November 2013

Report in Focus

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

The ocean is undergoing unprecedented change. Pollution, acidification, overfishing, demand for resources, and climate change are affecting marine populations and coastal communities alike. With the world's longest coastline along the Arctic, Atlantic, and Pacific ocean basins, Canada experiences these changes acutely and has a deep appreciation for the interconnected nature of Earth's biggest physical feature. These universal challenges demand the integration of multidisciplinary knowledge and coordination across traditional boundaries. While Canada is internationally recognized for its excellence in ocean research and leading role in international research collaboration (Coward *et al.*, 2000), a comprehensive understanding of national capacity to address future questions of ocean science is essential. The Council's report is intended to inform this discussion.

CHARGE TO THE EXPERT PANEL

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 embarked on this work in two phases.

During the first phase, the Council asked a Core Group of ocean experts from Canada and abroad to develop a set of priority research questions. This undertaking was published as *40 Priority Research Questions for Ocean Science in Canada* in July 2012 (CCA, 2012). CCORU then asked the Council for an assessment of Canada's capacity to address these 40 research questions. The Council convened a panel of national and international ocean science experts to consider future opportunities and challenges for Canada and its coasts, using the following charge 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 assess Canada's existing capacity, the Expert Panel on Canadian Ocean Science developed a framework of five categories of capacity and nine themes that group together the 40 priority research questions (see Figure 1). The Panel then used this framework to collect and evaluate evidence on each category of capacity and to analyze opportunities and challenges associated with each theme.

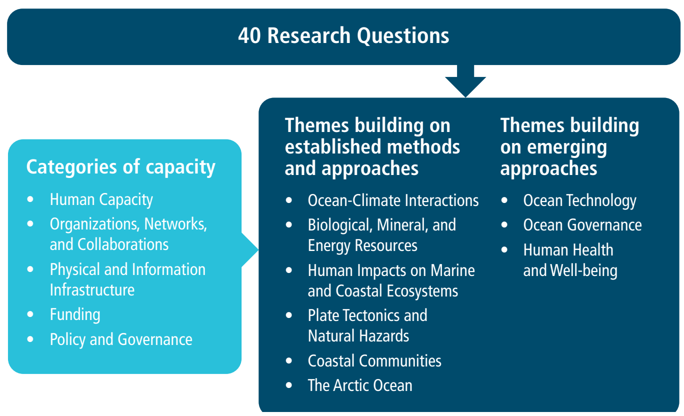

Figure 1. Conceptual Framework to Address the Charge

The Framework consists of five categories used to identify the capacities needed to address the 40 research questions determined in phase 1, and to assess Canada's existing research capacity. The Panel grouped the research questions into nine themes. Six themes contain questions that build on established methods and approaches. The remaining three themes contain forward-looking questions that anticipate paradigm shifts and have uncertain research needs.

Bibliometric analysis (i.e., the study of patterns in peer-reviewed journal articles) was used to assess ocean science output and as an indicator of research performance. The report also draws on other available evidence, such as data on funding and highly qualified personnel, academic literature, and reports from institutions and agencies active in ocean science.

Ocean science, for the purposes of this report, includes all research disciplines related to the study of the ocean and the coast, and their relationships with societies: the natural, health, and social sciences, as well as engineering, the humanities, and multidisciplinary research. Ocean science is broader than research and includes activities that apply or make use of scientific knowledge, such as monitoring, data integration and management, peer review, knowledge mobilization, integration of local and traditional knowledge, and outreach.

CCORU includes the following universities: Dalhousie University, Université du Québec à Rimouski (UQAR), Université Laval, University of British Columbia, University of Victoria, Memorial University, University of Prince Edward Island, University of New Brunswick, and University of Manitoba.

Assessing the State 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. The clusters are found mainly on Canada's East and West coasts, with substantial research capacity in central Canada (see Figure 2).

Historically, federal government organizations within this network have conducted and supported research as vital hubs for collaboration. They are also providers of essential expertise and infrastructure, such as vessels, specialized labs, databases, and computing and communication infrastructure. Provincial governments and associated institutions are also major funders and act as important partners for research in ocean science.

Universities serve as hubs that collaborate with government departments and, increasingly, with each other through research networks. More than half of all Canadian universities engage in ocean science activities. Ocean science benefits from contributions from many different disciplines, but sharing knowledge across organizational and disciplinary boundaries can present a challenge. For example, most social science papers in Canadian ocean science are written by academic authors, with fewer contributions by researchers in government or private sector organizations. Nevertheless, much of this work has provided key insights into translating knowledge into action.

A significant amount of ocean science work takes place in the private sector, particularly in the areas of defence and security, offshore energy, and marine transportation. A large number of small and medium-sized enterprises engage in the development of technologies for ocean research and observation. Lastly, non-governmental organizations play a role

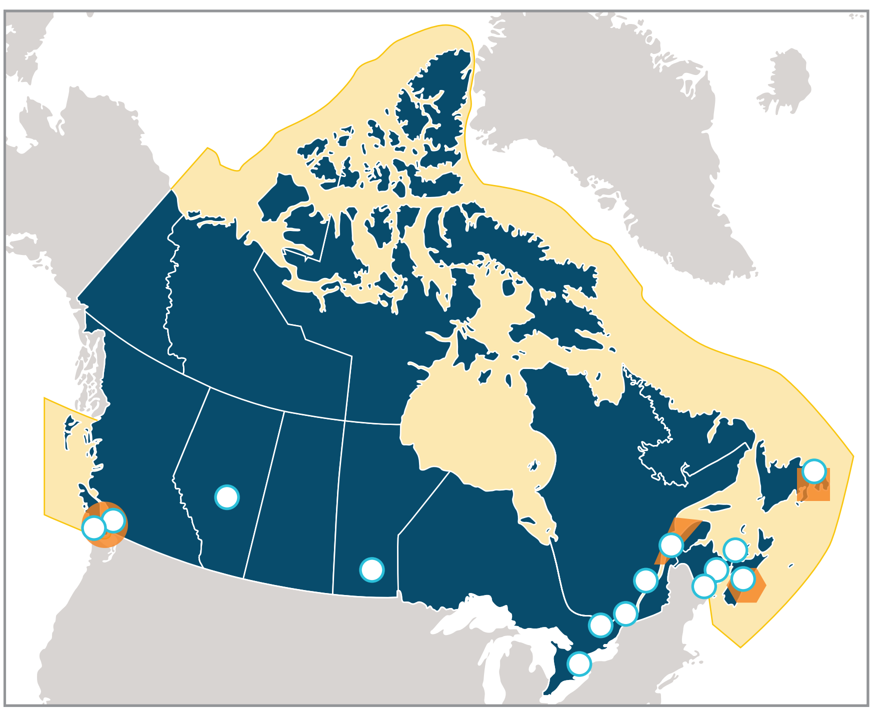

Figure 2. Locations of Major Ocean Science Facilities and Organizations in Canada

Each circle indicates locations of institutes of federal departments, universities and private companies, as well as laboratories, research vessels, observation infrastructure or other facilities used for ocean science. Many smaller facilities are located throughout the Arctic, but are not shown on the map. Orange shading identifies technology clusters. The yellow area denotes Canada's exclusive economic zone. (For a list of institutions, see page 19 of the full report).

Note: Many federal departments have offices in Ottawa-Gatineau (e.g., DFO, Canadian Hydrographic Service, Environment Canada, NRCan, and NRC) where much of the science conducted elsewhere is translated into policy making and advice.

in ocean science by, for example, contributing to conservation and management plans, providing channels for scientists to interact with others in the ocean science community, and enabling public engagement. Most organizations collaborate frequently with multiple partners, suggesting ocean science in Canada is well-integrated (see Figure 3).

While many of the existing networks and collaborations include scientists and experts from across the country, no single network, body, or forum currently represents the ocean science community in Canada as a whole. Although having dispersed regional clusters can make it more challenging to align research strategies, collaborate, and put large-scale infrastructure investments to use, it also avoids some of the risks associated with a central oceanographic research institution, which can lead to a strong geographic concentration of capacity. The existing diversity allows organizations to focus on regional and local science priorities and supports the emergence of regionally specialized clusters.

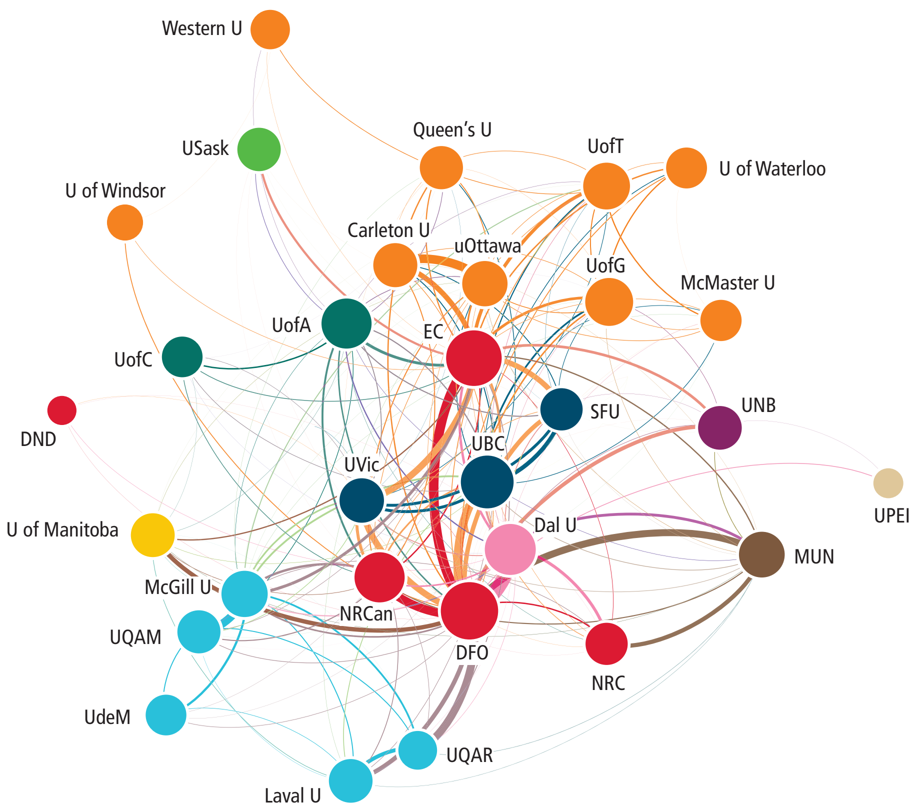

Figure 3. Collaboration Network of the Top 30 Publishing Canadian Organizations in Ocean Science, 2003-2011

The size of the nodes is proportional to the number of publications in ocean science and the thickness of the lines is proportional to the number of collaborations (co-authored papers). The nodes are coloured according to province. Collaboration between Canadian organizations in ocean science is relatively dispersed, with federal organizations and large universities acting as central hubs. DFO and Environment Canada show high levels of collaboration with each other and with universities across the country, due in part to their decentralized structure. Regional clusters of organizations suggest a natural tendency for collaboration to increase with proximity. Only a fraction of peer reviewed outputs in social sciences are captured in the database used for this analysis. A collaboration network of Canadian organizations publishing social science papers in ocean sciences can be found on page 55 of the full report.

Note: Only links representing 10 or more collaborations between institutions are displayed, to improve readability.

Key Findings

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 are 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, such as the number of researchers active in ocean science, capacity within universities, private-sector research activities, government spending across 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:

1. 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, described in *40 Priority Research Questions for Ocean Science in Canada,* 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.

2. 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.

3. 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 existing strengths in observation technology development. While these systems are ground-breaking and attractive to leading ocean scientists from around the world, challenges exist with regard to the geographic coverage of observation and monitoring, in particular in the Arctic. Other challenges

Photos of the Canadian Research Vessel the *CCGS Amundsen*. Courtesy of Andrea Hopkins.

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 changes to the ocean.

Highlights in Ocean Observation

Argo is a global array of more than 3,500 automated floats that transmit data via satellites. The system covers almost the entire ocean, with the notable exception of the Arctic. Canada is contributing about one-tenth of the active Argo floats and was one of the early developers of the Argo Software System (Argo, n.d.).

The Ocean Tracking Network, based at Dalhousie University, collects data on sea animal movements in relation to the physical characteristics of the surrounding ocean. It uses a global network of acoustic receivers to track individual tags attached to a variety of aquatic species (OTN, n.d.).

The Census of Marine Life used human-operated vehicles (HOVs), remotely-operated vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), and towed platforms in a concerted international effort to establish a baseline of marine biodiversity (Snelgrove, 2010).

The Ocean Networks Canada observatory combines the North-East Pacific Undersea Networked Experiments (NEPTUNE) and the Victoria Experimental Network Under the Sea (VENUS) into one of the world's most potent cabled networks (Taylor, 2009).

4. 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. Overall, data on ocean science expenditures of government organizations and the private sector were insufficient to estimate national trends in funding for ocean science.

5. 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 in the long run could lead to a decline of Canada's position in research output and impact.

Ocean Technology Clusters: Governments, Universities, and Private Sector Firms

Across Canada, regional partnerships among governments, universities, and private sector firms are contributing to the development of innovative ocean technologies and services. These regional groups, or clusters, share facilities and expertise to help businesses innovate and grow while developing new tools for scientific research. For example, firms in Halifax, NS have developed a particular strength in marine-derived food additives and other products, as well as marine defence and security. Newfoundland and Labrador is home to a number of firms specializing in cold-water engineering and oil and gas extraction. Similarly, a Pacific cluster has emerged in Victoria and Vancouver, BC around a range of government-funded research programs, including the NEPTUNE and VENUS cabled observatories, and offshore oil and gas exploration (Doloreux & Shearmur, 2009). In Quebec, the provincial government is investing in innovation-support organizations to stimulate technology and economic development along the St. Lawrence coast. These examples demonstrate the types of economic and scientific opportunities that can be realized when government, academic, and private sector organizations pool their collective knowledge and resources.

The report also analyzes Canada's capacity to perform research in each of the nine themes defined by the Panel, identifies opportunities arising out of Canada's existing capacity, and notes areas where additional capacity may be needed to address particular questions.

CONCLUSION

Canada's proximity to three of the world's ocean basins provides unlimited prospects for ocean science research. But the sheer size of Canada's coastline relative to its population, its dispersed infrastructure, and gaps in coordination and information also present unique challenges for meeting the growing needs of this field. With no single organization responsible for the coordination of ocean research activities in Canada, scientists face challenges when it comes to coordinating activities and pooling together ocean science resources. Addressing these challenges is essential to unlock the opportunities arising out of Canada's geography and its existing ocean science capacity.

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Coward *et al.*, 2000; Charles, 2001; for other examples of Canadian leadership and contributions, see: de Wit & Muir, 2010; AMAP, 2011; Greenan & Klymak, 2011; Picard-Aitken *et al.*, 2011.

Doloreux, D. & Shearmur, R. (2009). Maritime clusters in diverse regional contexts: The case of Canada. *Marine Policy*, *33*(3), 520-527. Doi: 10.1016/j.marpol.2008.12.001.

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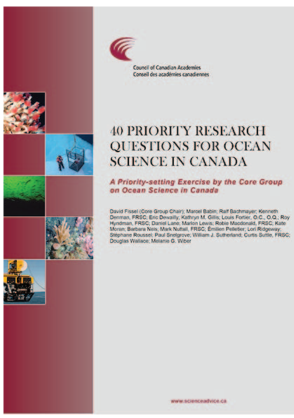
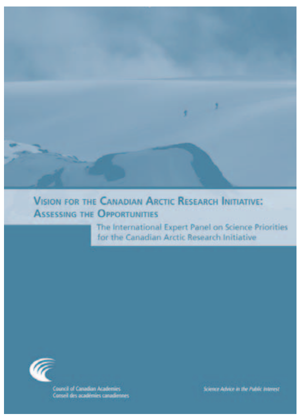
Taylor, S.M. (2009). Transformative ocean science through the VENUS and NEPTUNE Canada observing systems. *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *602*(1), 63-67. Doi: 10.1016/j.nima.2008.12.019.

OTHER COUNCIL REPORTS THAT MAY BE OF INTEREST:

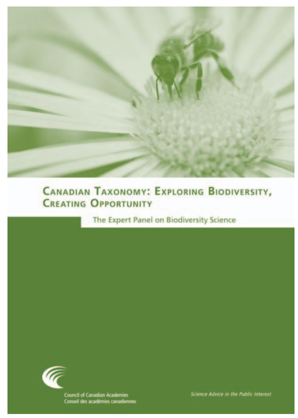
40 Priority Research Questions for Ocean Science in Canada



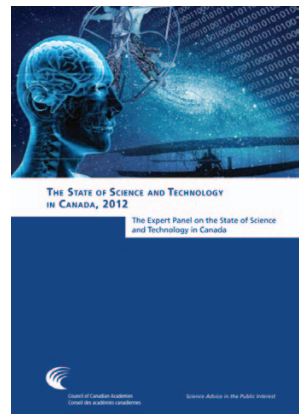
Vision for the Canadian Arctic Research Initiative: Assessing the Opportunities



Canadian Taxonomy: Exploring Biodiversity, Creating Opportunity



The State of Science and Technology in Canada, 2012



EXPERT PANEL ON CANADIAN OCEAN SCIENCE: David Strangway, O.C., FRSC (Chair), Former President and CEO, Canada Foundation for Innovation; Former President and Vice-Chancellor, University of British Columbia; Former Chief of Geophysics, NASA; Founding Chancellor, Quest University (Kelowna, BC); **Louis Fortier, O.C., O.Q.**, Professor, Department of Biology, Université Laval (Québec, QC); **Jim Hanlon**, Chief Executive Officer, Halifax Marine Research Institute (HMRI) (Halifax, NS); **Peter Herzig**, Executive Director, GEOMAR Helmholtz Centre for Ocean Research (Kiel, Germany); **Barbara Neis**, Professor, Department of Sociology, Memorial University; Co-Director, SafetyNet Centre for Occupational Health and Safety Research (St. John's, NL); **R. Ian Perry**, Research Scientist, Fisheries and Oceans Canada (Nanaimo, BC); Adjunct Professor, University of British Columbia (Vancouver, BC); **Martin Taylor**, Professor of Geography, University of Victoria; Former President and CEO of Ocean Networks Canada (Victoria, BC); **Wendy Watson-Wright**, Executive Secretary and Assistant Director General, Intergovernmental Oceanographic Commission (IOC), UNESCO (Paris, France).

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This *Report in Focus* was prepared by the Council based on the Report of the Expert Panel on Canadian Ocean Science.