specific knowledge.

UNDOS is one of several programs that fall within the UN's 2030 Agenda for Sustainable Development, the core of which are the Sustainable Development Goals (SDGs) introduced in 2015: seventeen call-to-action goals "to achieve a better and more sustainable future for all people and the world by 2030" (UNDOS mission statement).

SDG 14: Life below water deals specifically with oceans to more effectively protect and manage a resource that has been heavily abused. Defined goals include "[preventing] and significantly [reducing] marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution by 2025" and " [increasing] the economic benefits to Small Island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism by 2030."

This is our first report with a topical focus in a decade and comes at a crucial time for ocean science. Using bibliometric data and analyses, we identify existing and emerging research fields, across all ocean basins, as well as the current collaboration pathways. This study allows us to identify gaps and trends in international ocean science collaborations, including the rise of Mainland China and absence of sub-Saharan Africa in global collaboration networks. Such information is essential for the effective growth of the ocean science community and the ultimate achievement of SDG 14: Life below water.

[1] https://www.oceandecade.org/

Bibliometric studies

Over the past several decades, ocean science has captured the attention of bibliometricians and/or scientometricians – social scientists who typically use quantitative analysis of the journal literature to characterize the size, scope and trends of a research field. These analysts may also identify key players: nations, institutions, individuals, funders and journals. Briefly stated, papers serve as a proxy for activity in terms of research output, and citations to papers represent evidence of influence, visibility and scholarly impact. These indicators are usually adjusted, or normalized, to allow for comparisons across fields and years. Analysis of bibliometric data on a research domain benefits greatly from interpretation by experts in the area, hence the authorship of this report.

Published within the last decade, four general studies of oceanography applying bibliometric analysis merit mention here: a study of publications funded by the National Oceanic and Atmospheric (NOAA) Office of Ocean Exploration and Research (Belter, 2013); a comparison of different nations' contributions to the International Ocean Discovery Program (Wang et al., 2016); a survey of research activity in oceanography and marine geoscience since the end of the Second World War (Mitchell, 2020); and an analysis of ocean remote-sensing research over the last three decades (Wang et al., 2022). The sweep and depth of these themes illustrates one of the benefits of scientometric analysis: a top-down view derived from analysis of the global research literature offers insights that are beyond even the knowledge and experience of researchers themselves.

As may be expected in a field as broad and multidimensional as ocean science, a bibliometric approach produces a great diversity of topics identified in oceanography-related papers: acidification of the oceans; Antarctic research of many types; biodiversity studies; the emergence of the Blue Economy; fishing, fisheries, and sustainability; global change and the future ocean; marine protected areas and spatial planning; ocean engineering and power generation; ocean literacy as a concept; remote sensing; as well as analyses of specific journals of the field or nations and institutions active in this research area.

Data collection: many choices

In this report, we offer several quantitative descriptions of ocean science using different methods, each with its own perspective and degree of focus. We used a journal-based approach to produce one collection and, for another, a hybrid extraction method employing Web of Science categories plus keywords. Neither method should be considered definitive.

For comparison, we next examined select data from an article-level network scheme using Citation Topics in InCites Benchmarking & Analytics™. Identification of hot and emerging themes is a special analytical advantage of citation-based clustering. To demonstrate this capability in specifying a rapidly growing, hot subject in ocean science, we call out the topic of microplastics in the marine environment.

Finally, we analyzed the field from the perspective of research related to five major ocean basins. This revealed the attention each ocean basin is receiving, the national and international source of this attention as well as patterns of international collaboration.

Web of Science categories… and more

The Web of Science provides two field-classification schemes: not only 254 Web of Science categories corresponding to fields and subfields, but also 152 Research Areas, generally representing a higher-level aggregation. In InCites Benchmarking & Analytics™, 23 different field schemas are available for analysis, and all, except Citation Topics, are based on journal-to-field assignments.

In the Web of Science Core Collection™, for publication years 2000 to 2020, about 150,000 items were assigned to the Web of Science category Oceanography. This category is currently defined by 65 field-specific titles, such as *Journal of Physical Oceanography* and *Bulletin of Marine Science*. But plainly, much research related to ocean science is published in journals assigned to other Web of Science categories or in multidisciplinary journals not assigned to a specific field, such as *Nature* or *PLOS ONE*. Because the Web of Science category scheme allows a journal to be assigned to more than one category, based on the editorial judgment of Clarivate subject specialists, the other categories associated with the 150,241 papers classified as Oceanography can inform a broader, more comprehensive search for relevant items.

The other categories, in rank order by number of publications, are Marine and Freshwater Biology (40,028); Engineering, Ocean (19,456); Engineering, Marine (18,331); Geosciences, Multidisciplinary (13,671), Meteorology & Atmospheric Sciences (13,398); Ecology (12,361), Engineering, Civil (11,267); Limnology (10,697), Fisheries (10,205), and so on. Combining these categories and several more associated with Oceanography (and eliminating duplicate items) produced some 3.5 million publications. That search, of course, captured too much. So, a search for Web of Science Core Collection items with the terms "marine*", "ocean", "sea" or "seas" in title, abstract or keywords was conducted, for publication years 2000 to 2020. The search produced about 818,000 publications.

By combining the Web of Science category extraction and the second based on general ocean terms using the Boolean AND operation, we identified 475,515 publications that, after review, could be described as approximating ocean science – not exhaustive, but a large and sufficiently diverse collection to represent the field and give us a thumbnail sketch. Notice that by this hybrid method for defining the field, the resulting collection was three times as large as using the Web of Science category Oceanography alone.

Lastly, we searched for any item that carried the name of a major ocean basin (Arctic, Atlantic, Indian, Pacific, Southern) or its constituent parts (for example, Kara Sea, Laptev Sea, Beaufort Sea and Amundsen Gulf for the Arctic Basin). This produced 453,835 items in the Web of Science Core Collection for 2000-2020.

Combing the hybrid search (475,515 items) with the ocean basins search (453,835) using Boolean OR yielded a final collection of 742,788 publications.

Combining the hybrid search with the ocean basins search using Boolean OR yielded a final collection of 742,788 publications.

A few insights from analysis of these nearly three-quarters of a million items:

- Output in our ocean science collection grew more than threefold in two decades, from 17,757 items in 2000 to 59,275 in 2020. For comparison, the totality of Web of Science content increased about two and a half times during the period.

- The Web of Science categories represented most prominently in the collection were Marine Freshwater Biology (15.7% of items), Geosciences, Multidisciplinary (15.7%), Environmental Sciences (14.2%), Oceanography (13.8%), Ecology (8.5%), Meteorology & Atmospheric Sciences (7.6%) and Fisheries (7.0%).

- The top dozen journals by number of papers were *Geophysical Research Letters, Marine Ecology Progress Series, Marine Pollution Bulletin, Journal of Geophysical Research Oceans, Journal of Climate, Aquaculture, Earth and Planetary Science Letters, Zootaxa, Journal of Coastal Research, PLOS ONE, Science of the Total Environment,* and *Palaeogeography, Paleoclimatology, Palaeoecology*.

- The top five journals publishing the greatest number of highly cited papers (top 1% by citations for field and year of publication) were: *Science of the Total Environment, Environmental Pollution, Nature Geoscience, Nature* and *Nature Climate Change*.

- In terms of national output, the United States ranked first and Mainland China second with 227,355 items or 31% and 79,388 or 11%, respectively. In the last two decades, Mainland China has dramatically increased its publication output and has taken world share from others. In 2000 to 2004, Mainland China ranked 10th in output in our collection, with a 4% share, but by the 2015 to 2020 period it ranked second behind the United States, with a 16% world share compared to 28% for the United States, which fell from a 36% share in 2000 to 2004. The United Kingdom, France, Germany, and Canada occupied the middle ranks of the top 10, while Australia improved over the period, moving from 7th to 4th place. Japan lost ground, dropping to 10th from 6th at the beginning of the period.

- Large research organizations led in institutional output: National Centre for Scientific Research (France), the Chinese Academy of Sciences, NOAA, Helmholtz Association (Germany), the Russian Academy of Sciences, the Spanish National Research Council, University of Washington (U.S.), Sorbonne Universite (France), National Aeronautics and Space Administration (U.S.), and the U.S. Geological Survey.

Output in our ocean science collection grew more than threefold in two decades.

A deeper dive: Citation Topics

In addition to data collection using terms or journal groupings that define a field, an alternative method relies on networks of individual papers connected through citation linkages. For many years, Web of Science categories were the standard in bibliometric studies, both for analysis and for the creation of baselines to normalize citation counts. Increasingly, however, scientometricians express a preference for article-level, rather than journal-level, clustering of papers for field definition (Mingers and Leydesdorff, 2015). This preference underscores the benefit of citation indexing as originally described (Garfield, 1955): authors embed their expertise and judgment in the cited references appended to their papers, pointing to other relevant and closely related publications. Such informed, precise connections – by an "army of indexers," as Garfield put it – explain the efficiency and productivity of using a citation index for information retrieval, and, in aggregate, using a citation network for delineating fields and research topics.

In 2021, Clarivate introduced Citation Topics in InCites Benchmarking & Analytics™, developed in cooperation with leading scientometricians at the Centre for Science and Technology Studies (CWTS) of Leiden University (Potter, 2020[2]; Szomszor et al., 2021). Citation Topics offers an article-level clustering of Web of Science-indexed items from 1980 to today.

Clustering relies on an algorithm that examines all direct citations and calculates the strength of citation links among documents (Traag et al., 2019). Citation Topics includes more than 60 million items, each assigned to a single cluster. At the most granular level, there are currently 2,457 clusters, called Micro topics. A clustering of the Micro topics (by measuring similarity among the Micro topic clusters) yielded 326 Meso topics. And clustering Meso topics produced 10 Macro topics, the highest level of aggregation in the Citation Topics hierarchy.

Citation Topics allows for a deeper dive into the data. Micro topics can also highlight emerging areas that are difficult to recognize using characteristically broad journal-based schemes.

Among the 10 Macro topics are domains in which we expect to find ocean-related research, such as Agriculture, Environment & Ecology, Physics, or Earth Sciences. For example, nested beneath Earth Sciences, at the Meso level, we find Oceanography, Meteorology & Atmospheric Sciences, and under that cluster at the Micro topic level there is a specialty research area on Sea Level Rise. In the hierarchical structure for Agriculture, Environment & Ecology, we find Marine Biology at the Meso level and many ocean-related research themes at the Micro topic level: Microalgae, Copepods, Phytoplankton, Cephalopoda, Seagrass, Coral Reefs, and Fisheries.

Scientometricians express a preference for article-level, rather than journal-level, clustering of papers for field definition.

[2] Also see https://incites.help.clarivate.com/Content/Research-Areas/citation-topics.htm and https://wok.mimas.ac.uk/support/documentation/presentations/citationtopics202101.pdf

Microplastics: a macro concern

Of special interest in the hierarchy for the Macro area Agriculture, Environment & Ecology – nested beneath the Meso topic Herbicides, Pesticides & Ground Poisoning – is the Micro topic Microplastics.

For the period 2000 to 2020, some 6,500 documents constitute this cluster. Especially notable is the recent upsurge in publication: 289 items in 2015, 366 in 2016, 531 in 2017, 887 in 2018, 1,339 in 2019 and 2,089 in 2020. If we extend our view to 2021, the number of papers in this cluster more than doubled from 2020 to 2021 – to 4,572! In its rate of growth, microplastics represents a revolution in research activity resembling high-temperature superconductivity, graphene, induced pluripotent stem cells, or CRISPR (i.e., gene editing), for example.

Also, among the papers we surveyed that used bibliometric methods in studying ocean science research, the theme of microplastic material in the marine environment was dominant (e.g., Harris et al., 2021).

While the topic of microplastics in the environment has long been studied, the recent priority given to the SDGs and funding in support of these may have prioritized and accelerated research in this area. Among universities most active in this topic are the University of Plymouth, United Kingdom; Wageningen University and Research, Netherlands; and East China Normal University, Mainland China. The former published 134 papers in the Micro topic Microplastics during 2000 to 2020, and these exhibited category-normalized citation impact (CNCI) at more than twice the expected, or baseline, rate (2.24).

At Plymouth, the leading researcher is Richard C. Thompson, OBE, FRS, Professor of Marine Biology and Director of the Marine Institute at the University. His website states: "In 2019, the University was awarded the Queen's Anniversary Prize for the pioneering research of Richard and his colleagues on marine microplastics pollution and its impact on the environment and changing behaviour."

These details illustrate the value of drilling down in Micro topics and the level of data granularity and specific insights available in Citation Topics.

Data curation: ocean basins

As mentioned, the choice of method for data extraction and subsequent analysis should be appropriate for the assessment undertaken. We had a specific interest in understanding how research activities focused on different ocean basins were related to each other, and developed the ocean basins search, previously mentioned, to answer this question.

In the analysis that follows, we required one of these terms (though not necessarily the same term) to be present in both the title and abstract of articles for Web of Science Core Collection items published 2000 to 2020 (articles being the only document type considered – as opposed to reviews, letters, editorials and such – since articles represent original research). This search yielded 106,021 documents. The reason why this is different from the count of 453,835 mentioned above using the ocean basins search is the restriction to articles only and the requirement that relevant terms appear in both title and abstract. By tightening the search criteria, there is a higher probability that the items analyzed are specific to the analysis.

Table 1 records the number of publications identified with each main ocean basin. The items associated with each basin were then collated with the Citation Topics classification scheme, and the Macro, Meso and Micro topics most frequently matched were noted to give insight into the nature of research for each basin.

By tightening the search criteria, there is a higher probability that the items analyzed are specific to the analysis.

Table 1. The ocean basins

Ocean basin	Global ocean surface area† (%)	Volume† (million km³)	Bordering sovereign nations	Publications	Main Macro, Meso and Micro Citation Topics‡
Arctic	4.3	19	6§	5,101	Earth sciences; Marine biology; El Nino Southern Osciliations (ENSO)
Atlantic	23.5	310	94	46,559	Agriculture Environment & Ecology; Marine Biology; Fisheries
Indian	19.5	264	36	10,845	Earth sciences; Marine Biology; ENSO
Pacific	44.7	660	42	39,564	Agriculture Environment & Ecology; Marine Biology; ENSO
Southern	6.1	72	7#	3,952	Agriculture Environment & Ecology; Marine Biology; Phytoplankton

†. https://www.ngdc.noaa.gov/mgg/global/etopo1_ocean_volumes.html
‡. Citation Topics not necessarily children of the higher topic level
§. Greenland is excluded
#. Territorial claims

Source: Web of Science data and ISI research

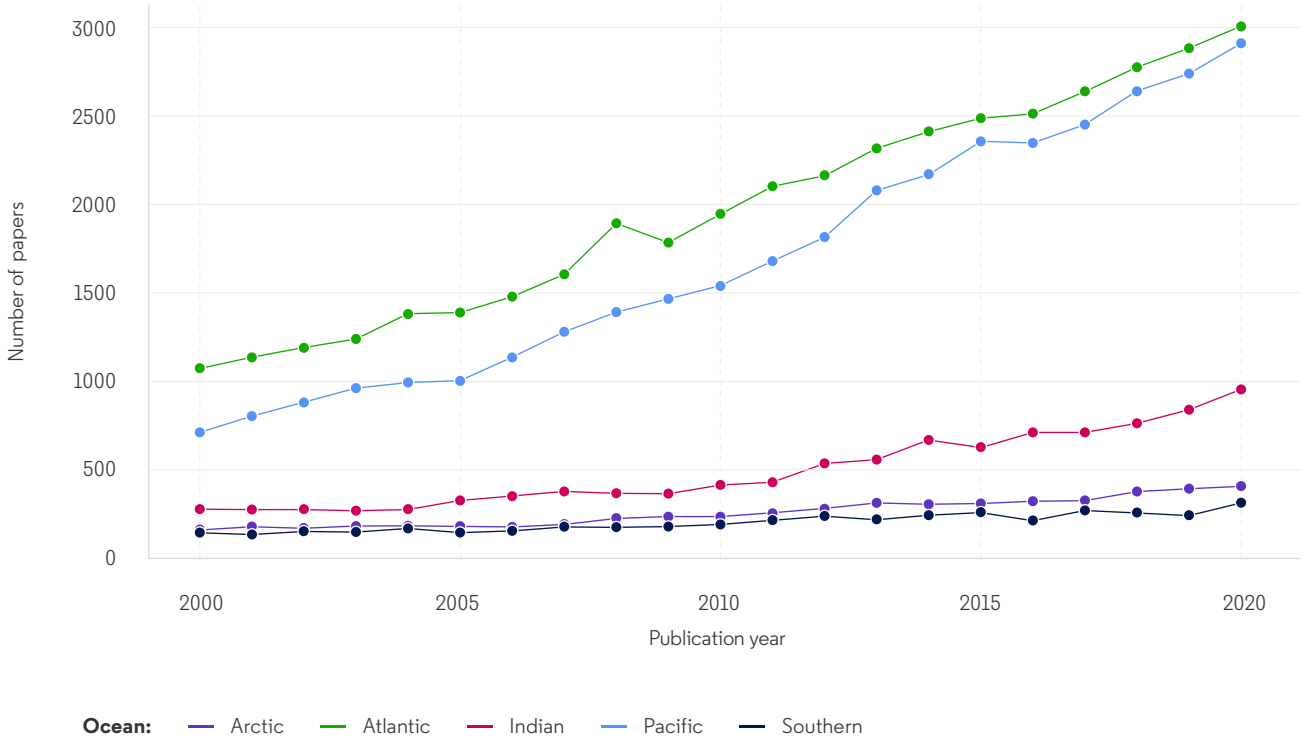
Ocean basins: research output and topic focus

Of the five ocean basins, the Atlantic Ocean is the most researched, and has been since 2000 (Figure 1). However, Pacific Ocean research is now close to reaching parity with its neighbor. The Pacific has seen a fourfold increase overall, whereas all other oceans have roughly tripled in output. As the largest two by volume, with proximity to well-established large research economies, the Atlantic and Pacific basins would be expected to take the largest share of article output. Indian Ocean research is hovering just under 1,000 papers a year, up from around 500 papers in 2010 and about 270 in 2000. Research output in each of the polar (Arctic and Southern) oceans is similar throughout the period and now numbers around 300 to 400 papers per year.

At the Citation Topic Macro level, the domains of Earth Sciences and Agricultural, Environment and Ecology dominate in studies of ocean basins, according to our matching of the articles with the Citation Topics classification scheme. Together, these account for more than 90% of research within any ocean (with a roughly even share between the two). For the Arctic and Indian oceans, Earth Sciences is the main topic; for the remaining oceans it is Agricultural, Environment and Ecology. Earth Sciences accounts for only 30% of Atlantic research – far lower than any other ocean.

At the Meso level, the largest topic for all oceans is Marine Biology (27% in the Atlantic and up to 42% in the Southern Ocean), followed by Oceanography, Meteorology and Atmospheric Sciences (OMAS) (14% in the Atlantic to 32% in the Southern Ocean). Other major Meso themes include Geology, Geochemistry and Geophysics (6 to 11%), Archaeology (4 to 8%), and Zoology and Animal Ecology (3 to 6%).

Figure 1. Yearly paper counts by ocean within our ocean basin-specific dataset.



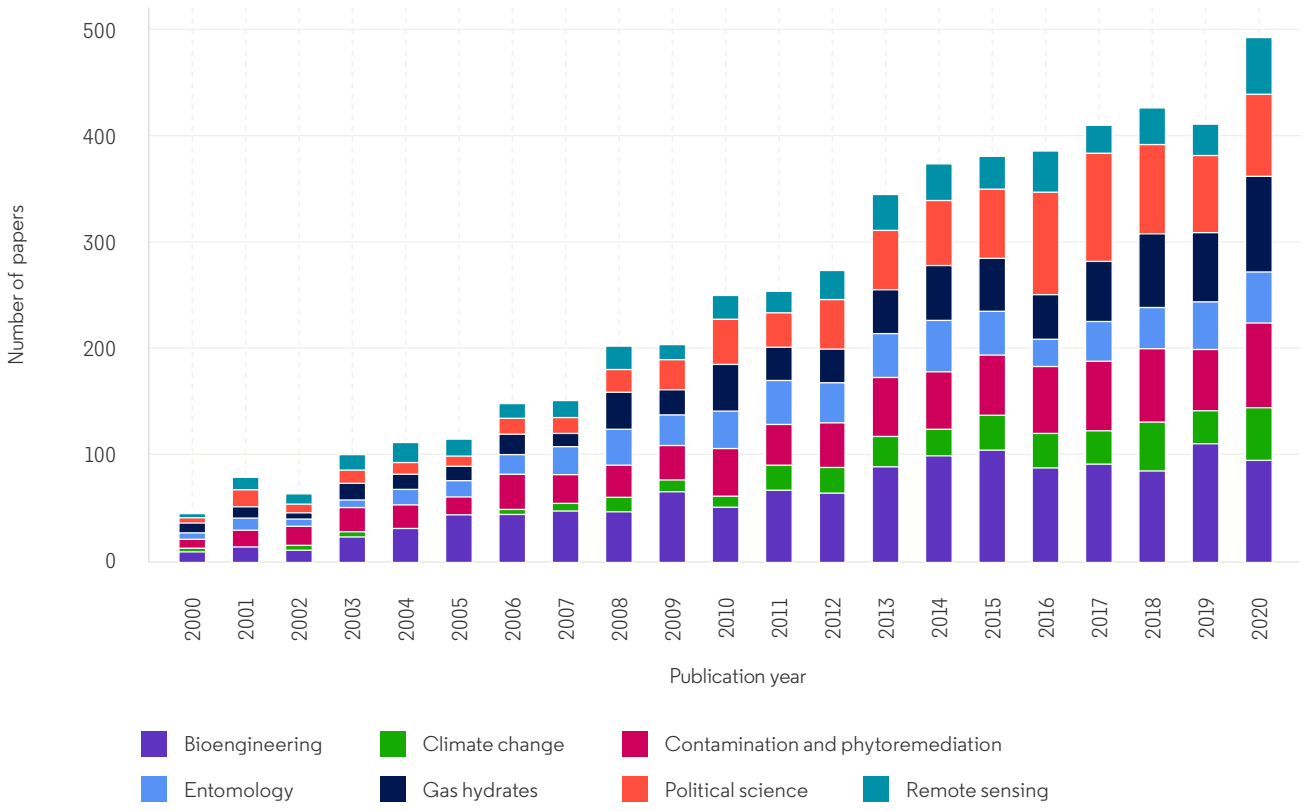
Source: Web of Science data and ISI research

At the Micro level, El Nino Southern Oscillation (ENSO) is the main topic for the Arctic (17%), Indian (16%), and Pacific (10%) oceans. Atlantic and Southern ocean research is mainly concerned with Fisheries (7%) and Phytoplankton (25%), respectively. These topics match with the broad human importance of ENSO, which influences global weather patterns, as well as the large fishing economy of the North Atlantic and the unique planet-wrapping geometry of the Southern Ocean which makes it a biological hotspot.

The number of papers within each Citation Topic can be analyzed over time to highlight topics of emerging or growing importance. Since this considers our ocean basin-specific dataset, which has a high precision but lower recall, not all papers within a given Citation Topic are considered. However, our dataset represents a 'sample' which may provide a good guide to overall trends (Rogers et al., 2020) within each Citation Topic (e.g., the sudden growth of Microplastics – see below).

Seven Meso topics that have received increasing attention since 2000 are Bioengineering, Climate Change, Contamination & Phytoremediation, Entomology, Gas Hydrates, Political Science, and Remote Sensing (Figure 2). Bioengineering exhibited the greatest increase in output, and this reflects innovation and activity in the Micro topics of Biodegradation, Microbial Fuel Cells, and Constructed Wetlands. The growth of Political Science represents the Micro topics of Foreign Aid, World Trade, International Relations, and Geoengineering in relation to ocean science. The diversity of these topics demonstrates the increasing breadth of ocean research.

Figure 2. Yearly paper counts for Meso level Citation Topics with ≤10 papers in 2000 and ≥50 papers in 2020 within our ocean basin-specific dataset.



Source: Web of Science data and ISI research

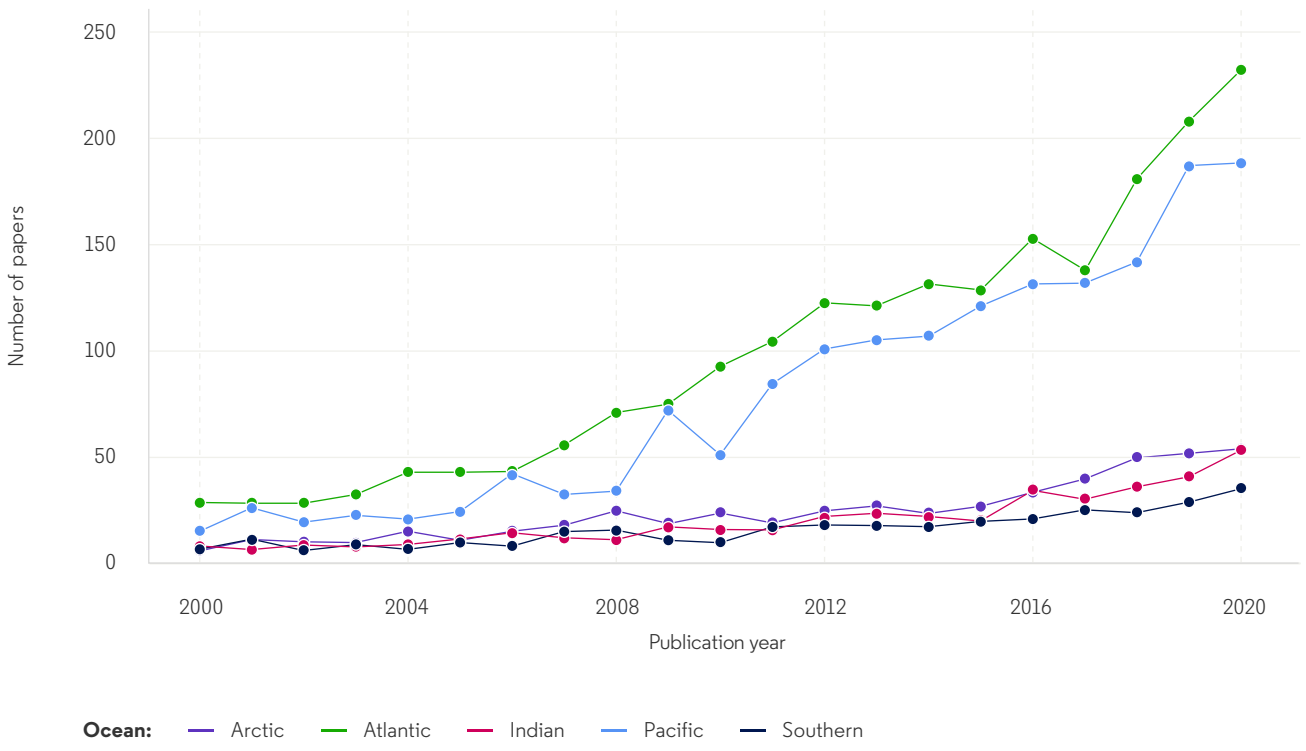
Climate change research has an inherent link to ocean science. Ocean water can hold huge amounts of heat and gases (carbon dioxide, oxygen, etc.), and the slow and global overturning of water governs where these properties are absorbed from the atmosphere, how long they are stored in the deep ocean, and when and where they get released back to the atmosphere. At the same time, increases in carbon dioxide drive ocean acidification. The warming and acidification of the oceans affect marine life, which supplies most of the oxygen we breathe (coral bleaching is an observed example of this effect).

These are just some of the many ways that the oceans mediate the human experience of climate change.

The growth of climate change research was also observed by tallying the number of papers with "climate change" appearing in either the title, abstract or keywords for each ocean subset of papers in our basin-specific dataset. As with our ocean basins research output findings, most climate change papers are associated with the Atlantic and Pacific oceans, with Pacific-focused papers lagging those that are Atlantic-focused (Figure 3).

The relative share of climate change papers, measured in this manner, is similar to the overall ocean basins share, except the Arctic Ocean, whose climate change paper share is roughly twice (10%) that of its overall ocean basin share. All oceans show an increase in climate change-related papers from 2015 which is likely attributable to the issuance of the SDGs. For a more in-depth analysis on global climate change research from both topical and collaboration perspectives, please read our recent ISI Insights paper[3] (Potter and Halevi, 2022).

Figure 3. Papers with "climate change" in the title, abstract or keywords of our ocean basin-specific dataset.



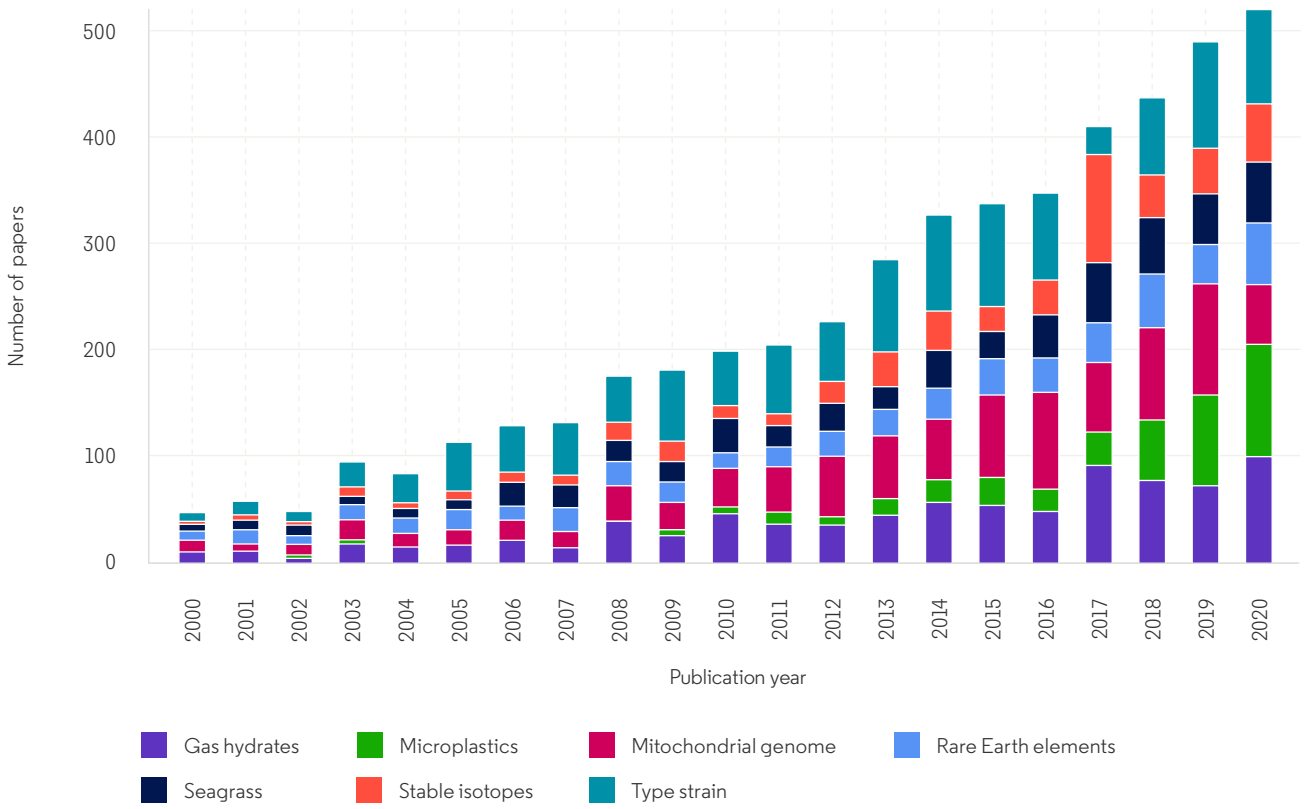
Source: Web of Science data and ISI research

[3] https://clarivate.com/lp/climate-change-research-collaboration/

At the Micro level, another seven topics could be identified whose output increased significantly since 2000: Gas Hydrates, Microplastics, Mitochondrial Genome, Rare Earth Elements, Seagrass, Stable Isotopes, and Type Strain (Figure 4). Gas hydrates reside in some marine sediments and can be associated with biological communities. Their carbon content makes them a valuable energy resource, though decomposition can release large amounts of methane (a greenhouse gas) that can impact climate.

Type Strain, with a tenfold increase in output, and Mitochondrial Genome are both associated with (micro) biology and genomics (they are subclasses of the Bioengineering and Phylogenetics & Genomics Meso topics, respectively). Seagrass (a child of the parent Marine Biology) concerns flowering plants that grow entirely underwater and which contribute to the ocean ecosystem. Rare Earth Elements (Geochemistry, Geophysics & Geology) and Stable Isotopes (Archaeology) are related to the structure, age and evolution of material. The theme of Microplastics has already been highlighted but the output by ocean closely mirrors that of overall ocean basin research: most activity is in the Atlantic, then Pacific, Indian, and the polar oceans, with a steep rise in papers in the most recent five years for the three most active oceans, coinciding with the SDG introduction.

Figure 4. Yearly paper counts for microlevel Citation Topics with ≤10 papers in 2000 and ≥50 papers in 2020 within our ocean basin-specific dataset.



Source: Web of Science data and ISI research

Ocean basins: country output

The United States and Mainland China are the largest ocean-research producers (Figure 5a). While the United States has continuously led in output during 2000 to 2020, Mainland China has increased its output substantially. In this ocean basin research-specific dataset (a sampling but not a random sample – see Rogers et al., 2020), Mainland China surpassed the United Kingdom as the second-largest producer in 2011. Mainland China is now publishing roughly three quarters the output of the United States, with about 1,500 articles in our dataset published in each of the last two years. Brazil and Australia boosted output to the level of Canada and have surpassed Japan and Norway.

While the absolute output of the United States has increased, its relative share of papers has decreased from some 35% in the early 2000s to less than 30% by 2020 (Figure 5b). This is almost entirely due to the rapid increase in papers from Mainland China whose share was a modest 3% in 2000 but more than 20% by 2020. Mainland China's growth is mainly due to increasing focus on the Pacific, where its share has increased from about 5% in 2000 to over 40% in 2020, making it the largest contributor for the most recent year of analysis. The United States, on the other hand, has seen its Pacific share decrease from 45% in 2000 to 30% by 2020. Over the period 2000 to 2020, Mainland China was one of the top 10 research-producing countries in all oceans, bar the Atlantic (where it ranked 15th with an output comparable to Australia), having grown from a very modest presence (less than 5%) to at least 10%. Most other nations in the Figure exhibit relatively stable or declining world share. Exceptionally, Brazil's relative share increased from less than 2% to above 6%. This can be explained by a surge in Atlantic Ocean research, where Brazil's output share increased from about 4% in 2000 to 13% in 2020, ranking it second and trailing only the United States in contribution.

However, different trends can be seen when analyzing the overall output by ocean basins. Table 2 illustrates, for the G20 countries and five other comparators, the percentage share of research papers by ocean.

Research output of the United States stands at about a third of world output with all but the Indian Ocean. Mainland China's output is generally below its world share (about 20%), except concerning the Pacific, where its share is greater and second to the United States. The G7 countries of Germany, France, and the United Kingdom have a sizeable share of output across all oceans.

Russia holds the largest share of Arctic research (30%), just ahead of the United States (29%). Given the length of Russian coastline on the Arctic this is not surprising. However, Russia does not contribute much to research on any other ocean. Canada and Norway have a similar share of Arctic research (about 19%) which is also explained by extensive research networks and ocean proximity.

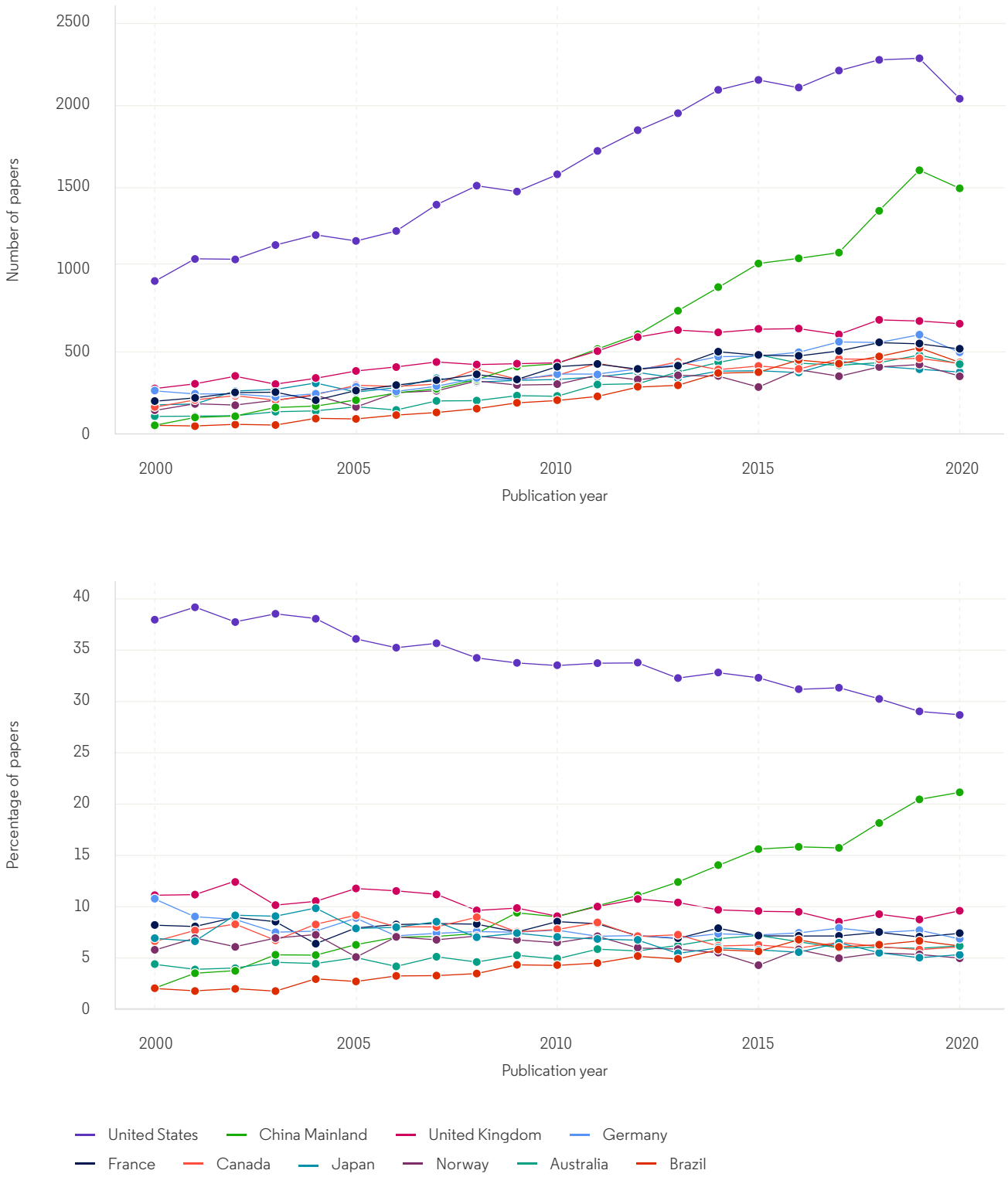
In the Atlantic, behind the United States, the United Kingdom has the highest share (14%). Norway, Germany, France, Canada, and Brazil have a similar output (around 10%) demonstrating an Americas-European research dominance in this basin.

Pacific research is dominated by its proximate, large research economies: the United States, Mainland China, Japan, Australia, Mexico and Canada. Each commands at least a 5% world share. The United Kingdom and France's shares are similar to that of Russia (about 4%), which borders the Pacific.

There is little remarkable about India claiming the largest share for research on the Indian Ocean (27%). France holds a 9% share, which is greater than established research economies that are far closer geographically, such as Mainland China (8%) and Australia (6%). This is likely due to the University of Reunion Island located in the Indian Ocean east of Madagascar, which contributes to 15% of all of France's papers on the Indian Ocean. The United States, geographically remote from the Indian Ocean, nonetheless has a share of 20%. Iran (9%) and Saudi Arabia (7%) exhibit a focus on the Indian Ocean; Egypt does too but has a slightly smaller share (6%). Year-on-year, Iran and Saudi Arabia have increased their Indian Ocean research programs at a similar rate, with both having a near zero share in 2000 and a roughly 13% share by 2020, ranking them behind only India, the United States, and Mainland China, having substantially surpassed countries including Germany, Japan and Australia.

Outside the Indian Ocean, India has a small share of Southern Ocean research (3%); otherwise its contribution is modest. Malaysia and Indonesia, despite their island settings between the Indian and the Pacific oceans, have surprisingly low levels of research output across all oceans. The same may be said of Turkey, despite its geographic position.

Figure 5. Yearly paper output for the Top 10 ocean basin research producing countries by: a) absolute output, b) percent (world share).



Source: Web of Science data and ISI research

In the Southern Ocean, apart from the United States, the United Kingdom holds the largest share (23%), despite its position on the Atlantic. This is likely explained by its territories in the Southern Ocean, a research base on Antarctica, as well as claims on Antarctica. Other countries with claims on Antarctica also hold notable research shares (Australia 17%, France 11%, New Zealand 7%), while Norway (4%) and Chile 2% (not shown) have minor shares, and Argentina (less than 1%) has a rather modest output despite its relative proximity. Germany, although it has no territorial claims in Antarctica, has a share of 18% – its largest research contribution to any ocean. This is mainly due to the work of the Alfred Wegener Institute of Polar and Marine Sciences (see Institutional Output, Table 3). Italy's largest share is also in the Southern Ocean, again likely due to the presence of two research bases on Antarctica.

South Africa's largest contributions are on the Indian and Southern oceans (3% shares). Despite the continent's extensive coastline on the Indian and Atlantic (and apart from Egypt's contribution in the Indian Ocean), no other African countries have a significant share of research output.

Table 2. Percentage of research papers by ocean for G20 countries and five comparator countries

	Ocean				
Country	**Arctic**	**Altantic**	**Indian**	**Pacific**	**Southern**
Argentina	0.08	1.97	0.06	0.22	1.09
Australia	1.39	2.52	6.57	8.47	16.93
Brazil	0.16	9.94	0.48	0.70	1.19
Canada	19.21	9.26	1.78	5.00	4.02
China Mainland	6.39	2.43	8.34	26.89	4.35
France	4.08	9.58	9.34	4.71	10.53
Germany	14.08	9.03	8.19	3.93	18.09
India	0.16	0.33	26.57	1.09	2.86
Indonesia	0.02	0.04	1.01	0.80	0.00
Italy	1.49	4.49	1.86	0.91	8.02
Japan	4.29	1.25	8.08	12.90	4.50
Mexico	0.08	3.03	0.23	5.85	0.20
Russia	30.31	1.92	1.89	4.41	3.54
Saudi Arabia	0.18	0.23	7.52	0.17	0.15
South Africa	0.18	0.82	3.32	0.32	3.44
South Korea	1.96	0.41	1.34	4.30	2.91
Turkey	0.12	0.68	0.21	0.13	0.03
United Kingdom	6.94	14.19	7.30	4.62	22.60
United States	29.27	33.43	20.40	36.52	37.22
Egypt	0.08	0.18	5.39	0.05	0.00
Iran	0.02	0.08	9.17	0.14	0.00
Malaysia	0.02	0.07	0.65	1.03	0.13
New Zealand	0.14	0.39	0.71	3.16	7.41
Norway	18.74	10.05	1.06	0.71	3.57

Source: Web of Science data and ISI research

Ocean basins: country collaboration

International collaboration has rapidly grown in all fields since the 1980s (Adams, 2012). Today, more than half of the articles attributable to any one country now have a co-author from another (Adams, 2013). Motivations for collaboration are manifold: technology, expertise, finance, etc., and generally result in more impactful research (Adams et al., 2019). However, while international networks are common in Europe, our recent G20 Scorecard[4] showed that about one-third of output from the United States and about one-quarter of China's output is international (Adams and Rogers, 2021) with collaboration networks still developing in much of Asia and in America.

In our ocean-basins dataset, international collaboration of the United States is just under 50% of its total ocean output, while Mainland China's is 40%. Both figures are far higher than we observe for other fields. G7 European countries average around 70% collaboration, as does Australia and Egypt. However, the large, populous G20 countries of Russia, Brazil and India have collaboration rates of 35 to 40%. Because of this, although India and Russia are the largest producers of Indian and Arctic ocean research, respectively, their number of collaborative papers are fewer than the United States (Russia also falls below Germany, Canada, and Norway). Conversely, the G20 countries of South Africa, Saudi Arabia, and Indonesia have collaboration rates of around 80%. Collaboration rates for ocean science, therefore, generally match or exceed their rate over all disciplines.

The global ocean research collaboration network is illustrated in Figure 6 for country pairs with at least 100 collaborative papers. These collaborations represent all types of international collaboration and range from bilateral to highly (>10 countries) and even hyper (>30 countries) multilateral collaborations. The network corroborates the previously shown analyses, with the United States being the largest collaborator amongst a central Americas-European nexus containing countries such the United Kingdom, Germany, and Canada. Around this network is a secondary group of European countries (e.g., Norway, Spain) with connections to Brazil. This group also connects to an Asian network, where Mainland China is the central partner. The peripheral zone includes countries from all continents.

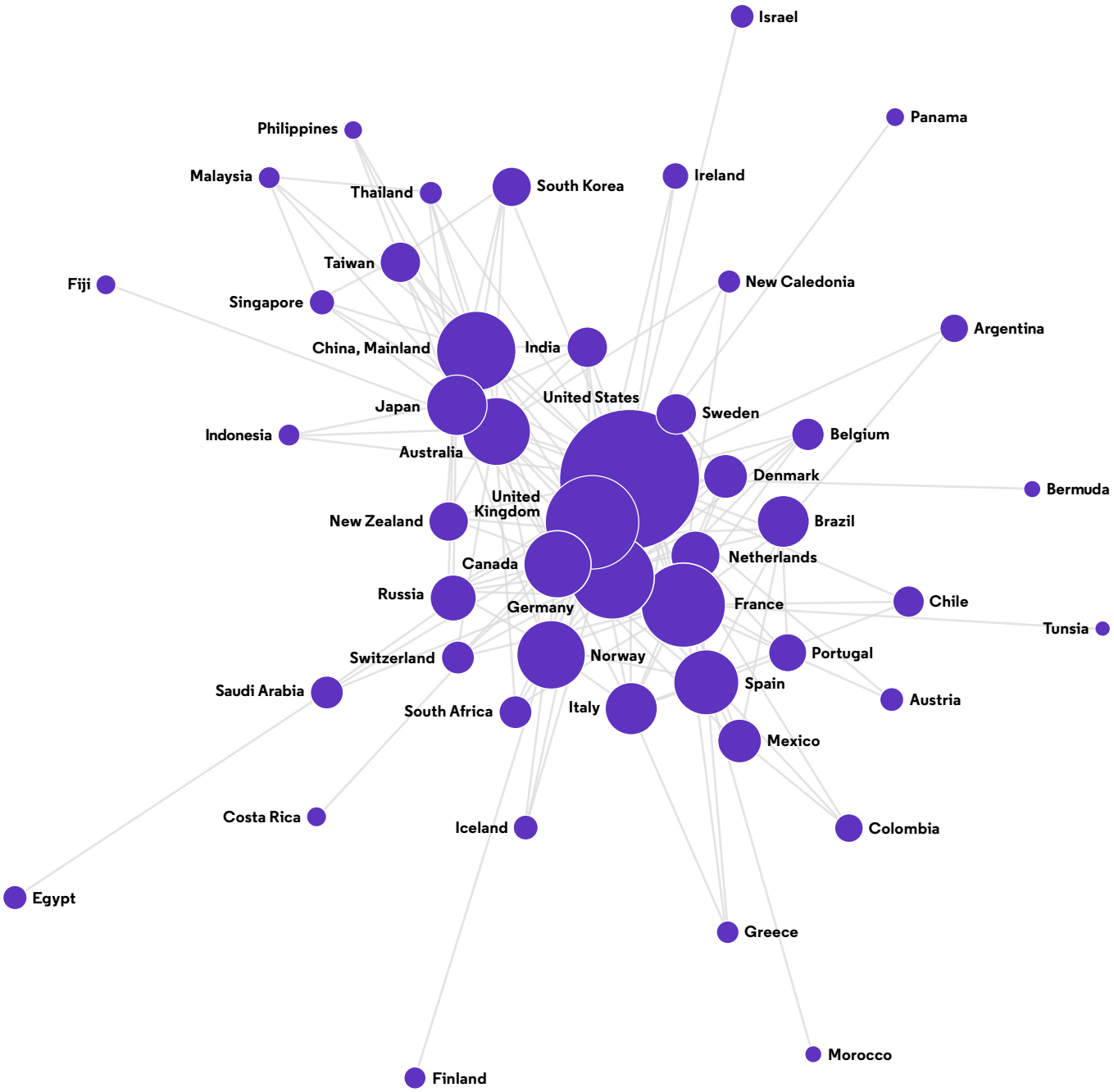
These collaborations can be driven by language (Mexico-Colombia), historical links (Spain-Mexico, Tunisia-France), geographic proximity (Malaysia-Singapore), or regional partnerships (Egypt-Saudi Arabia; Iceland-Norway), and even involve landlocked countries (Austria, Switzerland). These collaborations also include island nations and territories with a small research base. For example, collaborations between New Caledonia and the United States (136), Australia (135), and France (242, which is 61% of all New Caledonia's collaborations); Fiji and Australia (137, or 60% of Fiji's collaborations); Bermuda and USA (159, or 87% of Bermuda's collaborations).

Relationships are truly global (e.g., France-New Zealand (120), South Africa-Germany (110). Though North Africa is represented, sub-Saharan Africa, save for South Africa, is a notable absence. This may be because observational ocean sciences involve significant infrastructure (ships, docks, crews), so it may require proactivity to entrain new countries into the ocean-science fold. Achieving the SDGs may drive such activity.

Looking at a more granular level – at least 15 collaborations between country pairs – reveals a more diverse network. This shows sub-Saharan African contributions to the Atlantic (e.g., Benin, Cote d'Ivoire, Namibia, Senegal) and the Indian (Kenya) oceans. Caribbean (e.g., St. Kitts and Nevis) and Pacific (Vanuatu, Palau) island nation contributions also appear at this level. These collaborations may represent a significant percentage of the country's ocean output but are, ultimately, small in absolute terms.

[4] https://clarivate.com/lp/the-annual-g20-scorecard-research-performance-2021/

Figure 6. Collaboration network for all ocean-related research (at least 100 collaborative papers) within our ocean-specific dataset.



Source: Web of Science data and ISI research

Ocean basins: institutional output

Analyzing institutional activity and contributions to research on different oceans offers different perspectives (Table 3). Russia's primary focus on the Arctic Ocean is driven by the Russian Academy of Sciences – with over 18% of that ocean's papers – and, though to a lesser extent, Moscow Lomonosov State University, which contributes about 5% of Arctic research output. The Russian Academy of Sciences' share is largest of any ocean. The United Kingdom's presence in the Southern Ocean is driven by the British Antarctic Survey (BAS), which is responsible for some 11% of the ocean's research output. The BAS has a research base on, and others around, the Antarctic continent.

Germany's strong presence in the polar oceans is driven by research from the Alfred Wegener Institute of Polar and Marine Research. The institute was only founded in 1980 but has several research bases (also used by international partners) on the Antarctic continent and around the Arctic Ocean (Svalbard and Siberia).

The largest producer for Indian Ocean research is the National Institute of Oceanography in India, responsible for a 5% share. King Abdulaziz University contributes 3% of Indian Ocean output (as well as 30% of all Saudi Arabia's ocean research output).

In the Pacific, the institutions with the highest output are from the two main research producing countries: the United States and Mainland China. Whereas the United States holds the largest country share, the Chinese Academy of Sciences is the largest institutional contributor in the Pacific, with a 10% share. The Ocean University of China claims a share of 4%, about equal to that of NOAA.

Research in the Atlantic appears more diversified. NOAA is the largest producer but only accounts for 3%, closely followed by the University of Bergen (2%), and University of Sao Paolo (2%).

Table 3. Top three institutions by percentage of ocean output

Ocean	Institution	Country	Institutional ocean papers	Total ocean papers	Ocean %
Arctic	Russian Academy of Sciences	Russia	935	5,101	18.33
Arctic	Alfred Wegener Institute for Polar & Marine Research	Germany	230	5,101	4.51
Arctic	Moscow MV Lomonosov State University	Russia	221	5,101	4.33
Atlantic	NOAA	United States	1,165	46,559	2.50
Atlantic	University of Bergen	Norway	1,116	46,559	2.40
Atlantic	University of Sao Paulo	Brazil	1,016	46,559	2.18
Indian	National Institute of Oceanography	India	513	10,845	4.73
Indian	Chinese Academy of Sciences	China Mainland	415	10,845	3.83
Indian	King Abdulaziz University	Saudi Arabia	280	10,845	2.58
Pacific	Chinese Academy of Sciences	China Mainland	4,145	39,564	10.48
Pacific	NOAA	United States	1,683	39,564	4.25
Pacific	Ocean University of China	China Mainland	1,506	39,564	3.81
Southern	British Antarctic Survey	United Kingdom	413	3,952	10.45
Southern	University of Tasmania	Australia	253	3,952	6.40
Southern	Alfred Wegener Institute for Polar & Marine Research	Germany	240	3,952	6.07

Source: Web of Science data and ISI research

Some of the highlighted institutions are clearly specialized for ocean science, or an aspect of it. Other institutions dominate their country's ocean research output (Table 4): six institutions account for over 50% of their country's ocean research. This list mainly highlights smaller research economies which have a limited research capacity. For example, the Greenland Institute of Natural Resources accounts for 84% of Greenland's ocean research output; however, the country has only a handful of research institutions. The Russian Academy of Sciences' position as the main producer of ocean-related research is further corroborated here: the Academy is responsible for 62% of Russia's ocean research output, despite Russia producing nearly 4,500 papers. There is no clear comparator in this list. Other national academies, however, have a notable proportion of ocean research output: the Polish Academy (44%) and Chinese Academy (38%).

Table 4. Top 20 institutions by percentage of output of their respective country (countries with ≥ 100 papers)

Rank	Institution	Country	Total institute papers	Total country papers	Country %
01	Greenland Institute of Natural Resources	Greenland	88	105	83.81
02	University of the West Indies	Jamaica	213	269	79.18
03	University of the West Indies	Barbados	169	227	74.45
04	Smithsonian Tropical Research Institute	Panama	227	308	73.70
05	Bermuda Institute of Ocean Sciences	Bermuda	124	189	65.61
06	University of the West Indies	Trinidad and Tobago	239	370	64.59
07	Russian Academy of Sciences	Russia	2,765	4,433	62.37
08	University of Costa Rica	Costa Rica	265	432	61.34
09	National University of Singapore	Singapore	302	606	49.38
10	University of Vienna	Austria	213	482	44.19
11	Polish Academy of Sciences	Poland	198	450	44.00
12	University of Iceland	Iceland	212	496	42.74
13	University of Cape Town	South Africa	403	969	41.59
14	Institute of Oceanography and Fisheries	Croatia	56	135	41.48
15	Chinese Academy of Sciences	China Mainland	4,957	12,932	38.33
16	University of the South Pacific	Fiji	111	318	34.91
17	University of Helsinki	Finland	176	513	34.31
18	Hellenic Centre for Marine Research	Greece	177	534	33.15
19	National Taiwan University	Taiwan	600	1,814	33.08
20	University Republica	Uruguay	63	193	32.64

Source: Web of Science data and ISI research

Conclusion

With the fate of the Earth tied so inextricably to the oceans, and given the toll that humans have exacted on the marine environment within a relative handful of decades, the need for detailed scientific scrutiny of our ocean basins has never been more acute.

This significance is recognized by United Nations programs such as the Decade of Ocean Science, Sustainable Development Goals (particularly Goal 14: Life below water) and the 2022 Ocean Conference in Lisbon, Portugal. To foster a sustainable future, a key goal of the UN Decade of Ocean Science is to make our oceans clean, resilient, productive and safe.

All scientific investigation must be underpinned and guided by authoritative, current and readily accessible data — to mark progress, reveal opportunities for collaboration and provide timely intelligence on emergent areas of research activity and concentration. On the latter points, this report has touched on the scarcity of international collaboration with sub-Saharan Africa and the rapid emergence of microplastics as a central concern in ocean research. Our analysis of Citation Topics illustrated a rapid upsurge of publications on microplastics, uncovering a rate of growth resembling that of high-temperature superconductivity or CRISPR (i.e., gene editing). Although microplastics has long been studied, the recent priority given to the SDGs and funding in support of these may have prioritized and accelerated research in this area, as well as others with notable increases in content (e.g., Micro Citation Topic Climate Change).

The global importance of ocean science is undeniable. Research must rise to meet the challenges presented by, for example, microplastics pollution and whatever natural or human-made environmental crises might still await. Only with concerted, global commitment will the UN goals for the future — oceans that are clean, resilient, predictable, sustainable, not to mention sustaining — stand a chance of accomplishment.

References

Adams, J. (2012). Collaborations: the rise of research networks. Nature, 490(7420): 335-336. DOI: 10.1038/490335a

Adams, J. (2013). Collaborations: the fourth age of research. Nature, 497(7451): 557-60. DOI: 10.1038/497557a

Adams, J. and Rogers, G. (2021). The Annual G20 Scorecard – Research Performance, Clarivate, London, ISBN 978-1-8382799-5-0

Adams, J., Pendlebury, D., Potter, R., and Szomszor, M. (2019). Multi-authorship and research analytics, Clarivate Analytics, London UK, ISBN 978-1-9160868-6-9

Belter, C. W. (2013). A bibliometric analysis of NOAA's Office of Ocean Exploration and Research. Scientometrics, 95(2): 629-644. DOI: 10.1007/s11192-012-0836-0

Garfield, E. (1955). Citation indexes for science: a new dimension in documentation through association of ideas. Science, 122(3159): 108-111. DOI: 10.1126/science/122/3159.108

Harris, L. S. T., Fennell, J., Fales, R. J., and Carrington, E. (2021). Spatial-temporal growth, distribution, and diffusion of marine microplastic research and national plastic policies. Water Air and Soil Pollution, 232(10): 400. DOI: 10.1007/s11270-021-05352-4

Mingers, J. and Leydesdorff, L. (2015). A review of theory and practice in scientometrics. European Journal of Operational Research, 246(1): 1-19. DOI: 10.1016/j.ejor.2015.04.002

Mitchell, N. C. (2020). Comparing the post-WWII publication histories of oceanography and marine geoscience. Scientometrics, 124(2): 843-866. DOI: 10.1007/s11192-020-03498-2

Potter, I. (2020). Introducing Citation Topics in InCites. (Clarivate Blog/Academia and Government) https://clarivate.com/blog/introducing-citation-topics/

Potter, R., and Halevi, G. (2022). Climate change collaboration, Clarivate, London, doi:10.14322/ISI.insight.2

Rogers, G., Szomszor, M., and Adams, J. (2020). Sample size in bibliometric analysis. Scientometrics, 125(1): 777-794. DOI: 10.1007/s11192-020-03647-7

Szomszor, M., Adams, J., Pendlebury, D., and Rogers, G. (2021). Data categorization: Understanding choices and outcomes, Clarivate, London, ISBN 978-1-8382799-1-2

Traag, V. A., Waltman, L., and van Eck, N. J. (2019). From Louvain to Leiden: guaranteeing well-connected communities. Scientific Reports, 9, 5233. DOI: 10.1038/s41598-019-41695-z

Wang, Q., Wang, J. P., Xue, M. M., and Zhang, X. F. (2022). Characteristics and trends of ocean remote sensing research from 1990 to 2020: a bibliometric network analysis and its implications. Journal of Marine Science and Engineering, 10(3): 373. DOI: 10.3390/jmse10030373

Wang, Y. F., Tan, S. M., Ma, Y. Y., Zhao, X., Wang, Z. L., Chu, Z. Y., and Qin, H. H. (2016). Application of bibliometrics in analysis of output differences among countries under International Ocean Discovery Program. Scientometrics, 109(1): 447-462. DOI: 10.1007/s11192-016-2052-9

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