Ocean Science in Canada: Meeting the Challenge, Seizing the Opportunity

Executive Summary

Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

OCEAN SCIENCE IN CANADA: MEETING THE CHALLENGE, SEIZING THE OPPORTUNITY

The Expert Panel on Canadian Ocean Science

THE COUNCIL OF CANADIAN ACADEMIES
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Science Advice in the Public Interest

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Expert Panel on Canadian Ocean Science

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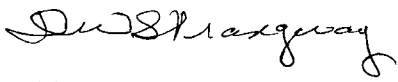
Message from the Chair

Ocean science is at the heart of understanding the complex relationships through which the ocean affects Canadian lives and through which Canadians affect the ocean. It provides the basis for developing ways of sustainably using ocean resources (biological, mineral, and energy) for the benefit of society while assuming the role of a responsible steward of the global ocean. Ocean science is unique because it draws on excellence from many sources. As an academic field, it knows no disciplinary or geographic boundaries. It combines knowledge generated by scientists in many disciplines from around the globe, and draws on the efforts of people in all parts of society. It benefits from universities and their role in teaching and research, as well as the research, monitoring, and policy development conducted by governments (federal, provincial, and municipal). Ocean science taps into the expertise of the private sector to responsibly develop ocean resources, often working together with public and private innovators to develop the necessary technologies and tools, which in turn enable new ways of conducting academic research. Ocean science also builds on the knowledge and experiences of large and small communities along Canada's three coasts as well as those of many interested citizens across the country.

The Expert Panel on Canadian Ocean Science was asked to assess what capacities would be needed to address a set of major research questions that were determined by a larger Core Group of Canadian ocean experts, and which of these capacities are currently available in Canada. Above all, these questions challenged us to expand our way of thinking about ocean science. Understanding the ocean, its coasts, and the continental shelf is a three-dimensional endeavour that requires ever more sophisticated methods of study and increasing detail in monitoring and observation. To enable societies to maintain healthy ocean systems that can deliver benefits now and in the future, we must also understand how marine social-ecological systems change over time, which adds a fourth dimension to the challenge. Canadian ocean scientists are part of a global community that is continuously pushing the boundaries of research to develop the methods, tools, and approaches necessary to meet the complex challenges embodied in these research questions, and to seize the opportunities arising from a better understanding of Canada's role as an ocean nation.

I would like to thank my fellow panel members for their commitment and their excellent spirit which has made this process a very enjoyable experience. The Panel is also very appreciative of the many individuals and organizations that have assisted in accessing much of the evidence reviewed in this report. Finally, the Panel and I express our sincere thanks to the staff members of the Council

for their excellent support in collecting and synthesizing evidence from many sources and their help in amalgamating the diverse ideas of the Panel into a high-quality report.



David Strangway, O.C., FRSC
Chair, The Expert Panel on Canadian Ocean Science

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Report Review

This report was reviewed in draft form by the individuals listed below — a group of reviewers selected by the Council of Canadian Academies for their diverse perspectives, areas of expertise, and broad representation of academic, industrial, policy, and governmental organizations.

The reviewers assessed the objectivity and quality of the report. Their submissions — which will remain confidential — were considered in full by the Panel, and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring Panel and the Council.

The Council wishes to thank the following individuals for their review of this report:

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The report review procedure was monitored on behalf of the Council's Board of Governors and Scientific Advisory Committee by **Dr. Joseph D. Wright, FCAE,** former President and CEO, Parpican. The role of the report review monitor is to ensure that the Panel gives full and fair consideration to the submissions of the report reviewers. The Board of the Council authorizes public release of an expert panel report only after the report review monitor confirms that the Council's report review requirements have been satisfied. The Council thanks Dr. Wright for his diligent contribution as report review monitor.

Elizabeth Dowdeswell, O.C.
President and CEO, Council of Canadian Academies

Executive Summary

Canada is shaped by the ocean. Three ocean basins and the world's longest coastline define Canada's borders, affect the weather, provide valuable resources and other benefits, and link Canada to neighbours both near and far through trade, transportation, and ocean currents. Canadians derive a wealth of goods and services from ocean systems: food from fish and other marine organisms, energy from offshore oil and gas and renewable sources, subsea minerals, biodiversity, transportation routes, recreational opportunities, and associated employment.

The ocean is a complex system under stress from unprecedented global change, including climate change, ocean acidification, and increasing pressure on ocean resources from a growing and more affluent world population. Canada's extensive exposure to the ocean and the rapidly changing Arctic offers almost unlimited opportunities in fundamental research to improve understanding of ocean processes, as well as applied research on sustainable ocean and coastal development and management for the benefit of Canadian society. At the same time, it bestows on Canada the responsibility to act as a steward of the global ocean.

Ocean science provides the foundation for understanding the many ways in which the ocean affects life on Earth, and the interactions between human societies and the ocean. The extent of these research concerns relative to Canada's small population creates a key challenge for Canadian society: how to ensure that capacities for ocean science are comprehensive and adaptive (taking advantage of insights and input from multiple disciplines, sectors, and groups), appropriately designed, and efficiently deployed. Ocean science, as considered in this report, includes all research disciplines related to the study of the ocean, the coast, and their relationships with societies: the natural, health, and social sciences, as well as engineering, the humanities, and multidisciplinary research. Ocean science seeks to understand complex, multi-scale social-ecological systems, which requires multidisciplinary and collaborative research.

Recognizing the importance of ocean science, the Canadian Consortium of Ocean Research Universities (CCORU) asked the Council of Canadian Academies (the Council) to undertake an assessment of the state of ocean science in Canada. The Council undertook this work in two phases. First, the Council asked a Core Group of ocean experts from Canada and abroad to develop a set of priority research questions, which were published as *40 Priority Research Questions for Ocean Science in Canada*. Second, CCORU asked the Council to convene a panel of Canadian and international ocean science experts to address the following charge, using the 40 research questions as a guide:

What are Canada's needs and capacities with regard to the major research questions in ocean science that would enable it to address Canadian ocean issues and issues relating to Canada's coasts and enhance its leading role as an international partner in ocean science?

To determine the capacity needed to address the 40 research questions and assess Canada's existing capacity (the "needs and capacities" of the charge), the Panel considered evidence in five categories of capacity and grouped the questions into nine themes (Figure 1). Some cross-cutting questions were assigned to more than one theme. The Panel used bibliometric analysis of peer-reviewed journal articles to estimate Canada's current research performance in ocean science, complemented by a review and analysis of other available information on capacity, such as data on funding and highly qualified personnel, academic literature, and reports, to identify opportunities and challenges for each theme.

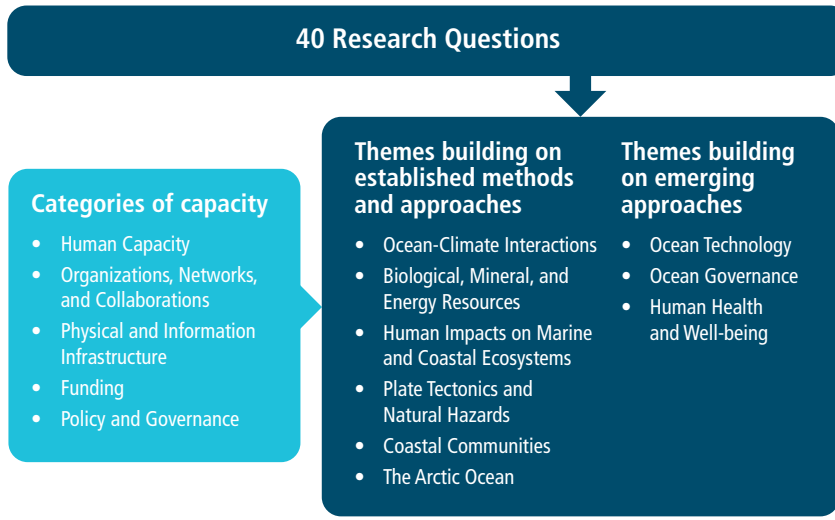

Figure 1

Conceptual Framework to Address the Charge

The Panel defined five categories to identify the capacities that would be needed to address the 40 research questions determined in phase 1 of the assessment and to assess Canada's existing research capacity. To facilitate the analysis, the Panel grouped the research questions into nine themes: six themes contain questions that build on established methods and approaches in ocean science; research questions in the other three themes are more forward-looking, with uncertain future research needs and anticipated paradigm shifts.

THE SEASCAPE OF OCEAN SCIENCE IN CANADA

Ocean science in Canada is organized into a network of regional clusters of diverse organizations with different research interests and capacities. While much of the capacity in Arctic research is located along the St. Lawrence River, for example, the main hubs for offshore oil and gas research are concentrated along the east coast, and a world-leading cabled observatory on the sea-floor is located off the west coast. This structure avoids some of the risks of relying on a central oceanographic research institution, which can lead to a strong geographic concentration of capacity. Canada's dispersed network of clusters, however, can create challenges for certain kinds of collaboration, alignment of research strategies, and coordination and use of large-scale infrastructure investments.

Bibliometric analyses show the historical importance of federal government organizations within this network, in particular Fisheries and Oceans Canada (DFO), Natural Resources Canada, Environment Canada, and the National Research Council of Canada. These decentralized organizations with national mandates are vital hubs for collaboration and access to essential expertise and infrastructure, such as vessels, specialized labs, databases, and computing and communication infrastructure. Universities are also important hubs that collaborate with government departments, and increasingly with each other through research networks. The activities of government departments, universities, and other actors vary by research theme. The private sector has significant research capacity in areas such as offshore oil and gas development, deep-sea mining, and ocean technology. Ocean science capacity in Canada is thus not only geographically dispersed, but also distributed across a variety of organizations with diverse mandates and priorities. This adds another dimension to the challenge of coordinating activities and scarce ocean science resources across the country.

THE STATE AND CAPACITY OF OCEAN SCIENCE IN CANADA

The Panel found that the data and information needed to assess ocean science capacity are held by a large number of institutions, recorded in formats that are not comparable, and often incomplete or not accessible to the public. The multidisciplinary nature of ocean science also made it difficult to delineate it within existing data sets. The Panel identified a number of areas in which the information was limited or structured in a way that reduced its usefulness for the assessment, e.g., the number of researchers active in ocean science,

capacity within universities, private-sector research activities, ocean science spending across government departments, inventories of large instruments, and international collaboration. Based on the best available information, the Panel developed an overview of ocean science capacity in Canada and the following key findings:

- **The state of human capacity in ocean science cannot be determined because of data limitations**. Despite a steady increase in undergraduate and graduate students in many fields related to ocean science in Canada from 2001 to 2009, it is unclear whether overall trends in human capacity are positive on balance or whether the skills needed to address the 40 research questions are available. Due to its interdisciplinary character, ocean science draws on highly qualified personnel from many programs and departments, which makes human capacity one of the most challenging categories to assess. This is a particular concern, since human capacity determines the use and productivity of all other elements of ocean science capacity.
- **Canada has a substantial but aging research fleet**. The Coast Guard operates the Canadian research fleet, which includes several large oceanographic vessels and a dedicated research icebreaker that provides access to the Arctic. Half of these vessels were built over 25 years ago, and older vessels lead to more breakdowns, higher costs, and operational days lost to maintenance. Furthermore, the Panel observed that other countries have established more transparent systems of ship time allocation, which allow for more efficient use of ship time, and provide data to inform the planning of infrastructure investments. The ongoing renewal of the Canadian research fleet provides an opportunity not only to update aging infrastructure but also to improve the alignment of vessel specifications with science needs.
- **Canada has several world-class systems for ocean observation and monitoring; however, challenges exist in achieving geographical coverage and integration of data management**. Canada has recently invested in innovative observation platforms, such as the NEPTUNE cabled observatory and the Ocean Tracking Network, which build on historical strengths in development of remote sensing and observation technology. While these systems are ground-breaking and will attract leading ocean scientists from around the world, challenges exist with regard to the geographical coverage of observation and monitoring, in particular in the Arctic. Other challenges remain with regard to data integration and accessibility through the use of modern data portals. Addressing these challenges is especially important for research on global change, including climate change.

- **Although funding for ocean science in Canadian universities is increasing, trends in total funding are unclear due to insufficient data**. Total spending by funding agencies in Canada increased from 2002 to 2011, but direct funding for individual research projects has declined since 2008. While more funding is available for large research networks and investments in major infrastructure, changes in the policies and programs of funding organizations require higher levels of coordination among researchers, and alignment of funding from multiple sources. DFO expenditures on science activities also peaked between 2006 and 2008, followed by a decline to the same level as 2002. Overall, data on ocean science expenditures of government organizations and the private sector were insufficient to estimate national trends in funding for ocean science.
- **Canada ranks among the top countries in output and impact of ocean science papers, but this position is at risk**. The Panel used bibliometric analysis as a proxy indicator for an international comparison of the performance of ocean science in Canada. According to this analysis, Canada ranks 7th in the number of peer-reviewed papers, and 11th in scientific impact, by average relative citations. Ocean science in Canada is growing at a slower pace than other fields of science in Canada. Canada also has the lowest domestic growth index of the 25 leading countries in ocean science. This implies that ocean science is losing ground relative to other fields faster in Canada than in other countries, which could lead to a decline in Canada's position in research output and impact.

ADDRESSING THE MAJOR RESEARCH QUESTIONS: OPPORTUNITIES AND CHALLENGES

The Panel evaluated the capacity required to address the research questions in each of the six themes dealing with established methods and approaches in ocean science. This was followed by an assessment of the existing capacity using bibliometric analysis and other available information. Based on these assessments, the Panel then identified opportunities and challenges for ocean science in Canada for each theme:

- **Ocean-climate interactions**: Canada has substantial capacity in remote sensing and climate modelling which provides opportunities to advance research on ocean-climate interactions, particularly in addressing questions requiring better integration of ocean and sea ice in climate models. Realizing this opportunity, however, requires sustained observation and monitoring of climate-related ocean data. This is a challenge for Canada, primarily due to its vast and remote coastline, much of which is in the Arctic where observation and monitoring are inherently more costly.

- **Biological, mineral, and energy resources**: Canada has significant capacity for fundamental research in this theme, which is based to a large extent on historical strengths in government research, particularly fisheries science and marine geology, as well as fisheries research conducted by several top-publishing university research institutes. These strengths create opportunities in fisheries science and provide the basis for emerging capacity in marine biodiversity research using genomic technologies and approaches. The main challenges in this area are to prevent further loss of capacity in taxonomy and to continue the transition towards more holistic approaches such as ecosystem-based and social-ecological frameworks. The private sector holds substantial research capacity in mineral and energy resources, particularly in geological databases and other information resources. The main challenges in this area are to better coordinate and align capacity held by private, government, and academic institutions; and to effectively integrate research on the environmental and societal impacts associated with ocean resource development.
- **Human impacts on marine and coastal ecosystems**: Research in this theme also benefits from historical strengths in government departments and universities. The challenge is to adapt existing capacity to the changing context and priorities of this research. Adjustments made to date have led to a gap in research on invasive species — a gap that may soon be filled through a new network project — as well as on monitoring and understanding the behaviour of contaminants, in particular novel contaminants and known contaminants under new and changing conditions. (e.g., oil spills under sea ice). At the same time, there are shifts and overlaps in the responsibilities of government departments for research and monitoring of existing and novel contaminants. These parallel dynamics make it challenging for research on human impacts to keep pace with the development of new ocean resources and emerging sources of land-based pollution.
- **Plate tectonics and natural hazards**: Past achievements in geological and hydrographic surveying and recent investments in cutting-edge cabled observatories offer major opportunities in this theme. These investments also create challenges in ensuring long-term coverage of costs to operate and use these platforms for research. Other challenges lie in mobilizing the capacity necessary to comprehensively map the geology and bathymetry of Canada's vast ocean floor.
- **Coastal communities**: Canada has an active community of scientists from various disciplines that performs research in this theme, including the impacts of climate change, resource degradation, expanding coastal populations, and increasingly diverse uses of coastal areas and the ocean. Interdisciplinary networks that cut across the natural and social sciences and engineering are essential to mobilizing this potential. A key challenge is therefore to ensure continuing support for interdisciplinary collaboration and training in these areas.

- **The Arctic Ocean**: Recent and upcoming investments in icebreakers and research labs in the Arctic will create opportunities to address research questions on the Arctic Ocean. Some of these opportunities will be driven by the increasing strategic and economic importance of the Arctic region. As many of the questions relate to impacts of climate change, similar challenges arise in ensuring sustained observations. There are other challenges in prioritizing research on specific impacts of human activities in the Arctic such that research keeps pace with development dynamics.

The remaining three themes comprise research questions of a more forward-looking nature that describe future research needs or anticipate paradigm shifts that cannot be captured by bibliometric analysis. The Panel therefore focused on emerging research approaches, and the conditions that support their development and adoption. Using this approach, the Panel identified the following opportunities and challenges:

- **Ocean technology**: Canada's diverse and dynamic ocean technology sector has ample capacity to develop tools and technologies for advancing ocean science in Canada and abroad. These technologies can enable new kinds of observations and experiments and lower the cost of large-scale and long-term monitoring which also contributes to reducing challenges in other research themes. A key challenge for technology development for ocean science is to better align the research-driven technology development in the science sector with opportunities for commercial technology development, and to improve access to international markets for science instruments so as to make such innovations economically viable.
- **Ocean governance**: This theme faces growing uncertainty in both ecological and social elements of social-ecological systems, and increasingly requires the integration of knowledge from multiple sources. The need to develop adaptive and participatory approaches to ocean governance opens up opportunities for developing innovative approaches to research as well as new alignments and collaborations between researchers, policy-makers, and practitioners.
- **Human health and well-being**: Research on the relationship between the ocean and human health and well-being is undergoing a paradigm shift from a focus on contaminants and disease towards a more holistic understanding of the social and environmental determinants of health. Although several research questions allude to this shift, current research in Canada mostly addresses selected biological determinants such as pathogens and biotoxins. The main challenges relate to integrating research capacities in ocean-specific determinants of health with research framed by a broader population health perspective.

NEW ALIGNMENTS FOR CANADIAN RESEARCH ON THE GLOBAL OCEAN

Ocean science is becoming increasingly complex, multidisciplinary, multi-scale, and internationally connected. Addressing the 40 research questions will require new forms of alignment and collaboration both nationally and internationally. The Panel found that the seascape of ocean science in Canada is already changing in response to these needs. Innovative networks, such as the Networks of Centres of Excellence, are facilitating collaboration between scientists from universities, government, the private sector, civil society organizations, and communities. Novel funding opportunities, such as those offered by the Canada Foundation for Innovation, are enabling the establishment and management of large-scale infrastructure, such as vessels and observation networks, outside of federal government organizations. Consortia of actors, such as CCORU, are emerging to create momentum for change. These new networks and alignments have already resulted in several innovative, world-leading initiatives.

Despite these advances, the Panel identified the following gaps in the coordination and alignment of the ocean science community in Canada, which are currently not being addressed:

- **The vision gap**: In contrast to other countries, or other disciplines in Canada, no comprehensive national strategy or vision currently exists for ocean science in Canada. This makes it difficult to prioritize needs and comprehensively plan investments for ocean science.
- **The coordination gap**: Addressing the increasingly complex issues of ocean science requires enhanced collaboration at the local, regional, national, and international levels, and across disciplines and sectors. Despite the many instances of successful collaboration in Canada, coordination in key areas, such as ocean observation, is lacking, and support for research networks has often been constrained by temporary funding. More generally, there is no effective national-level mechanism to coordinate the allocation of resources and facilitate the sharing of infrastructure and knowledge among ocean scientists. This also hinders the sharing of resources and knowledge at the international level.
- **The information gap**: Limitations in access to, and availability and comparability of, information made it difficult to assess several categories of ocean science capacity (e.g., the number of active researchers, comprehensive data on research spending, or inventories of large instruments relevant to ocean science). While many actors in ocean science maintain inventories for internal use, no existing mechanism or repository systematically collects and regularly updates information on key research activities, infrastructure, and other capacities in ocean science for the entire country. Although gathering this information is a complex task in other countries as well, some, such as

the United States, Germany, and the United Kingdom, have established institutions and processes to collect such data and make it available to ocean science stakeholders. The information is then used not only to assess capacity, but also to inform development of national science strategies and plans on a regular basis and to prioritize decision-making on research infrastructure investments. The absence of such inventories in Canada makes it difficult to identify capacity needs at the national level. Similarly, opportunities to address research questions through national or international collaboration are more difficult to identify.

The Panel concluded that addressing these gaps is essential if Canada is to meet the growing needs of ocean science with limited resources, and make best possible use of existing capacities to meet the challenges and seize the opportunities of ocean science. None of the current and emerging alignments, consortia, or networks can address these gaps singlehandedly. Doing so requires a national effort involving the entire community of ocean scientists in Canada, as well as users of ocean science including policy-makers, entrepreneurs, communities, and civil society.