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

Appendices

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

Table of Contents

COMMON ABBREVIATIONS USED IN THIS REPORT

Labels for Canadian Organizations

The following labels are used to identify Canadian organizations in figures throughout this appendix.

AAFC	Agriculture and Agri-Food Canada
Acadia U	Acadia University
Acadian Seaplants	Acadian Seaplants Limited
ACWERN	Atlantic Cooperative Wildlife Ecology Research Network
AECL	Atomic Energy of Canada Ltd.
ASL	ASL Environmental Sciences Inc.
BCMAL	BC Ministry of Agriculture and Lands
BCMF	British Columbia Ministry of Forests, Lands and Natural Resource Operations
BMSC	Bamfield Marine Sciences Centre
Brandon U	Brandon University
Brock U	Brock University
Carleton U	Carleton University
CBU	Cape Breton University
CCG	Canadian Coast Guard
C-CORE	Centre for Cold Ocean Resources Engineering
CEN	Centre for Northern Studies (Centre d'études nordiques)
C-FER	C-FER Technologies (Centre for Frontier Engineering Research)
CFIA	Canadian Food Inspection Agency
CHS	Canadian Hydrographic Service
CIFAR	Canada Institute for Advanced Research
CM nature	Canadian Museum of Nature
Concordia U	Concordia University
Dal U	Dalhousie University
DFO	Fisheries and Oceans Canada
DND	National Defence Canada
EC	Environment Canada
ETS	School of Technology (École de technologie supérieure)
Geotop	Geotop Research Centre in Geochemistry and Geodynamics
Golder	Golder Associates Ltd.
HBI	Hotchkiss Brain Institute
HC	Health Canada
Hydro-Québec	Hydro-Québec
INRS A-F	INRS University, Armand-Frappier Institute
INRS ETE	INRS University, Research Centre on Water, Earth, and the Environment
Lakehead U	Lakehead University
Laurentian U	Laurentian University
Laval U	Laval University
LGL	LGL Ltd.
MAPAQ	Quebec Ministry of Aquaculture and Food
McGill U	McGill University
McMaster U	McMaster University
MRNFQ	Quebec Ministry of Natural Resources and Fauna
MtAU	Mount Allison University
MUN	Memorial University of Newfoundland
NEPTUNE	NEPTUNE Canada
Nipissing U	Nipissing University
NRC	National Research Council of Canada
NRCan	Natural Resources Canada

NSAC	Nova Scotia Agricultural College
Okapi Wildlife Associates	Okapi Wildlife Associates
OME	Ontario Ministry of Environment
OMNR	Ontario Ministry of Natural Resources
Ouranos	Ouranos Consortium
Paprican	Pulp and Paper Research Institute of Canada
PC	Parks Canada
Québec-Océan	Québec-Océan
Queen's U	Queen's University
RBCM	Royal British Columbia Museum
RMC	Royal Military College of Canada
ROM	Royal Ontario Museum
RTM	Royal Tyrrell Museum
Ryerson U	Ryerson University
SAIC	Science Applications International Corporation
SEVE	Society for the Exploration and Valuing of the Environment
SFU	Simon Fraser University
SL Ross	SL Ross Environmental Research Ltd.
SMU	Saint Mary's University
StFX U	St. Francis Xavier University
Trent U	Trent University
U de Moncton	University of Moncton
U Lethbridge	University of Lethbridge
U of Manitoba	University of Manitoba
U of Regina	University of Regina
U of Waterloo	University of Waterloo
U of Windsor	University of Windsor
U Sherbrooke	University of Sherbrooke
U Winnipeg	University of Winnipeg
UBC	University of British Columbia
UdeM	University of Montréal
UNB	University of New Brunswick
UNBC	University of Northern British Columbia
UofA	University of Alberta
UofC	University of Calgary
UofG	University of Guelph
UofT	University of Toronto
UOIT	University of Ontario Institute of Technology
uOttawa	University of Ottawa
UPEI	University of Prince Edward Island
UQAC	University of Quebec at Chicoutimi
UQAM	University of Quebec at Montréal
UQAR	University of Quebec at Rimouski
UQTR	University of Quebec at Trois-Rivières
USask	University of Saskatchewan
UVic	University of Victoria
WesternU	Western University (University of Western Ontario)
Vancouver Aquarium	Vancouver Aquarium Marine Science Centre
VCH	Vancouver Coastal Health
VIU	Vancouver Island University
WLU	Wilfrid Laurier University
York U	York University

Labels for International Organizations

The following labels are used to identify international organizations in figures throughout this appendix.

Academia Sinica	Taiwan Central Research Academy
Academy Sci. Czech Rep.	Academy of Sciences of the Czech Republic
AIST	Advanced Industrial Science and Technology
ANU	Australian National University
CAFS	Chinese Academy of Fishery Science
CalTech	California Institute of Technology
Cardiff U	Cardiff University
CEA	Atomic Energy and Alternative Energies Commission
CEFAS	Centre for Environment, Fisheries & Aquaculture Science
Chinese Academy Geo. Sci.	Chinese Academy of Geological Sciences
Chinese Academy Sci.	Chinese Academy of Sciences
CNR	Italian National Research Council
CNRS	National Centre for Scientific Research (France)
Columbia U	Columbia University
CONACYT	National Council of Science and Technology (Mexico)
CONICET	National Scientific and Technical Research Council (Argentina)
Cornell U	Cornell University
CSIC	Spanish National Research Council
CSIR	Council of Scientific and Industrial Research
CSIRO	Commonwealth Science and Industrial Research Organisation
CSU	Colorado State University
CWM	College of William and Mary
Dal U	Dalhousie University
Dalian U Tech	Dalian University of Technology
DFO	Fisheries and Oceans Canada
DTU	Technical University of Denmark
Duke U	Duke University
EC	Environment Canada
ETH Zurich	Swiss Federal Institute of Technology
FSU	Florida State University
Georgia Tech	Georgia Institute of Technology
Ghent U	Ghent University
Harvard U	Harvard University
Helmholtz	Helmholz Association of German Research Centres
HIT	Harbin Institute of Technology
Hokkaido U	Hokkaido University
ICL	Imperial College London
Ifremer	French Institute for Exploitation of the Sea
IMR	Institute of Marine Research (Norway)
INRA	French National Institute for Agricultural Research
IPN	National Polytechnic Institute (Mexico)
IRD	French Institute of Research for Development
James Cook U	James Cook University
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
J-FRA	Fisheries Research Agency (Japan)
KIOST	Korea Institute of Science and Technology (formerly the Korea Ocean Research & Development Institute)

Kyoto U	Kyoto University
Kyushu U	Kyushu University
Leibniz	Leibniz Association
Louisiana State U	Louisiana State University and Agricultural and Mechanical College
Lund U	Lund University
McGill U	McGill University
ME-PRC	Ministry of Education of the People's Republic of China
MIT	Massachusetts Institute of Technology
MNHN	National Museum of Natural History
Monash U	Monash University
Moscow State U	Moscow State University
MPG	Max Planck Society
MUN	Memorial University of Newfoundland
N Carolina State U	North Carolina State University
Nagoya U	Nagoya University
Nanjing U	Nanjing University
NAS Ukraine	National Academy of Sciences of Ukraine
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NERC	Natural Environment Research Council
Newcastle U	Newcastle University
NHM	Natural History Museum, London
NIWA	National Institute of Water and Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NRCan	Natural Resources Canada
NTNU	Norwegian University of Science and Technology
NTOU	National Taiwan Ocean University
NTU	National Taiwan University
NUS	National University of Singapore
NWO	Dutch National Science Foundation
Ocean U	Ocean University of China
Ohio State U	Ohio State University
Oregon U	Oregon State University
Paul Sabatier U	Paul Sabatier University
Peking U	Peking University
Penn State U	Pennsylvania State University
PNY	Pukyong National University
Polish Academy Sci	Polish Academy of Sciences
Princeton U	Princeton University
Russian Academy Sci.	Russian Academy of Sciences
Rutgers U	Rutgers University
SFU	Simon Fraser University
SJTU	Shanghai Jiao Tong University
Smithsonian	Smithsonian Institution
SNU	Seoul National University
SOA	State Oceanic Administration (China)
Stanford U	Stanford University
State UNY Stony Brook	State University of New York at Stony Brook
Statoil	Statoil ASA
Stockholm U	Stockholm University
Sun Yat-sen U	Sun Yat-sen University

Texas A&M	Texas A and M University - College Station
Tohoku U	Tohoku University
Tokyo UMST	Tokyo University of Marine Science and Technology
Tongji U	Tongji University
Tsinghua U	Tsinghua University
TU Delft	Delft University of Technology
U Aix-Marseille	University Aix-Marseille
U Montpellier 2	Montpellier 2 University
U of Aarhus	University of Aarhus
U of Aberdeen	University of Aberdeen
U of Adelaide	University of Adelaide
U of Algarve	University of the Algarve
U of Arizona	University of Arizona
U of Auckland	University of Auckland
U of Barcelona	University of Barcelona
U of Bergen	University of Bergen
U of Bremen	University of Bremen
U of Bristol	University of Bristol
U of C Boulder	University of Colorado at Boulder
U of Cambridge	University of Cambridge
U of Cape Town	University of Cape Town
U of Connecticut	University of Connecticut
U of Copenhagen	University of Copenhagen
U of Delaware	University of Delaware
U of East Anglia	University of East Anglia
U of Edinburgh	University of Edinburgh
U of Florida	University of Florida
U of Georgia	University of Georgia
U of Gothenburg	University of Gothenburg
U of Hamburg	University of Hamburg
U of Helsinki	University of Helsinki
U of Kiel	University of Kiel
U of Leeds	University of Leeds
U of Lisbon	University of Lisbon
U of Maine	University of Maine
U of Melbourne	University of Melbourne
U of Miami	University of Miami
U of Michigan	University of Michigan
U of New Hampshire	University of New Hampshire
U of Oslo	University of Oslo
U of Otago	University of Otago
U of Oxford	University of Oxford
U of Plymouth	University of Plymouth
U of Porto	University of Porto
U of Queensland	University of Queensland
U of Rio	Federal University of Rio de Janeiro
U of Southampton	University of Southampton
U of St. Andrews	University of St. Andrews
U of Sydney	University of Sydney
U of Tokyo	University of Tokyo
U of Tromsø	University of Tromsø

U of Washington	University of Washington
U S California	University of Southern California
U S Carolina	University of South Carolina
U Tasmania	University of Tasmania
U Wisconsin-Madison	University of Wisconsin-Madison
UA Fairbanks	University of Alaska Fairbanks
UBC	University of British Columbia
UC Berkeley	University of California, Berkeley
UC Davis	University of California, Davis
UC San Diego	University of California, San Diego
UC Santa Barbara	University of California, Santa Barbara
UC Santa Cruz	University of California, Santa Cruz
UCL	University College London
UCLA	University of California, Los Angeles
UCM	Complutense University of Madrid
UH Manoa	University of Hawaii at Manoa
UHK	University of Hong Kong
UL Urbana-Champaign	University of Illinois at Urbana-Champaign
UM Twin Cities	University of Minnesota-Twin Cities
UMCP	University of Maryland College Park
UNAM	National Autonomous University of Mexico
UNC Chapel Hill	University of North Carolina at Chapel Hill
Unesp	Sao Paulo State University
Unibo	University of Bologna
Unige	University of Genoa
Unipd	University of Padova
Uniroma1	Sapienza University of Rome
UNSW	University of New South Wales
UofA	University of Alberta
UofT	University of Toronto
UPMC	Pierre and Marie Curie University
Uppsala U	Uppsala University
URI	University of Rhode Island
US Navy	U.S. Navy
USC	University of Santiago de Compostela
USDA	U.S. Department of Agriculture
US-DOE	U.S. Department of Energy
US-EPA	U.S. Environmental Protection Agency
USF	University of South Florida
USGS	U.S. Geological Survey
USP	University of São Paulo
UST	University of Science and Technology
UT Austin	University of Texas at Austin
Utrecht U	Utrecht University
UVic	University of Victoria
UWA	University of Western Australia
WHOI	Woods Hole Oceanographic Institution
Wuhan U	Wuhan University
WUR	Wageningen University and Research Centre
Xiamen U	Xiamen University
Yale U	Yale University
Zhejiang U	Zhejiang University

Appendix A
Additional Information on Canada's Capacity in Ocean Science

This is an appendix to the Council of Canadian Academies' 2013 report, *Ocean Science in Canada: Meeting the Challenge, Seizing the Opportunity*. It provides additional information on the data, methods, and sources of information used to assess Canada's capacity in ocean science in the following categories: human capacity, organizations and networks, and funding.

A1 HUMAN CAPACITY

This section presents the methodological details of data analyses on human capacity presented in Section 2.1 of the report.

A1.1 Statistics Canada CIP Codes Used to Identify Ocean Science Programs

The following codes from Statistics Canada's Classification of Instructional Programs (CIP) were used to select data on graduates from the Postsecondary Student Information System (PSIS) related to ocean science from 2001 to 2009. Some of these programs may include graduates in areas that are not related to ocean science.

A1.2 Canada Research Chairs (CRC) Search Terms

Data on Canada Research Chairholders were provided by the CRC program, based on a search of its database using the following terms in the *title* and *keywords* fields:

- English: *ocean**, *marine*, *coast**, *estuar**, *tidal*, and *maritime*
- French: *océan**, *marin**, *côte*, *côtière*, côt*, *estuar**, *estuair**, *marée*, and *maritime*

Table A1

CIP Codes Used to Identify Graduates of Ocean-Science-Related Programs in Statistics Canada's PSIS Database

CIP code	Program
01.0303	Aquaculture
01.1002	Food Technology and Processing
03.0205	Water, Wetlands and Marine Resources Management
03.0301	Fishing and Fisheries Sciences and Management
03.9999	Natural Resources and Conservation, Other
14.0805	Water Resources Engineering
14.2201	Naval Architecture and Marine Engineering
14.2401	Ocean Engineering
14.2501	Petroleum Engineering
14.3901	Geological/Geophysical Engineering
15.0903	Petroleum Technology/Technician
26.1302	Marine Biology and Biological Oceanography
40.0605	Hydrology and Water Resources Science
40.0607	Oceanography, Chemical and Physical
47.0616	Marine Maintenance/Fitter and Ship Repair Technology/Technician
49.0303	Commercial Fishing
49.0304	Diver, Professional and Instructor
49.0309	Nautical Science/Merchant Marine Officer
49.0399	Marine Transportation, Other

A2 ORGANIZATIONS AND NETWORKS

The *Federal S&T Map: Oceans Science Case Study* includes an overview of the involvement of various federal departments and agencies in ocean science (GC, 2010). This information has been reorganized in Table A2, according to the research themes used in this report. Each of these 10 federal departments and agencies contributes to different aspects of research relating to the 40 research questions. Fisheries and Oceans Canada (DFO), Environment Canada, Natural Resources Canada (NRCan), and the National Research Council of Canada (NRC) are the most active departments in research relevant to the 40 research questions. The number of departments and agencies with a role in ocean science and technology reflects the breadth of the 40 research questions, as well as the wide distribution of the capacity to address these questions across many agencies with specialized abilities. Further findings are presented in Section 2.2.1 of the main report.

Table A2

Involvement of Federal Departments/Agencies in Selected Ocean Science Programs and Activities

	Canadian Food Inspection Agency	Canadian Space Agency	Fisheries and Oceans Canada	Defence Research and Development Canada	Environment Canada	Health Canada	National Research Council of Canada	Natural Resources Canada	Public Health Agency of Canada	Transport Canada
Ocean-Climate Interactions										
Ocean Processes		○	○		○		○	○		
Climate Processes			○		○		○	○		
Mitigation			○		○					
Adaptation and Impacts			○		○	○	○	○		
Biological, Mineral, and Energy Resources										
Sustainable Methods of Production			○		○		○	○		
Gas Hydrates							○	○		
Frontiers in Oil and Gas			○		○		○	○		
Integrating Renewable Energy Sources & Small Scale Systems			○		○		○	○		
Carbon Capture and Storage			○		○					
Biodiversity			○	○	○					○
Sustainable Use of Resources	○		○		○			○		○
Vulnerable Ecosystems			○		○			○		
Plant and Animal Resource Base	○		○			○	○	○		○
Earth, Ocean, and Ecosystem Interactions		○	○		○			○		
Human Impacts on Marine and Coastal Ecosystems										
Air Quality					○	○				○
Water Quality			○		○					○
Pollutants, Waste, and Harmful Substances	○		○	○	○	○	○	○		○
Remediation			○		○		○			
Plate Tectonics and Natural Hazards										
Natural Disaster Alert and Mitigation			○		○			○		
Territorial Delimitation		○	○				○	○		
Ocean Technology										
Innovation Capacity of Communities			○				○	○		

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	Canadian Food Inspection Agency	Canadian Space Agency	Fisheries and Oceans Canada	Defence Research and Development Canada	Environment Canada	Health Canada	National Research Council of Canada	Natural Resources Canada	Public Health Agency of Canada	Transport Canada
Innovation Capacity of Industrial Sectors		○	○				○	○		
Innovation Capacity of Firms			○				○	○		
Emerging Technologies			○				○	○		
Human Health and Well-Being										
Vulnerable Populations			○			○			○	
Circumpolar Health			○		○	○				
Environmental Hazards			○		○		○	○		
Information and Services			○	○	○		○			
Animal Environment Interactions	○		○		○					
Air Quality						○	○			
Recreational Water Quality						○	○			
Aids to Navigation			○		○	○	○	○		○
Safe Food and Water	○		○		○	○	○	○	○	
Nutritional and Innovative Food						○	○			
Safe and Effective Health Products						○	○			
Safe and Sustainable Pest Control Products			○		○	○				
Human Safety and Injury Prevention			○							○
Emerging Technologies						○				○
Disease Prevention and Control			○			○			○	
Emergency Preparedness and Response				○	○	○	○		○	

Adapted and reproduced with permission from GC (2010)

The topics in rows have been re-organized according to the themes used in this report. The rows themselves were selected from Annex C of the *Federal S&T Map: Oceans Science Case Study* (GC, 2010). Not all relevant topics discussed in this report were included in the *Federal S&T Map*, and some areas of involvement for various departments and agencies may have changed since the map's development.

A3 OCEAN SCIENCE FUNDING

Since ocean science encompasses a broad range of disciplines, it is eligible for funding from a range of funding agencies, depending on the approaches and disciplinary focus of a particular research project or program. This assessment included an analysis of data from six major science funding agencies:

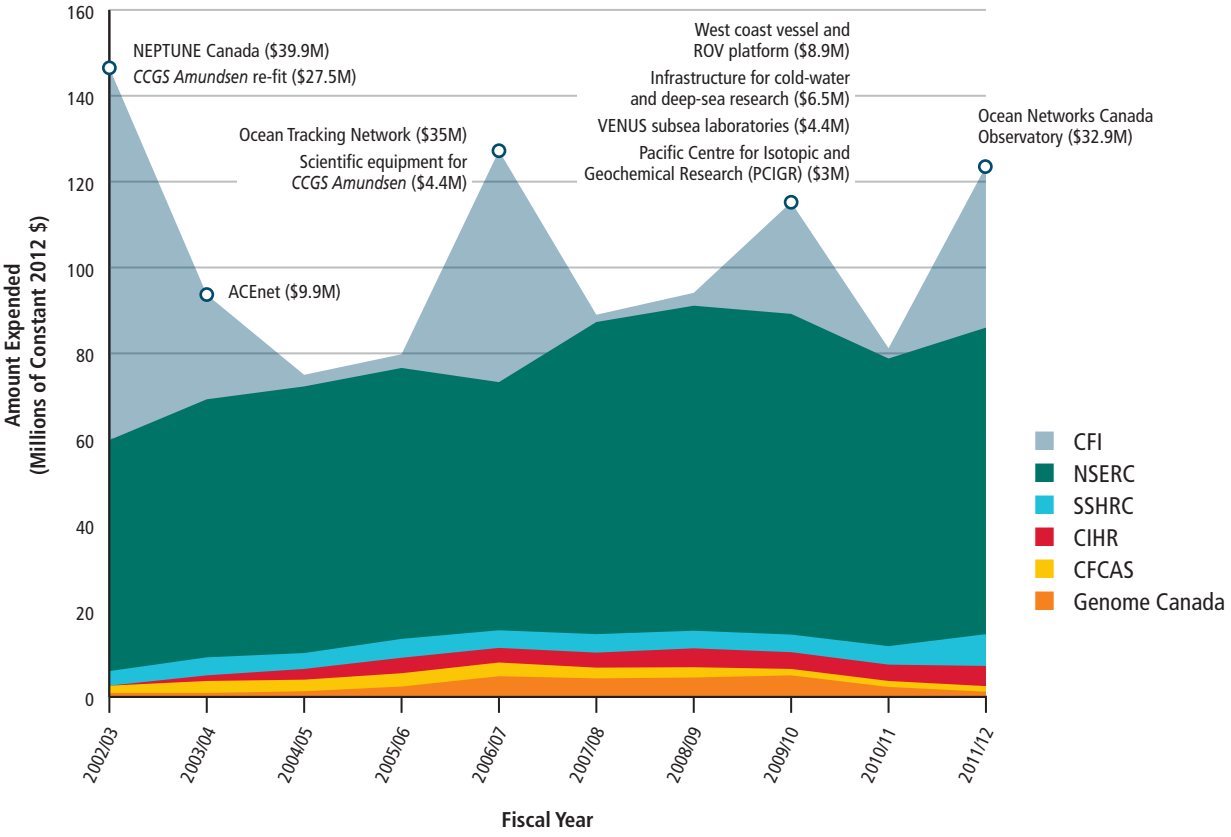
- Canada Foundation for Innovation (CFI);
- Natural Sciences and Engineering Research Council of Canada (NSERC);
- Social Sciences and Humanities Research Council (SSHRC);
- Canadian Institutes of Health Research (CIHR);
- Canadian Foundation for Climate and Atmospheric Science (CFCAS, now the Canadian Climate Forum); and
- Genome Canada.

Each agency searched its own database to provide data relevant only to ocean science. Although each agency adjusted the terms used, depending on the keywords in its database, the search strategies were based on a common set of suggested keywords:

- *ocean** AND NOT *Oceania*
- *marin**
- *coast* OR *côte* OR *côtier*
- *estuar**
- *tidal*
- *fish* AND NOT *freshwater*

The search strategy for the NSERC database was based on the full list of keywords used to identify ocean science papers in the bibliometric study, adjusted to remove false positives.

Data from these agencies identified over $920 million in public funding to nearly 4,900 ocean science projects and facilities in fiscal years 2002/03 to 2011/12 (see Section 2.4.1 of the report for full findings). Funding from NSERC accounted for a majority of this funding (Figure A1). CFI provided partial funding to several large infrastructure projects, making its contribution appear variable from year to year. SSHRC and CIHR funding accounted for a smaller proportion of ocean science funding during this period, but these have been growing slowly in terms of real spending. The funding mandate of the CFCAS ended in 2012 (CFCAS, 2012), while Genome Canada funded a handful of large collaborative projects related to ocean science primarily between fiscal years 2006/07 and 2009/10.



Data source: Calculated using data provided by CFI, NSERC, SSHRC, CIHR, CFCAS, and Genome Canada

Figure A1

Expenditures of Major Funding Agencies on Ocean Science, in Constant 2012 Dollars, Fiscal Years 2002/03 to 2011/12

The majority of ocean science funding identified in this analysis has been provided by NSERC, along with several large investments by CFI, which are indicated in the figure. Fiscal years start on April 1st and end on March 31st of the following calendar year.

Appendix B
Bibliometric Comparisons of Canada to Other Leading Countries in Ocean Science

This appendix provides additional details on the bibliometric data and indicators described in Chapters 3 and 4 of *Ocean Science in Canada: Meeting the Challenge, Seizing the Opportunity*.

B1 BIBLIOMETRIC ENTITIES

In bibliometric analyses, an *entity* represents any group of publications for which indicators are calculated, such as countries, universities, or other organizations to which authors can be assigned an affiliation. Entities with smaller publication outputs tend to have scores in aggregate indicators that are more variable, and more sensitive to individual articles or years. To reduce the influence of individual publications, no additional indicators were calculated for entities with fewer than 30 publications.

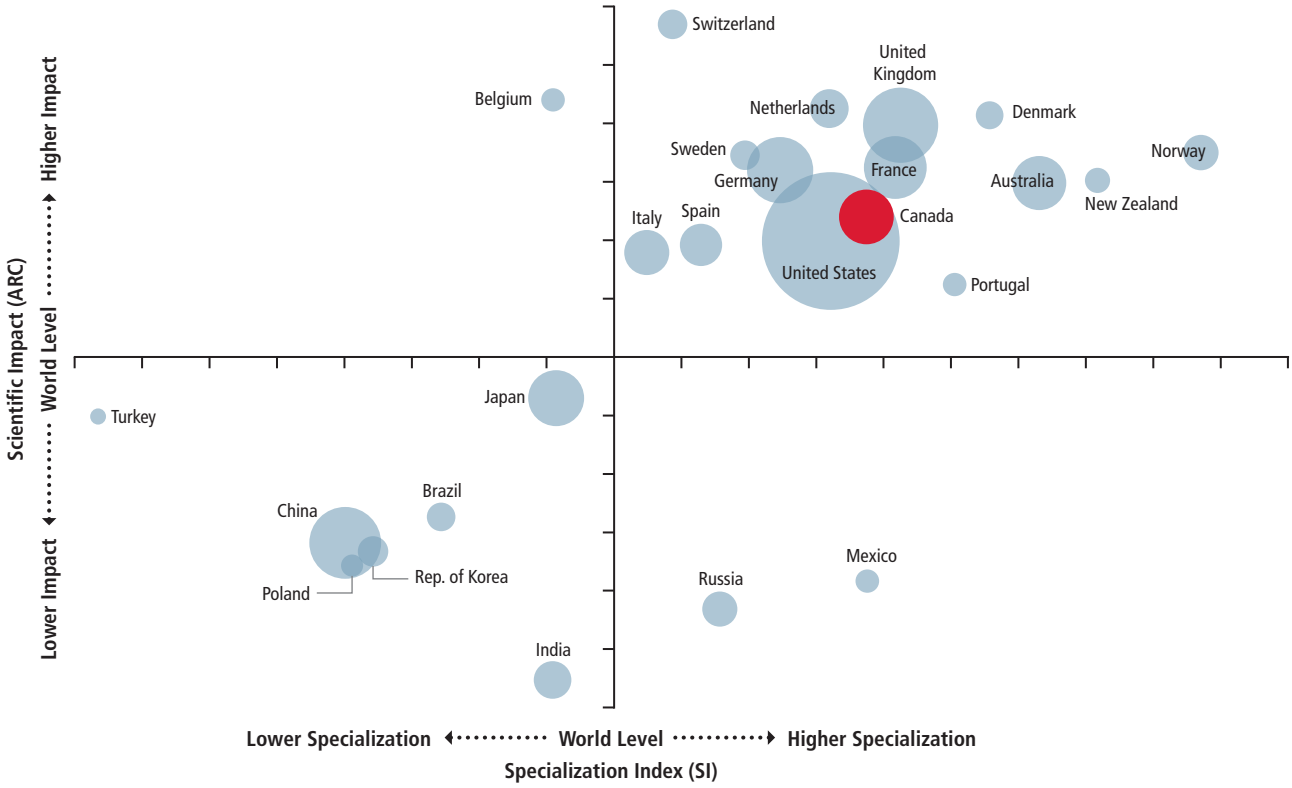
To assess Canada's performance in ocean science, bibliometric indicators were computed at three levels:

- **Countries:** Indicators were computed for the top 25 countries with the most publications in ocean science (see Section 3.1.1 in the report for key metrics). These indicators were computed for each country in ocean science as a whole, and within each research theme.
- **International organizations:** Indicators were computed for the top 200 international organizations with the most publications in ocean science. The position of Canadian organizations was assessed within an international collaboration network, using graphs and network indicators.
- **Canadian organizations:** Indicators were computed for the top 100 Canadian organizations with the most publications in ocean science. These indicators were computed for each organization in ocean science as a whole, and within each research theme. Collaboration networks for Canadian organizations were also produced for each theme.

Collaboration networks for this study were drawn by Gephi software (Bastian *et al.*, 2009), using a layout algorithm to position nodes whereby linked nodes are attracted to each other, while unlinked nodes are pushed apart. Links representing few collaborations are sometimes omitted from graphs to improve readability. Nevertheless, the layout algorithm generally places nodes near other connected nodes, even if the links themselves are not shown. This also means that more central nodes in the network diagram tend to be linked by collaboration to many other nodes in the network, though there may be few collaborations per link.

B2 CANADA'S POSITION IN OCEAN SCIENCE OUTPUT RELATIVE TO OTHER LEADING COUNTRIES BY RESEARCH THEME

The graphs in this section show Canada's position relative to other leading countries in ocean science, in terms of the number of scientific papers (output), the scientific impact of those papers (ARC), and the specialization of each country in the six research themes that build on established methods and approaches. Countries closer to the right side of each graph are more specialized in that theme, measured by the specialization index (SI), meaning that a larger proportion of papers produced by authors in that country are in that particular research theme. Countries closer to the top edge of a graph have produced papers with higher scientific impact, as measured by the ARC of those papers.

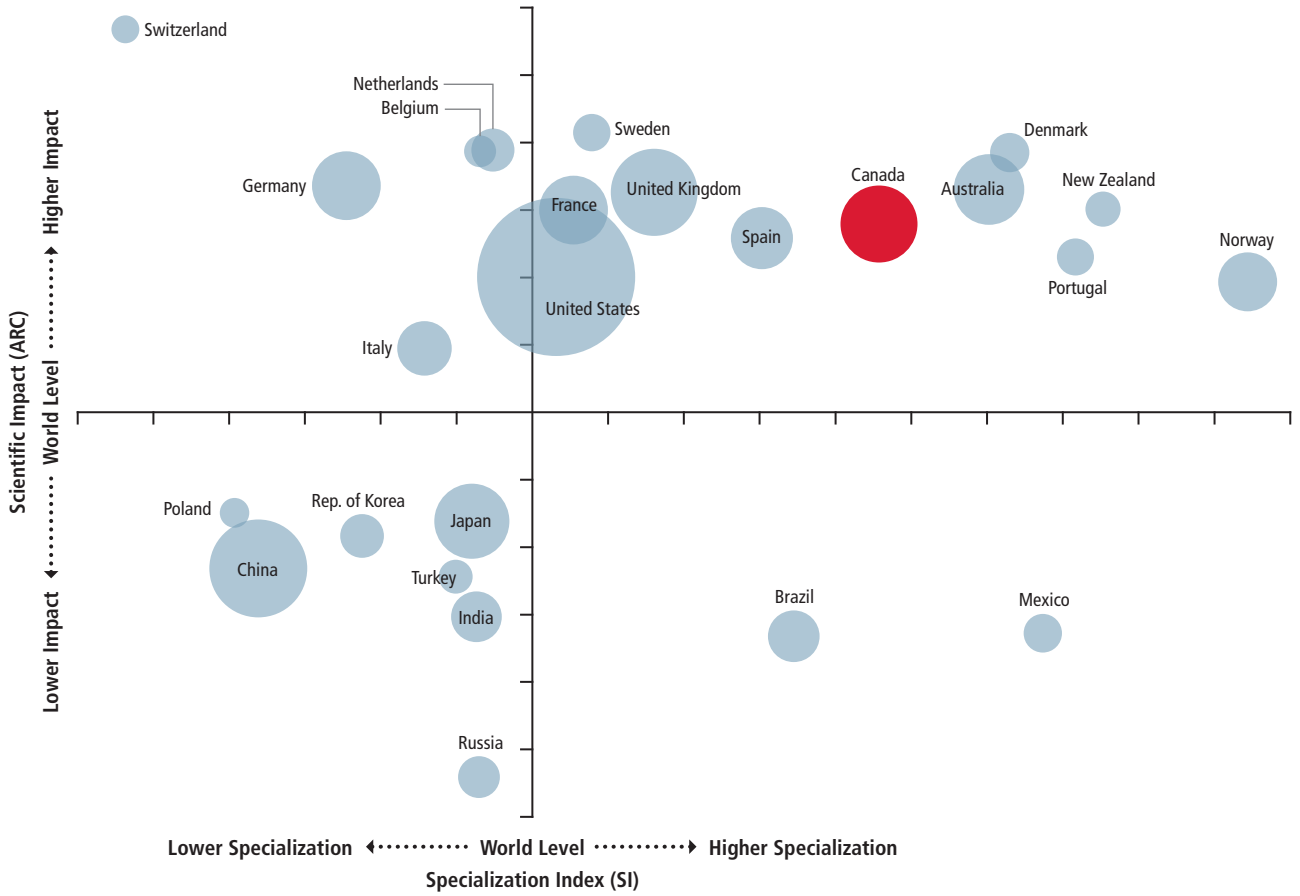


Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)

Figure B1

Position of Leading Countries in Research on Ocean-Climate Interactions, 2003–2011

Note: The ARC and SI values in the figure were log-transformed for visualization.

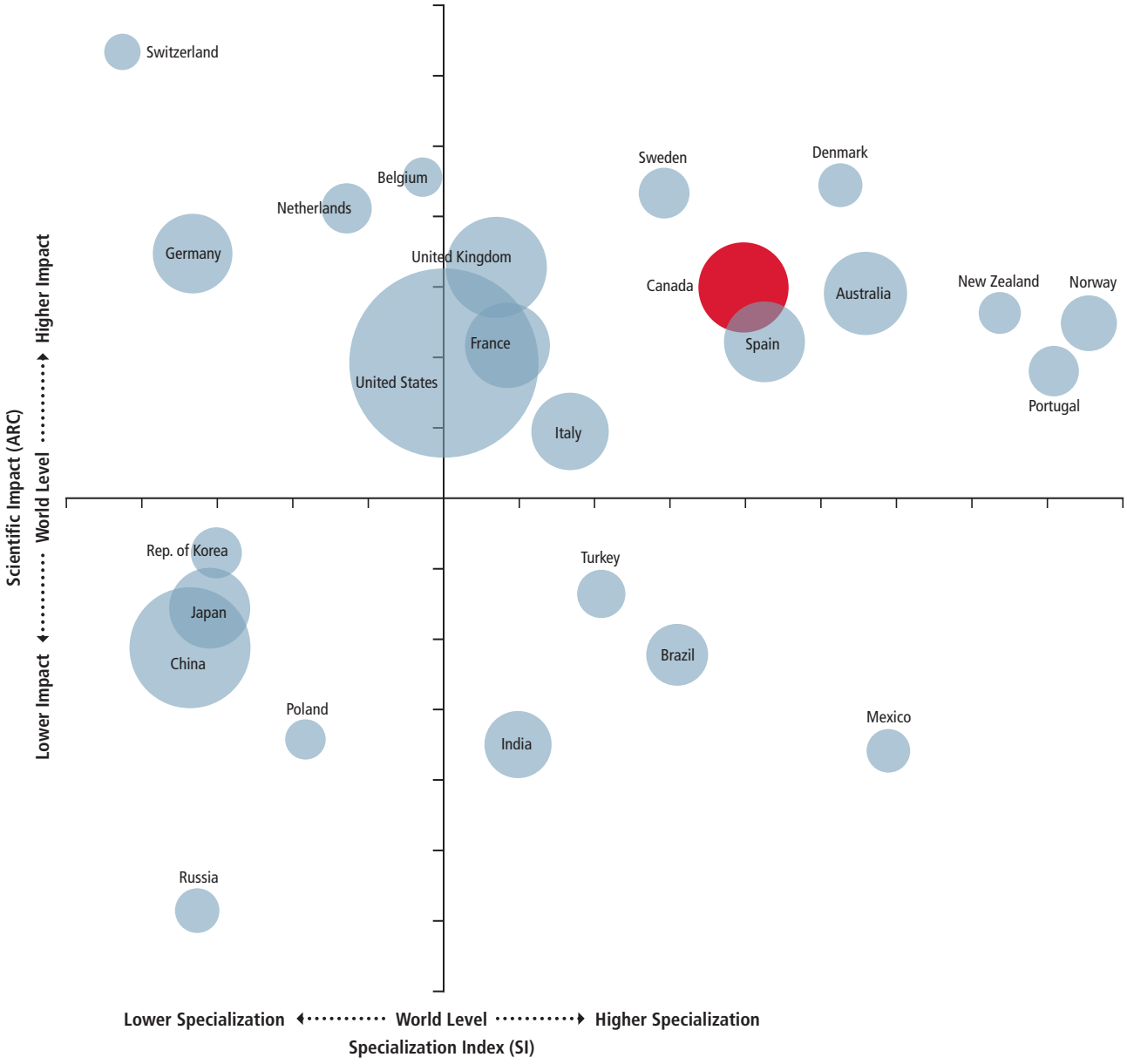


Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)

Figure B2

Position of Leading Countries in Research on Biological, Mineral, and Energy Resources, 2003–2011

Note: The ARC and SI values in the figure were log-transformed for visualization.

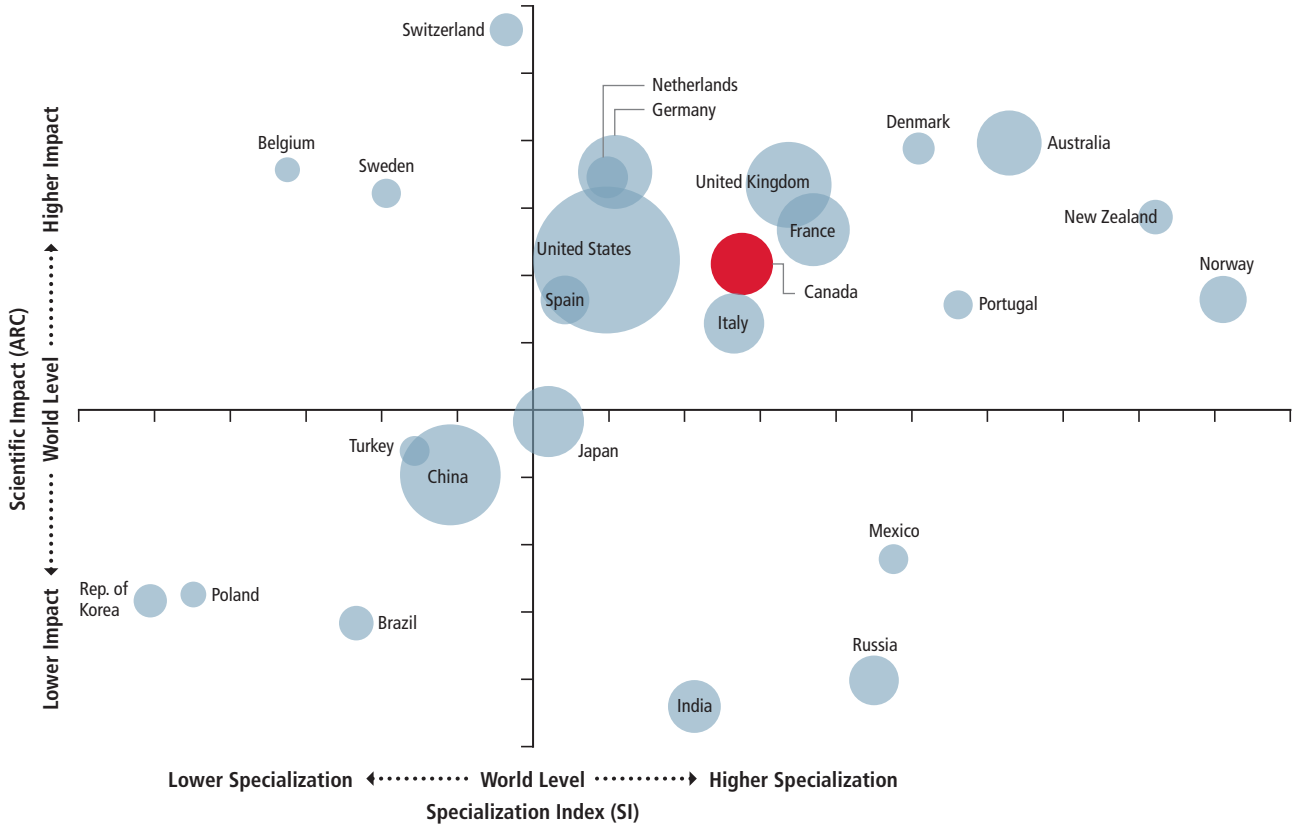


Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)

Figure B3

Position of Leading Countries in Research Related to Human Impacts on Marine and Coastal Ecosystems, 2003–2011

Note: The ARC and SI values in the figure were log-transformed for visualization.

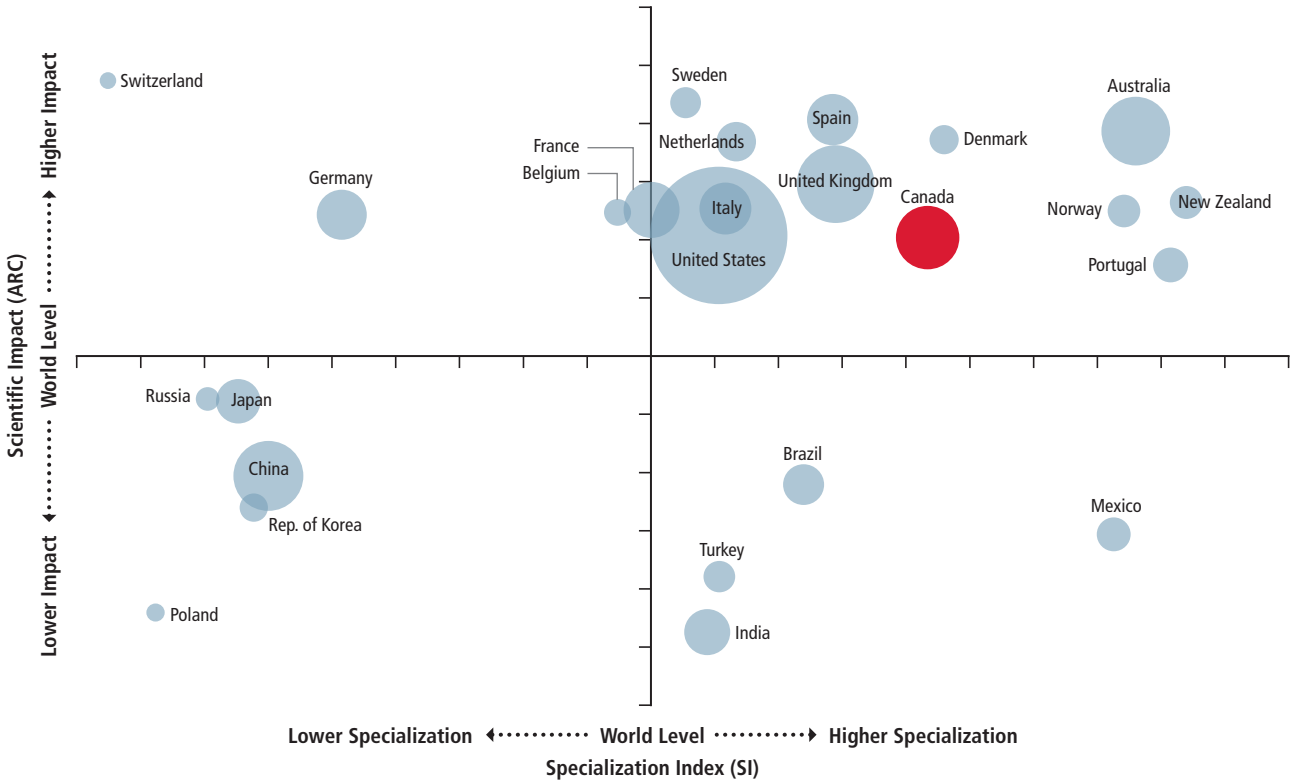


Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)

Figure B4

Position of Leading Countries in Research on Plate Tectonics and Natural Hazards, 2003–2011

Note: The ARC and SI values in the figure were log-transformed for visualization.

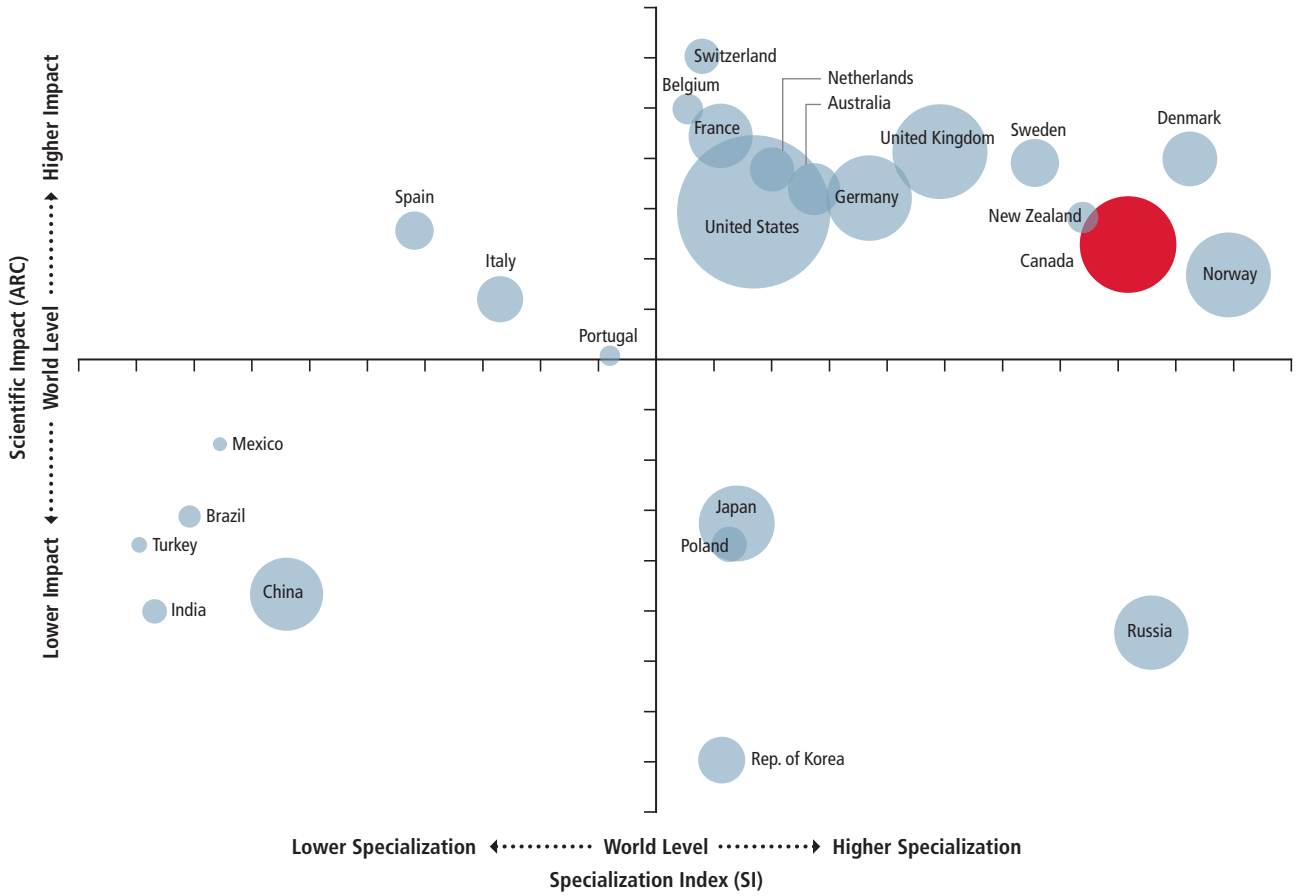


Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)

Figure B5

Position of Leading Countries in Research on Coastal Communities, 2003–2011

Note: The ARC and SI values in the figure were log-transformed for visualization.



Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)

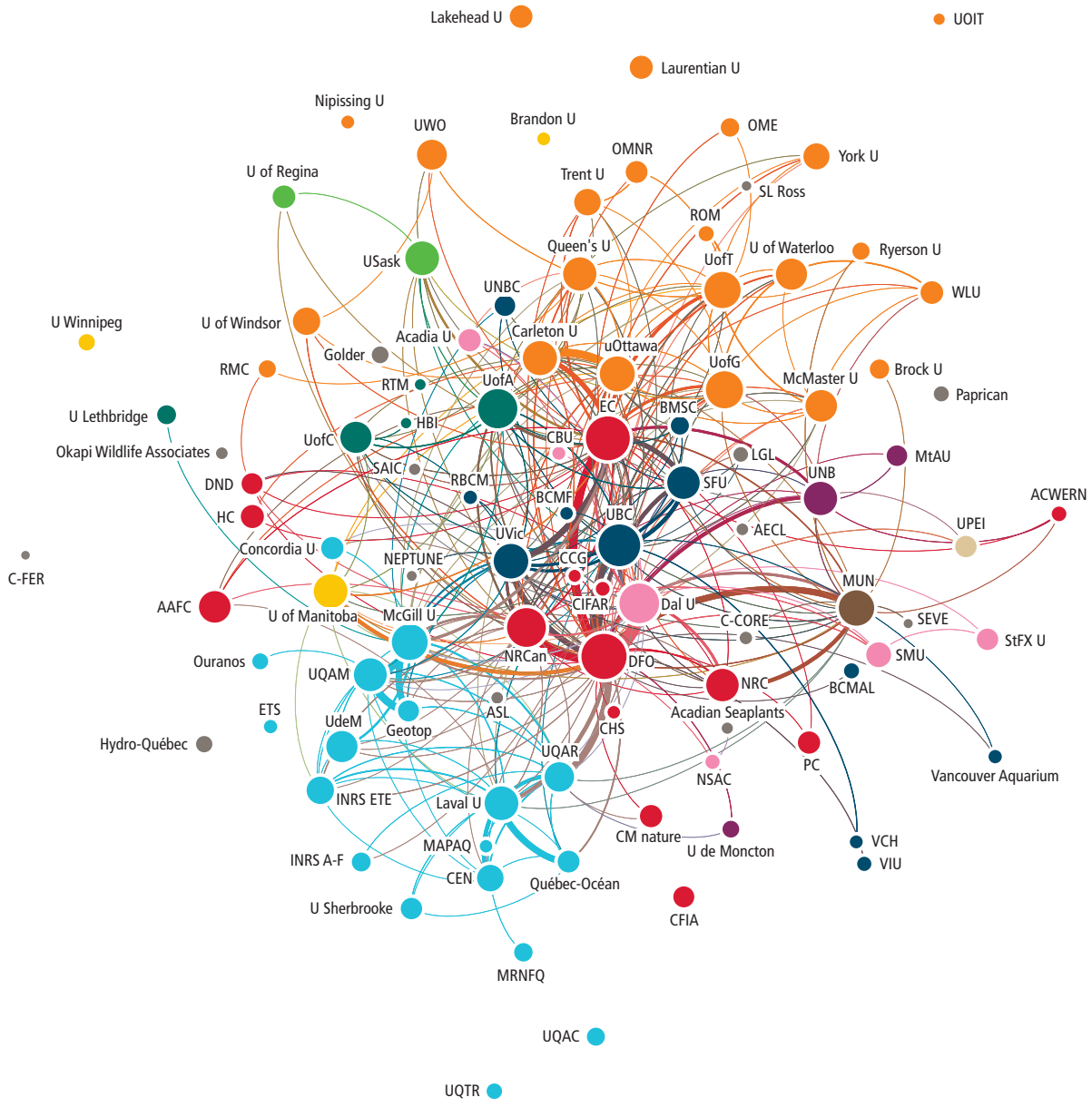
Figure B6

Position of Leading Countries in Research on the Arctic Ocean, 2003–2011

Note: The ARC and SI values in the figure were log-transformed for visualization.

B3 COLLABORATION BETWEEN CANADIAN ORGANIZATIONS IN OCEAN SCIENCE

Section 3.3.1 of the report includes a collaboration network graph for the top 30 publishing Canadian organizations in ocean science for 2003–2011 (Figure 3.2). Figure B7 shows the same network graph for the top 100 publishing organizations in Canada. This figure is intended to be viewed onscreen and can be magnified to explore in finer detail.



Canada (National or Federal Organization)	Manitoba	Ontario
Private Sector	New Brunswick	Prince Edward Island
Alberta	Newfoundland and Labrador	Quebec
British Columbia	Nova Scotia	Saskatchewan

Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)

Figure B7

Collaboration Network of the Top 100 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 publications). 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 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. Note: Only links representing 10 or more collaborations between institutions are displayed.

B4 COLLABORATION BETWEEN INTERNATIONAL ORGANIZATIONS IN OCEAN SCIENCE

Section 3.3.2 of the report includes a collaboration network graph of selected top international publishing organizations in ocean science for 2003–2011 (Figure 3.4). Figure B8 shows the full network graph for the top 200 international organizations. Larger patterns and regional clusters remain evident, as in Figure 3.4. Figure B8 also includes additional organizations in each cluster and a few smaller isolated regional clusters, such as Taiwan, the Republic of Korea, Mexico, and Brazil, which have organizations with comparable publication output but show few collaborative links to organizations in other countries. This figure is intended to be viewed onscreen and can be magnified to explore in finer detail.

B4.1 Social Network Indicators

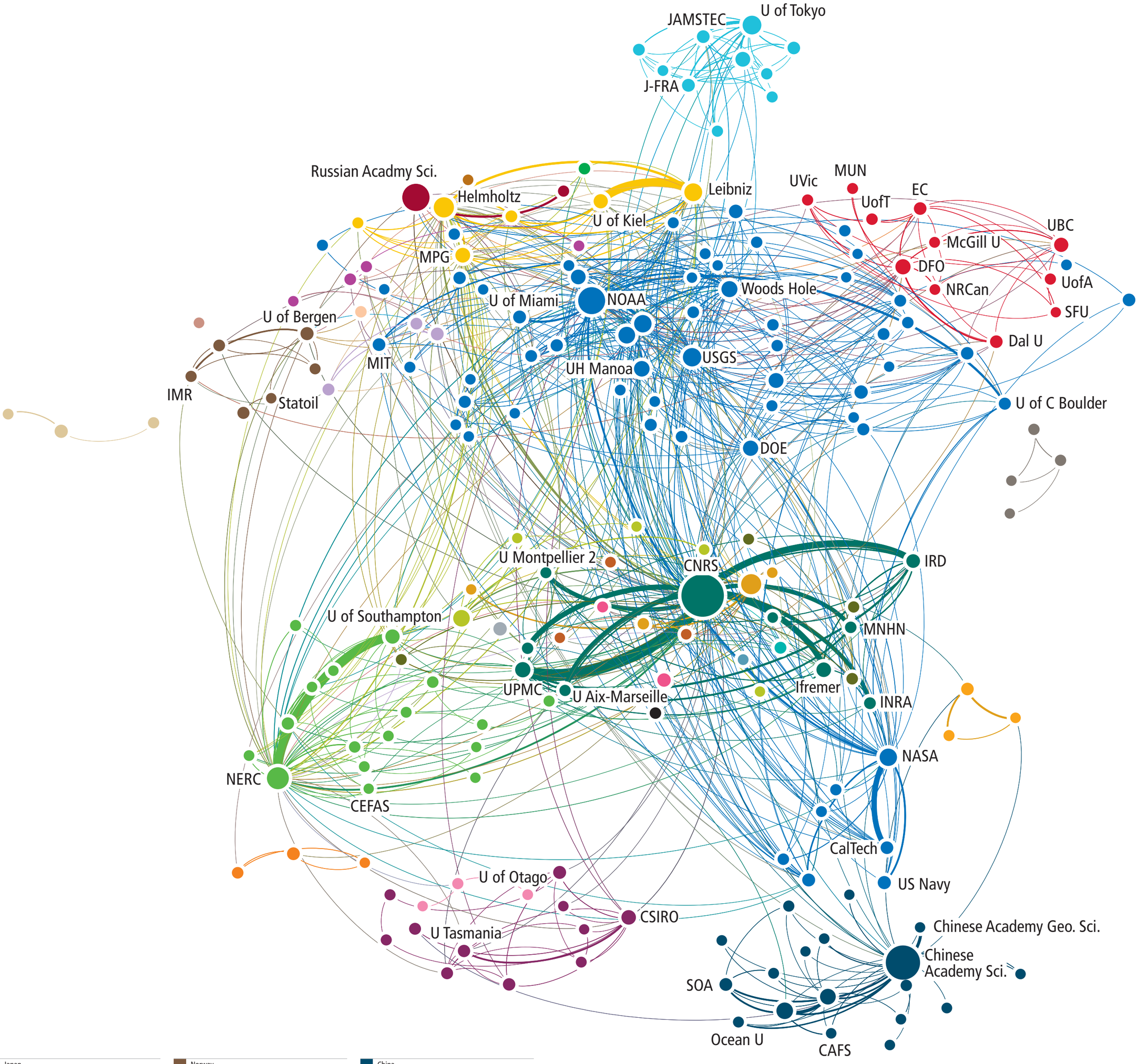
To characterize the networks produced for this study and the positioning of each institution in the networks, network indicators were produced using Gephi software (Bastian *et al.*, 2009). As described by Gephi's documentation, these indicators are as follows:

Clustering Coefficient: The clustering coefficient (Watts-Strogatz), when applied to a single node, is a measure of the extent to which the neighbourhood of a node is complete. The *neighbourhood* of a node is the set of other nodes that are connected to it. If every node in that neighbourhood is connected to every other node, then the neighbourhood is complete and will have a clustering coefficient of 1.0. If none of the nodes in the neighbourhood of a node are connected, then the clustering coefficient for that node will be 0.

Closeness Centrality: The closeness centrality refers to the average distance from a given node to all other nodes in the network. A node directly connected to every other node in the network would score 1.0, the highest possible closeness centrality score.

Betweenness Centrality: This indicator measures how often a node appears on the shortest paths between nodes in the network.

Eigenvector Centrality: This indicator is a measure of the level of integration of an entity (institution) in a collaboration network. The level of integration of institutions within a collaboration network is reflected by the number of institutions to which they are connected, as well as the quality of their collaborations (i.e., the strength of the links measured by the number of co-authored publications and the importance of the institutions to which they are connected in the network). The mathematical definition of the eigenvector centrality is such that the centrality score of a node in a network is proportional to the sum of the centrality scores of all nodes that are connected to it. Thus, this indicator offers a good appreciation of both the number and quality of an entity's collaborations since connections to high-scoring nodes (which represent the entities in the network) contribute more to the score of that entity than equal connections to low-scoring nodes. An institution scoring high with respect to this indicator operates closer to the core of the network (i.e., it is central and highly important to the network's structure) than a low-scoring institution such that the eigenvector centrality provides a good appreciation of the integration of an individual country within a network (i.e., the higher the score, the more integrated the country). It is similar to the PageRank indicator.



Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)

Figure B8

Collaboration Network of Top 200 International Organizations in Ocean Science, 2003–2011

Note: Only links representing 50 or more collaborations between organizations are displayed. Nodes are coloured based on the country where the organization is located or based.

Table B1

Network Indicators for Selected Top International Organizations in Ocean Science, 2003–2011

Organization	Number of Collaborating Organizations	Total Number of Collaborations	Clustering Coefficient	Rank	Closeness Centrality	Rank	Betweenness Centrality	Rank	Eigenvector Centrality	Rank*
French National Centre for Scientific Research (CNRS)	197	24,084	0.785	195	1.010	1	49.14	2	1.00000	1
Leibniz Association	195	7,720	0.790	194	1.020	3	47.72	3	0.99259	2
Chinese Academy of Sciences	196	6,913	0.778	196	1.015	2	57.03	1	0.99011	3
Natural Environment Research Council (NERC)	193	10,875	0.801	182	1.030	4	40.97	13	0.98975	4
Woods Hole Oceanographic Institution	193	6,308	0.801	185	1.030	4	41.13	12	0.98914	5
Helmholz Association of German Research Centres	193	7,466	0.796	188	1.030	4	44.17	6	0.98659	6
Max Planck Society (MPG)	192	5,515	0.798	187	1.035	7	43.46	8	0.98215	7
National Oceanic and Atmospheric Administration (NOAA)	191	11,996	0.802	181	1.040	8	40.82	14	0.97974	8
University of Hawaii at Manoa	190	4,656	0.801	184	1.045	9	41.29	11	0.97363	9
Spanish National Research Council (CSIC)	189	4,909	0.809	172	1.050	11	38.81	17	0.97334	10
University of California, San Diego	188	5,306	0.815	164	1.055	12	35.14	24	0.97182	11
Russian Academy of Sciences	190	3,750	0.796	189	1.045	9	44.03	7	0.97095	12
Columbia University	188	4,213	0.812	171	1.055	12	36.86	19	0.96996	13
US Geological Survey (USGS)	187	5,187	0.818	156	1.060	16	34.83	26	0.96842	14
Commonwealth Science and Industrial Research Organisation (CSIRO)	187	3,444	0.816	159	1.060	16	36.56	20	0.96732	15
University of Southampton	188	5,921	0.803	180	1.055	12	40.37	15	0.96464	16
U.S. Department of Energy	188	4,682	0.801	183	1.055	12	45.73	4	0.96358	17
University of Washington	186	6,062	0.817	157	1.065	20	34.94	25	0.96286	18
University of Cambridge	187	2,459	0.805	177	1.060	16	40.02	16	0.96071	19
Kiel University	186	6,388	0.814	166	1.065	20	35.23	23	0.96067	20
Oregon State University	186	4,146	0.813	167	1.065	20	35.55	22	0.96065	21
NASA	184	7,986	0.829	140	1.075	26	29.96	39	0.95876	22
Stanford University	187	2,757	0.800	186	1.060	16	44.64	5	0.95810	23
University of British Columbia	186	2,921	0.808	173	1.065	20	43.28	9	0.95714	24
Pierre and Marie Curie University (UPMC)	185	7,620	0.816	161	1.070	24	34.09	31	0.95667	25
University of Miami	184	3,190	0.824	149	1.075	26	31.48	36	0.95612	26
Dalhousie University	184	2,431	0.816	160	1.075	26	34.50	28	0.95160	27
University of California, Berkeley	182	2,396	0.830	137	1.085	31	29.02	46	0.94950	28
University of Tokyo	185	4,621	0.804	178	1.070	24	42.20	10	0.94948	29
Massachusetts Institute of Technology (MIT)	182	2,848	0.829	138	1.085	31	29.16	45	0.94872	30
Fisheries and Oceans Canada (DFO)	177	3,967	0.823	151	1.111	45	34.05	32	0.91940	52
University of Toronto	172	1,473	0.834	124	1.136	58	29.81	40	0.89947	66
University of Alberta	167	1,215	0.840	108	1.161	80	25.07	72	0.87638	87
Environment Canada	163	2,482	0.855	61	1.181	98	23.31	87	0.86283	95
University of Victoria	161	1,784	0.875	24	1.191	104	15.20	147	0.86173	96
McGill University	161	1487	0.857	53	1.191	104	18.18	127	0.85323	105
Natural Resources Canada (NRCan)	154	1332	0.870	29	1.226	128	14.94	151	0.82246	125
Memorial University of Newfoundland	144	920	0.862	48	1.276	144	16.17	138	0.76611	146
Simon Fraser University	137	1,125	0.889	9	1.312	156	9.92	182	0.73810	153

Data source: Calculated by Science-Metrix using the Scopus database (Elsevier) and Gephi

* Only the 30 most central international organizations, as measured by the Eigenvector Centrality, are listed, plus all Canadian organizations in the top 200.

B5 CANADA'S INTERNATIONAL COLLABORATION IN OCEAN SCIENCE

Ocean science papers with international co-authors tend to have higher scientific impact, as measured by average relative citations (ARC), than papers by authors from the same country (Table B2). This is especially true for Canadian papers, whose ARC scores increase from 1.06 to 1.57 when published with an international co-author.

Table B2

Difference in Scientific Impact of Publications (ARC Scores) Between Ocean Science Papers with International Co-authors, and Those from the Same Country, 2003–2011

Country	Total		International		National		Difference (International – National)
	Number of Papers	ARC	Number of Papers	ARC	Number of Papers	ARC	Δ ARC
United States	146,658	1.28	52,225	1.53	94,433	1.15	**0.38**
China	66,598	0.77	13,645	1.38	52,953	0.61	**0.77**
United Kingdom	44,422	1.43	25,505	1.64	18,917	1.14	**0.50**
Japan	36,812	0.88	11,612	1.28	25,200	0.70	**0.58**
Germany	32,616	1.42	19,475	1.64	13,141	1.09	**0.56**
France	31,408	1.36	18,375	1.59	13,033	1.03	**0.56**
Canada	29,162	1.33	15,263	1.57	13,899	1.06	0.51
Australia	26,696	1.36	13,048	1.64	13,648	1.10	**0.54**
Spain	21,798	1.24	10,464	1.46	11,334	1.04	**0.42**
Italy	20,703	1.12	9,110	1.48	11,593	0.85	**0.63**
India	16,033	0.71	3,281	1.10	12,752	0.61	**0.48**
Norway	13,874	1.28	7,409	1.49	6,465	1.05	**0.44**
Brazil	13,869	0.73	4,367	1.03	9,502	0.59	**0.45**
Russia	13,827	0.52	4,820	1.08	9,007	0.22	**0.86**
Rep. of Korea	11,983	0.83	4,078	1.09	7,905	0.69	**0.40**
Netherlands	11,843	1.53	7,655	1.72	4,188	1.20	**0.52**
Sweden	8,266	1.49	5,128	1.69	3,138	1.16	**0.53**
Turkey	7,540	0.85	1,655	1.23	5,885	0.75	**0.48**
Denmark	7,428	1.53	4,746	1.70	2,682	1.22	**0.48**
Mexico	7,069	0.71	3,298	0.97	3,771	0.49	**0.49**
Portugal	7,043	1.20	3,739	1.35	3,304	1.03	**0.33**
New Zealand	6,606	1.37	3,883	1.62	2,723	1.02	**0.59**
Belgium	6,128	1.49	4,155	1.64	1,973	1.18	**0.46**
Poland	6,108	0.75	2,122	1.19	3,986	0.51	**0.68**
Switzerland	6,023	1.90	4,550	2.02	1,473	1.52	**0.50**
World	520,734	1.00	130,733	1.34	390,001	0.89	0.45

Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)

Canadian researchers publish more frequently with authors from different countries (Table B3). Canada is naturally more likely to publish papers with countries that have high publication counts, therefore the affinity index is used to determine countries with which Canada collaborates more or less often than expected, relative to the number of papers published by authors from that country.

Affinity Index: This index is the ratio of observed to expected co-authored publications, with the expected number determined by a log-log linear regression of the number of co-authored publications against the number of papers produced by that country. When the indicator is above 1.0, a country produces more publications in collaboration than expected based on the size of its scientific output, while an index value below 1.0 means the reverse. This indicator was computed asymmetrically for Canada to identify the countries with which Canada has the strongest positive affinities and the strongest negative affinities for collaboration in ocean science between 2003 to 2011.

Table B3

Number of Bilateral Co-Authored Ocean Science Publications with Canadian Authors, and Canada's Affinity Index for Selected Countries, 2003–2011

Country	Number of collaborations with Canada	Canada's *affinity* towards this country
New Zealand	399	2.82
United States	7,419	2.45
China	1,088	2.42
Iran	107	2.37
Iceland	83	2.05
Mexico	246	1.99
Tunisia	44	1.97
Argentina	175	1.87
Panama	36	1.83
Venezuela	50	1.81
Norway	741	1.75
Rep. of Korea	229	1.73
Brazil	309	1.69
South Africa	236	1.59
Singapore	84	1.58
Australia	1,094	1.58
Chile	158	1.57
Egypt	66	1.56
Denmark	454	1.55
United Arab Emirates	35	1.53
United Kingdom	2,119	1.32
India	186	1.31
Saudi Arabia	36	1.25
Kenya	31	1.24
Peru	32	1.21
Japan	688	1.20
Finland	171	1.20
Switzerland	337	1.16
Ireland	150	1.14
Thailand	72	1.14
Israel	103	1.09
Sweden	405	1.06
Belgium	268	1.04
France	1,345	1.03
Philippines	33	1.00
Ukraine	37	0.99
Indonesia	41	0.96
Netherlands	471	0.95
Estonia	31	0.94
Malaysia	55	0.94
Colombia	32	0.91
Austria	124	0.87
Russia	241	0.83
Portugal	143	0.77
Germany	1,240	0.77
Turkey	64	0.75
Czech Republic	81	0.75
Hungary	38	0.74
Italy	435	0.72
Bulgaria	30	0.69
Spain	481	0.68
Greece	91	0.61
Poland	92	0.54

Data source: Calculated by Science-Metrix using the Scopus database (Elsevier)