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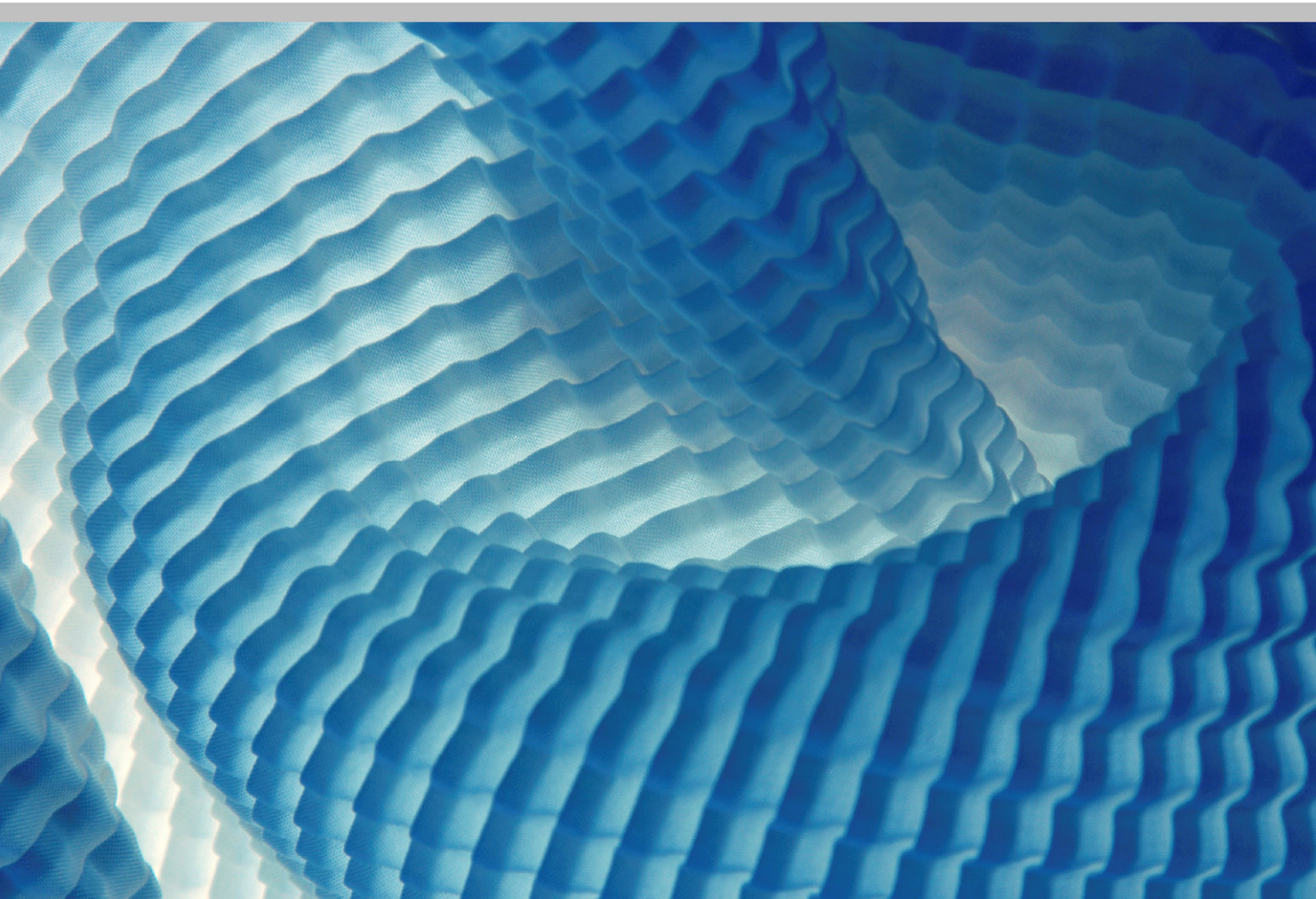
# Bibliometric Analysis of Aquaculture Research at DFO and in Canada

## Final Report



Science-Metrix

# Bibliometric Analysis of Aquaculture Research at DFO and in Canada

## Final Report

March 31st, 2010

*by*

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*submitted to*

Fisheries and Oceans Canada (DFO)

Science-Metrix specializes in the measurement and evaluation of research, science and technological development. Our data collection and assessment methods include bibliometrics, surveys and interviews, case studies, environmental scans, and intelligence gathering. We perform program evaluations and performance measurement studies, evaluability assessments, design and evaluation frameworks, benchmarking and comparative analyses, and strategic planning.

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# Executive Summary

DFO commissioned Science-Metrix to conduct an assessment of the scientific production in aquaculture research for the 1996–2008 period using bibliometric analysis. The present report also presents an analysis of aquaculture research in three subtopics: habitat impacts of aquaculture, wild/farmed interactions, and sea lice. A series of bibliometric indicators were used to measure the scientific output and scientific collaborations of countries, institutions and researchers in aquaculture research and selected subtopics.

Particular attention was paid to DFO's contributions to this research area, its leading researchers, as well as collaborative relationships observed at the country and institution level. Note that the three subtopics were found to involve a relatively small number of papers (approximately 500–1000 papers each, compared to about 27,000 papers in aquaculture research overall). This implies that indicators and trends on these subtopics are limited by the sample size; areas where findings must be interpreted with caution are indicated throughout the text.

The main findings of this study are as follows:

- Aquaculture research is a growing research area all levels examined: at the world level, in Canada and at DFO.
- Canada figures prominently among leading countries, which also include Norway, the US, Spain, Australia, the UK and France.
- DFO ranks highly in terms of number of papers and scientific impact in aquaculture research, and plays a central role in the collaboration networks of leading Canadian institutions in aquaculture research and its three subtopics.
- However, collaboration patterns between institutions at the world level suggest that research in aquaculture and its subtopics is fragmented, with institutions collaborating mainly within national borders.
- Finally, several of DFO's researchers are among leading Canadian researchers in aquaculture, as well as being world-leading researchers in the subtopics of wild/farmed interactions and sea lice research.

A more detailed presentation of key findings can be found in the conclusion of the report.

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# Acronyms

| | |
|---|---|
| AIMS | Australian Institute of Marine Science (Australia) |
| CEAR | Centre for Aquaculture and Environmental Research |
| CIBNOR | Centro de Investigaciones Biológicas del Noroeste (Mexico) |
| CNRS | Centre national de la recherche scientifique (France) |
| CSIC | Consejo Superior de Investigaciones Científicas (Spain) |
| CSIRO | Commonwealth Science and Industrial Research Organization (Australia) |
| DFO | Fisheries and Oceans Canada |
| GIROQ | Groupe interuniversitaire de recherches océanographiques du Québec (Canada) |
| ICAR | Indian Council of Agricultural Research (India) |
| IFREMER | Institut français de recherche pour l'exploitation de la mer (France) |
| INRA | Institut national de la recherche agronomique (France) |
| IOLR | Israel Oceanographic and Limnological Research (Israel) |
| NIFES | National Institute of Nutrition and Seafood Research (Norway) |
| NINA | Norwegian Institute for Nature Research (Norway) |
| NOAA | National Oceanic and Atmospheric Administration (USA) |
| NOFIMA | Norwegian Institute of Fisheries and Aquaculture Research (Norway) |
| NRC | National Research Council Canada |
| NTNU | Norges teknisk-naturvitenskapelige universitet (Norway) |
| SEAFDEC | Southeast Asian Fisheries Development Center (intergovernmental) |
| TAFI | Tasmanian Aquaculture and Fisheries Institute (Australia) |
| UQAR | Université du Québec à Rimouski (Canada) |
| USDA | US Department of Agriculture (USA) |
| USFWS | US Fish and Wildlife Service (USA) |
| USGS | US Geological Survey (USA) |

# 1 Introduction

Fisheries and Oceans Canada (DFO) is committed to advancing socially and environmentally sustainable aquaculture development in Canada.[1] In addition to developing improved regulatory science and helping transfer the latest innovations and technologies to the aquaculture industry, DFO conducts research into the environmental impacts of aquaculture, in order to provide a solid scientific foundation for the conservation and protection of fish and fish habitat in marine or freshwater ecosystems.

DFO has thus commissioned Science-Metrix to perform a bibliometric analysis of aquaculture research, with a particular emphasis on research conducted by DFO and in Canada. The present report also presents an analysis of aquaculture research in three subtopics: habitat impacts of aquaculture, wild/farmed interactions, and sea lice. These subtopics relate to DFO's research efforts to better understand environmental effects of aquaculture on freshwater and marine habitat and ecosystems, as well as their work in aquatic animal health research to understand how best to prevent, mitigate and treat disease.

A series of bibliometric indicators are used to measure the scientific output, scientific impact and scientific collaborations of countries, institutions and researchers in aquaculture research and selected subtopics. These indicators are listed below and described in more detail in the Appendix (Bibliometric methods).

- Number of papers
- Growth rate and growth index (GI)
- Average of relative citations (ARC)
- Positional analysis (number of papers, ARC and specialization index)
- Collaboration rates
- Collaboration networks

These indicators will allow DFO to benchmark its research efforts in aquaculture research and the three subtopics. In addition, data presented in this report can help DFO identify key partners and potential collaborators in aquaculture research at the country, institution and researcher levels. Note that in its International Science Strategy, DFO recognized the importance of collaboration, both domestically and internationally and listed "Best practices for sustainable aquaculture" as one of its priorities within the "Science Advice for Fisheries and Oceans Management" priority area.[2]

The first section of this report provides a general overview of aquaculture research at DFO, in Canada and at the world level, followed by sections that examine leading countries (Section 3), institutions (Section 4), as well as trends in collaboration for DFO and Canada in this research area (Section 5). Finally, leading international and Canadian researchers are examined in Section 6.

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[1] See, for example: DFO, 2009. *National Aquaculture Strategic Action Plan Initiative: Strengthening Sustainable Aquaculture Development in Canada* (Discussion Document). Accessed at: http://www.dfo-mpo.gc.ca/aquaculture/lib-bib/nasapi-inpasa/nasapi-inpasa-eng.pdf

[2] DFO, 2009. *International Science Strategy*. Accessed at: http://www.dfo-mpo.gc.ca/science/Publications/intss-ssint/index-eng.html

# 2 Overview of Aquaculture Research

Aquaculture science includes research being performed on a large variety of aquatic species – from fish to algae to bivalves. In the Scopus database (produced by Elsevier), aquaculture research represents almost 27,000 papers published at the world level from 1996 to 2008, an output which increased by 53% over this period (Table I). Canada published approximately 1,700 of these papers, or 6.4%. With a 56% growth rate, Canada has also kept up with the world growth in this research area.[3] The fact that Canada's growth followed that of the world is illustrated by the growth index (GI) indicator, which is in the centre of the scale; otherwise, when the indicator is in the green (right side) zone, the entity experienced greater growth in this research area relative to the world, whereas the indicator in the red (left side) zone means the reverse.

Meanwhile, DFO published 430 papers in aquaculture research, which represents a 48% increase over the period. This growth rate is not appreciably different from that of the world. Note that DFO contributed to 25% of Canada's aquaculture research papers during the 1996–2008 period.

Table I Papers in aquaculture research by DFO, Canada and the world, 1996–2008

| | Papers | Trend | Growth rate | GI |
|---|---|---|---|---|
| World | 26,798 |  | 53% |  |
| Canada | 1,705 |  | 56% |  |
| DFO | 430 |  | 48% |  |

Note: The growth rate represents the percentage increase in number of papers over the course of the study period. The growth index (GI) compares the increase in the number of papers to that of the world: when the indicator is in the green (right side) zone, the entity experienced greater growth in this research area relative to the world, whereas the indicator in the red (left side) zone means the reverse.
Source: Calculated by Science-Metrix using the Scopus database

Aquaculture science can be analysed at the level of subtopics, which are comprised within the large aquaculture research dataset but focus on specific research areas of interest. In this study, three subtopics are examined: habitat impacts of aquaculture, wild/farmed interactions and sea lice. As these subtopics are quite specific and, consequently, the numbers of papers that concern them are relatively small. At the world level, 1,048 papers focus on habitat impacts of aquaculture, 766 papers focus on wild/farmed interactions and 465 papers focus on sea lice (Table II). Canada's scientific output was approximately 100 papers in each of these subtopics between 1996 and 2008. At the world level, growth in these three areas varied from a 10% growth rate in sea lice research to a 108% growth rate in wild/farmed interactions. In contrast, Canada's output invariably increased by at least 140% in all three subtopics. Thus, Canada's growth rates indicate greater increases in its number of papers than at the world level, particularly in sea lice research and habitat impacts research.

[3] Please note that growth is calculated as the increase in the number of papers between two periods of six years each (later period/earlier period, see the Bibliometric indicators section in the Appendix) and is not equivalent to a compound annual growth rate. Using this method to compute growth is preferred to using an annual growth rate because it does not require that exponential growth be present.

Interestingly, DFO contributes to a large percentage of the Canadian output in all three subtopics: DFO's 44 papers in habitat impacts research represent 44% of the Canadian output, while it published 39% of Canada's papers on wild/farmed interactions, and 34% of Canada's papers in sea lice research (Table II). These percentages are greater than the proportion of Canadian papers to which DFO contributes in aquaculture research overall (i.e., 25%, see above).

It should be noted that because of the small size of the scientific outputs in the three aquaculture research subtopics, subsequent analyses of these subtopics at the institution and researcher level are relatively limited. Certain indicators cannot be calculated when the number of papers is smaller than a certain threshold,[4] at which point they become susceptible to a high degree of variability. This is the case for indicators relating to growth and scientific impact, for example, and so some of the findings that relate to these indicators must be interpreted with caution. In the three subtopics, DFO total output over the period is less than 100 papers, and so any assessment or comparison of its growth indicators should be considered cautiously given of the variability these results. Nonetheless, the "Trend" column can help illustrate patterns in DFO's output over the period; these data confirm that, generally, DFO has increased its scientific output in the latter half of the period in all three subtopics.

Table II Papers in aquaculture research subtopics by DFO, Canada and the world, 1996–2008

| Habitat impacts | Papers | Trend | Growth rate | GI |
|---|---|---|---|---|
| World | 1,048 | | 72% | |
| Canada | 99 | | 156% | |
| DFO | 44 | | 123% | |

| Wild/farmed inter. | Papers | Trend | % | GI |
|---|---|---|---|---|
| World | 766 | | 108% | |
| Canada | 100 | | 141% | |
| DFO | 39 | | 60% | |

| Sea lice | Papers | Trend | % | GI |
|---|---|---|---|---|
| World | 465 | | 10% | |
| Canada | 95 | | 154% | |
| DFO | 32 | | 144% | |

Note: The growth rate represents the percentage increase in number of papers over the course of the study period. The growth index (GI) compares the increase in the number of papers to that of the world. Note that growth indicators are less reliable when the scientific output is small.

Source: Calculated by Science-Metrix using the Scopus database

[4] For instance, following best practice in statistics, Science-Metrix usually uses a minimum threshold of 30 papers to compute averages.

# 3 Leading Countries in Aquaculture Research

At the country level, the results of this bibliometric analysis confirm that aquaculture research is a growing field, with almost all leading countries increasing their scientific output in this area between 1996 and 2008. Note that leading countries are defined as those having published at least 100 papers in aquaculture research during the study period. The United States (US) is the largest producer of aquaculture research, with almost 6000 papers and 22% of world papers (Table III). The US is followed by Japan, the UK, Norway and Canada, each of which contributed to between 1,700 and 2,100 papers and at least 6% of the world's aquaculture papers.

All these countries, as well as Australia and Spain (nearing on 1,600 papers each), were well-established in aquaculture research at the beginning of the period, and increased their scientific output at a pace relatively similar to that of the world level between 1996 and 2008. Indeed, the indicator for the GI is within or adjacent to the centre zone of the scale for the top seven countries (except for the UK, whose production has grown less rapidly than the world). In contrast, the appearance of China in eighth position, with a 377% increase in its scientific output resulting in a total of 1,463 papers, is remarkable. Other countries whose output has increased by a growth rate of more than 150% over the study period include Brazil (638 papers), Portugal (425 papers), Turkey (373 papers), Bangladesh (150 papers), Vietnam (149 papers), and Iran (112 papers) – the latter having an impressive 1633% growth rate.

The strengths and weaknesses of leading countries in aquaculture research are best examined using positional analyses (Figure 1). In these graphs, each country's scientific output is represented by a circle that is proportional to the size of that output (i.e., number of papers); the position of the countries is determined by the degree to which they are specialized in the field (horizontal axis), and, the degree to which their papers have a high level of scientific impact (vertical axis), as determined by the average of relative citations (ARC). Thus, a country – like Canada – that is positioned in the top right quadrant is both specialized and has more scientific impact that the world level. Further explanation of this graphical representation and the indicators that are used to produce it are provided in the Appendix (see Bibliometric indicators section).

As shown in the positional analysis graph (Figure 1), countries that have the highest level of scientific impact in aquaculture science include Denmark, Norway, Belgium, the Netherlands, the UK, Sweden, Canada and Germany. Of these, Denmark, Norway, Belgium and Canada are also specialized in aquaculture research, while the UK also publishes a relatively large number of papers on this topic. The fact that the US has the largest output in aquaculture research can also be easily observed on this figure, although its level of impact is barely above that of the world, and it is not specialized in this area of research. Other countries notable for their high impact and/or presence in the top right quadrant include Spain, Australia, France, New Zealand, Ireland, Portugal, Greece, Iceland, Finland and the Czech Republic.

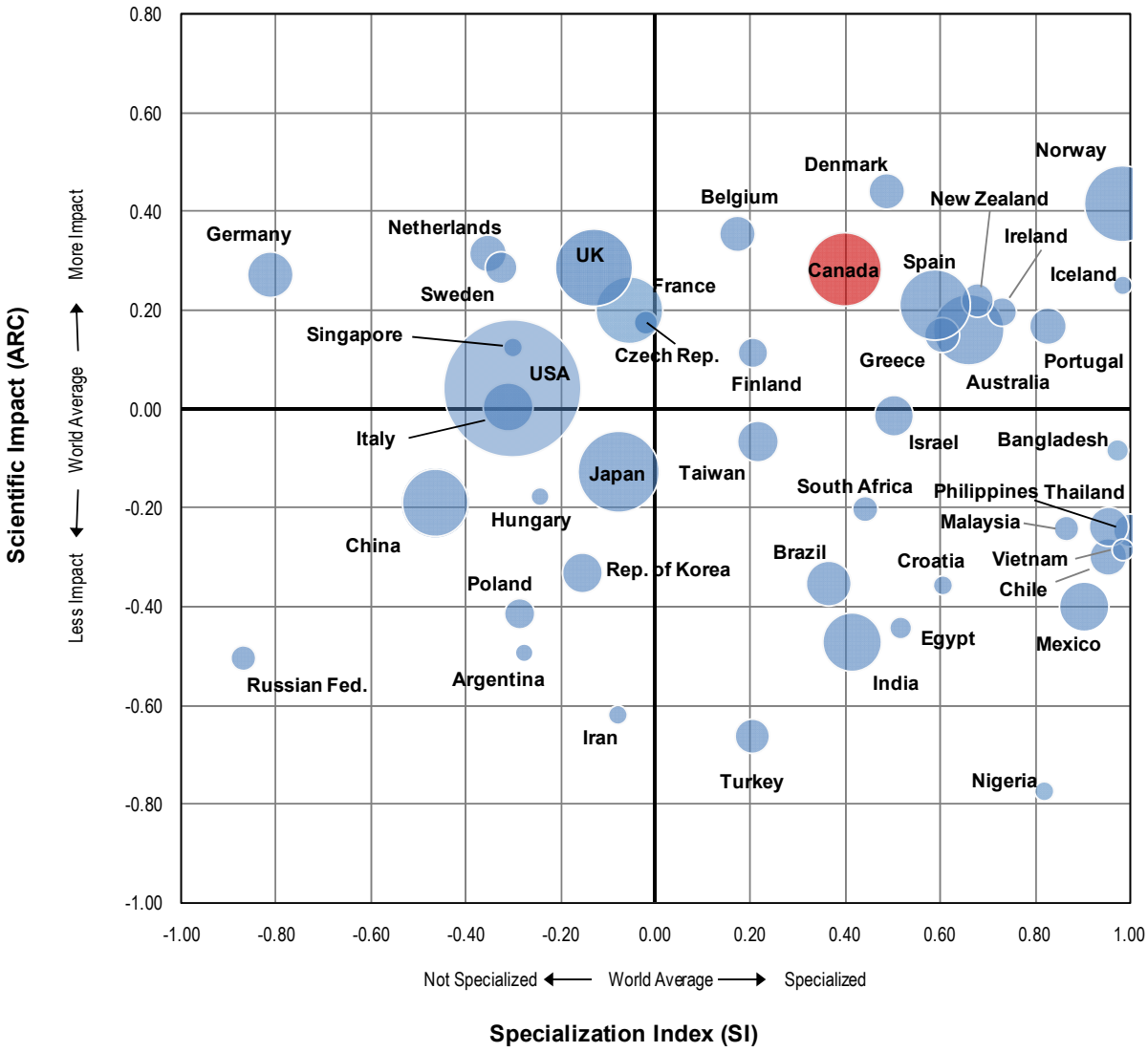
Table III Leading countries in aquaculture research, 1996–2008

| Country | Papers | Trend | Growth rate | GI | Share of world |
|---|---|---|---|---|---|
| United States | 5,957 |  | 34% |  | 22.2% |
| Japan | 2,082 |  | 35% |  | 7.8% |
| United Kingdom | 1,886 |  | 20% |  | 7.0% |
| Norway | 1,826 |  | 63% |  | 6.8% |
| Canada | 1,705 |  | 56% |  | 6.4% |
| Australia | 1,578 |  | 60% |  | 5.9% |
| Spain | 1,569 |  | 81% |  | 5.9% |
| China | 1,463 |  | 377% |  | 5.5% |
| France | 1,412 |  | 17% |  | 5.3% |
| India | 1,085 |  | 128% |  | 4.0% |
| Italy | 785 |  | 121% |  | 2.9% |
| Mexico | 773 |  | 63% |  | 2.9% |
| Germany | 657 |  | 61% |  | 2.5% |
| Brazil | 638 |  | 194% |  | 2.4% |
| Taiwan | 527 |  | 52% |  | 2.0% |
| Republic of Korea | 503 |  | 134% |  | 1.9% |
| Thailand | 487 |  | 107% |  | 1.8% |
| Israel | 480 |  | 11% |  | 1.8% |
| Chile | 429 |  | 96% |  | 1.6% |
| Netherlands | 428 |  | 60% |  | 1.6% |
| Portugal | 425 |  | 189% |  | 1.6% |
| Denmark | 401 |  | 22% |  | 1.5% |
| Belgium | 400 |  | 38% |  | 1.5% |
| Greece | 388 |  | 101% |  | 1.4% |
| Turkey | 373 |  | 258% |  | 1.4% |
| Philippines | 338 |  | -5% |  | 1.3% |
| Sweden | 321 |  | 7% |  | 1.2% |
| New Zealand | 321 |  | 69% |  | 1.2% |
| Poland | 291 |  | 41% |  | 1.1% |
| Finland | 276 |  | 28% |  | 1.0% |
| Ireland | 262 |  | -4% |  | 1.0% |
| South Africa | 203 |  | 31% |  | 0.8% |
| Russian Federation | 195 |  | 27% |  | 0.7% |
| Malaysia | 193 |  | 97% |  | 0.7% |
| Czech Republic | 171 |  | 122% |  | 0.6% |
| Egypt | 152 |  | 104% |  | 0.6% |
| Bangladesh | 150 |  | 161% |  | 0.6% |
| Vietnam | 149 |  | 192% |  | 0.6% |
| Croatia | 117 |  | 88% |  | 0.4% |
| Nigeria | 116 |  | 36% |  | 0.4% |
| Singapore | 114 |  | 10% |  | 0.4% |
| Iran | 112 |  | 1633% |  | 0.4% |
| Iceland | 111 |  | 63% |  | 0.4% |
| Hungary | 103 |  | 97% |  | 0.4% |
| Argentina | 100 |  | 113% |  | 0.4% |
| **WORLD** | **26,798** |  | **53%** |  | **100%** |

Note: The growth rate represents the percentage increase in number of papers over the course of the study period. The growth index (GI) compares the increase in the number of papers to that of the world.

Source: Calculated by Science-Metrix using the Scopus database

Figure 1 Positional analysis of leading countries in aquaculture research, 1996–2008




Source: Calculated by Science-Metrix using the Scopus database

The only Asian country to have an impact above the world level in aquaculture research is Singapore. China, Japan, India and the Republic of Korea, while contributing to at least 500 aquaculture papers each, are not cited frequently enough to be positioned above the world level in this area of research (Figure 1). Finally, note the cluster of Asian and Latin American countries that are highly specialized in aquaculture research but which have not achieved a high level of scientific impact with their papers: Thailand, the Philippines, Malaysia, Vietnam, Bangladesh, Chile and Mexico.

## 3.1 Habitat impacts

Habitat impacts of aquaculture are principally studied in the US, Canada, the UK, Italy, Australia and France: these countries have contributed to at least 75 papers each (or at least 7% of the world total) on this subtopic (Table IV). Growth in the scientific output has been strongest in Greece, Italy, China, Spain and Canada, whose growth rates range from 156% to 286%. In contrast, other countries

have fallen behind the world pace in terms of their output, notably Sweden and Norway, as illustrated by the growth index (GI) below the world level. As mentioned previously, the low total number of papers published in this subtopic makes growth indicators unreliable for several countries; nonetheless, it appears clear that Ireland has almost stopped publishing in this subtopic.

Table IV Leading countries in habitat impacts research (within aquaculture), 1996–2008

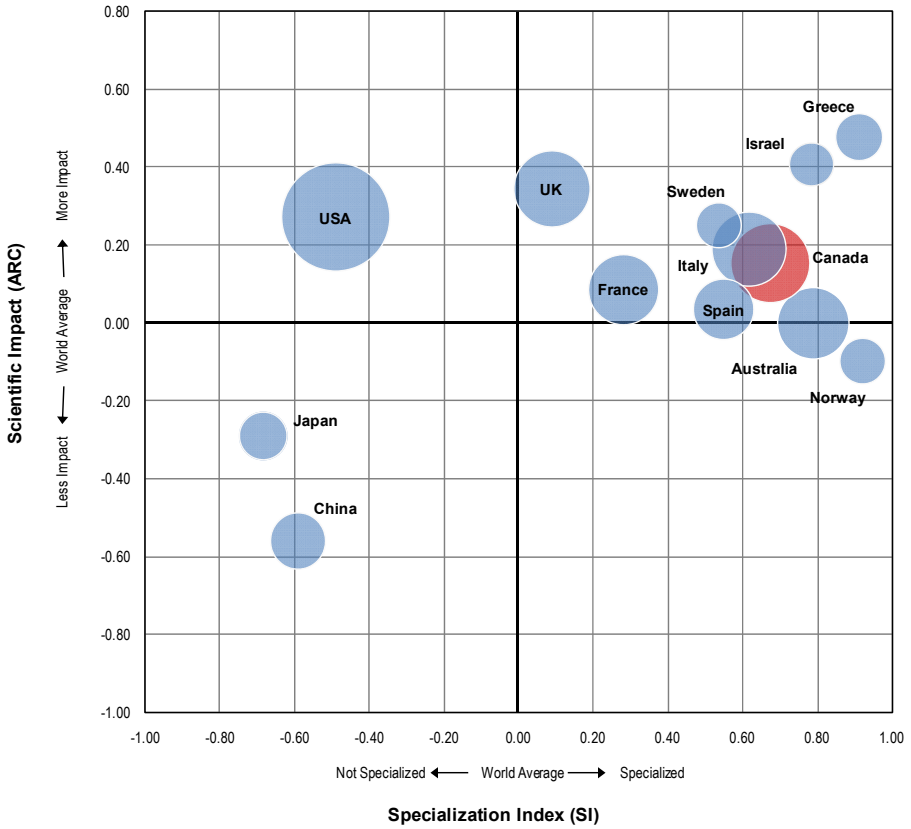
| Country | Papers | Trend | Growth rate | GI | Share of world |
|---|---|---|---|---|---|
| United States | 186 | | 97% | | 17.7% |
| Canada | 99 | | 156% | | 9.4% |
| United Kingdom | 92 | | 21% | | 8.8% |
| Italy | 87 | | 278% | | 8.3% |
| Australia | 81 | | 58% | | 7.7% |
| France | 78 | | 18% | | 7.4% |
| Spain | 58 | | 163% | | 5.5% |
| China | 48 | | 236% | | 4.6% |
| Japan | 38 | | 64% | | 3.6% |
| Greece | 35 | | 286% | | 3.3% |
| Norway | 33 | | 7% | | 3.1% |
| Sweden | 32 | | -19% | | 3.1% |
| Thailand | 32 | | 58% | | 3.1% |
| Israel | 31 | | 133% | | 3.0% |
| Denmark | 26 | | n.s. | n.s. | 2.5% |
| Brazil | 25 | | n.s. | n.s. | 2.4% |
| India | 25 | | n.s. | n.s. | 2.4% |
| Mexico | 24 | | n.s. | n.s. | 2.3% |
| Ireland | 22 | | n.s. | n.s. | 2.1% |
| Chile | 21 | | n.s. | n.s. | 2.0% |
| **WORLD** | **1,048** | | **72%** | | **100%** |

Note: The growth rate represents the percentage increase in number of papers over the course of the study period. The growth index (GI) compares the increase in the number of papers to that of the world. Note that growth indicators are less reliable when the scientific output is small.

Source: Calculated by Science-Metrix using the Scopus database

The positional analysis of leading countries in habitat impacts research is shown in Figure 2. Most countries that contribute to papers in this subtopic are cited more than the world level (i.e., high scientific impact); the exceptions are China, Japan and Norway. Of these three, only Norway is specialized in this subtopic. In fact, most countries are both specialized and have a scientific impact above the world level in habitat impacts research, particularly Greece, Israel, Sweden, Italy and Canada, although the UK, France and Spain are also positioned in the top right quadrant. Like in many research areas, the US is not specialized in habitat impacts research but has an impact that is higher than the world level.

Figure 2 Positional analysis of leading countries in habitat impacts research, 1996–2008




Note: Only countries that published more than 30 papers in this subtopic are included.
Source: Calculated by Science-Metrix using the Scopus database

## 3.2 Wild/farmed interactions

Research on wild/farmed interactions is performed almost exclusively in developed countries, with the US, Canada, the UK and Norway producing over 60% of papers in this subtopic (Table V). However, the growth index for many other countries is high, namely for Australia, Japan and Spain, which suggests these countries may eventually catch up to the leaders. Although they have published fewer than 30 papers each between 1996 and 2008, both China and Italy appear to be establishing new research programs in this subtopic.

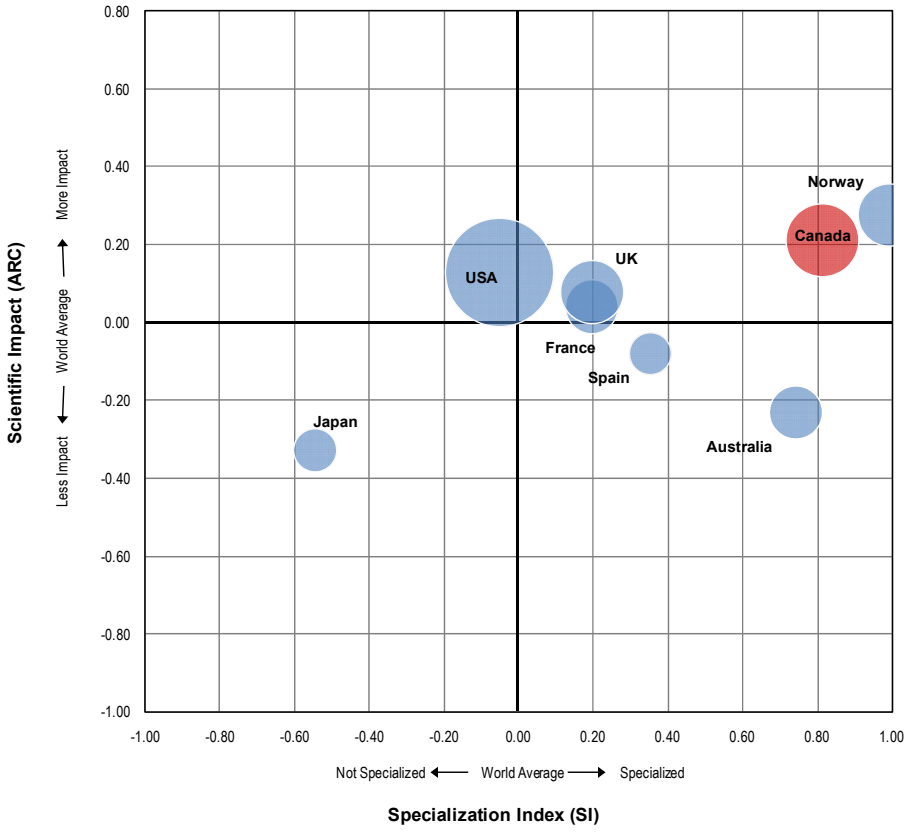
In terms of strengths and weaknesses in the wild/farmed interactions subtopic of aquaculture research, the positional analysis clearly shows that Canada and Norway are well positioned with regard to both scientific impact and specialization, whereas the US, the UK and France also have a level of scientific impact above the world level (Figure 3). The other countries that have published more than 30 papers in this subtopic – Australia, Japan and Spain – contribute to papers that score below the world level in terms of scientific impact.

Table V Leading countries in wild/farmed interactions research (within aquaculture), 1996–2008

| Country | Papers | Trend | Growth rate | GI | Share of world |
|---|---|---|---|---|---|
| United States | 221 | | 119% | | 28.9% |
| Canada | 100 | | 141% | | 13.1% |
| United Kingdom | 75 | | 32% | | 9.8% |
| Norway | 73 | | 63% | | 9.5% |
| Australia | 53 | | 192% | | 6.9% |
| France | 52 | | 45% | | 6.8% |
| Japan | 35 | | 189% | | 4.6% |
| Spain | 33 | | 167% | | 4.3% |
| Ireland | 23 | | n.s. | n.s. | 3.0% |
| Sweden | 22 | | n.s. | n.s. | 2.9% |
| China | 21 | | n.s. | n.s. | 2.7% |
| Italy | 21 | | n.s. | n.s. | 2.7% |
| **WORLD** | **766** | | **108%** | | **100%** |

Note: The growth rate represents the percentage increase in number of papers over the course of the study period. The growth index (GI) compares the increase in the number of papers to that of the world. Note that growth indicators are less reliable when the scientific output is small.
Source: Calculated by Science-Metrix using the Scopus database

Figure 3 Positional analysis of leading countries in wild/farmed interactions research, 1996–2008




Note: Only countries that published more than 30 papers in this subtopic are included.
Source: Calculated by Science-Metrix using the Scopus database

## 3.3 Sea lice

The UK is clearly the most productive country in the area of sea lice research, having contributed to almost 150 papers between 1996 and 2008 – over 30% of the world's share of papers on this subtopic (Table VI). However, its scientific output has slowed in the latter half of the period, as shown by a growth rate of -17%. In contrast, Canada's output has increased by 154% over the same period, resulting in a total of 95 papers and 20% of the world's share of papers. Thus, it has almost caught up to Norway, which is the second largest producer with 99 papers and a growth rate of 74%. The US is the only other country to have published more than 30 papers in this subtopic (63 papers). Note that the "Trend" column suggests that Ireland has almost stopped publishing on sea lice research.

Table VI Leading countries in sea lice research (within aquaculture), 1996–2008

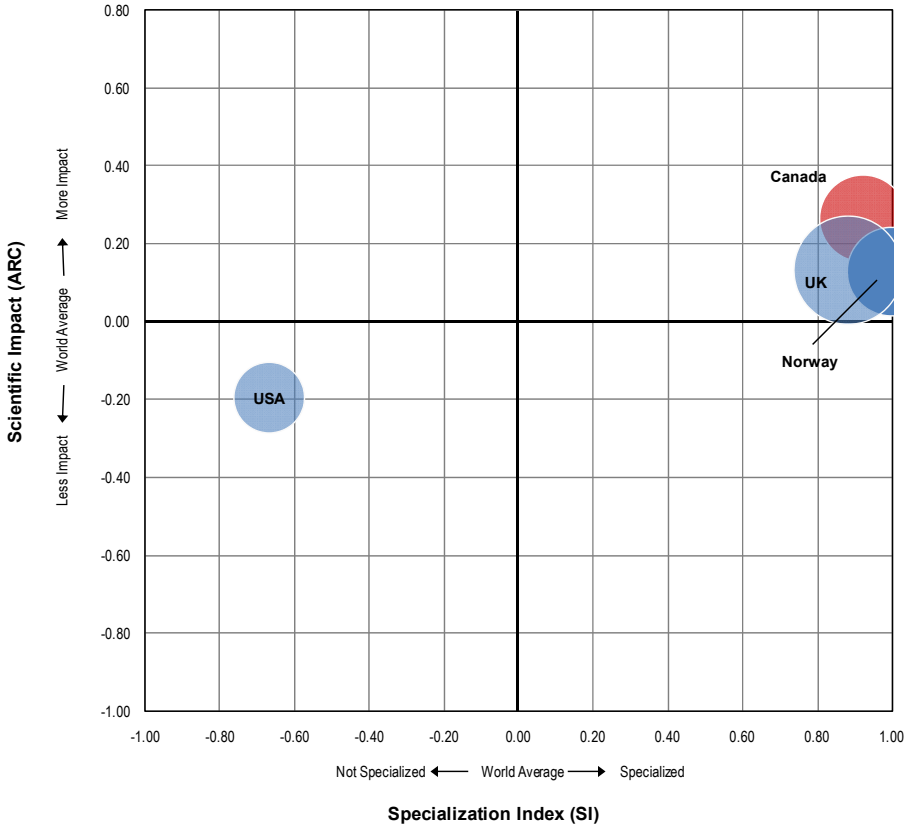
| Country | Papers | Trend | Growth rate | GI | Share of world |
|---|---|---|---|---|---|
| United Kingdom | 148 |  | -17% |  | 31.8% |
| Norway | 99 |  | 74% |  | 21.3% |
| Canada | 95 |  | 154% |  | 20.4% |
| United States | 63 |  | 23% |  | 13.5% |
| Ireland | 29 |  | n.s. | n.s. | 6.2% |
| Chile | 23 |  | n.s. | n.s. | 4.9% |
| Japan | 20 |  | n.s. | n.s. | 4.3% |
| Australia | 18 |  | n.s. | n.s. | 3.9% |
| Taiwan | 10 |  | n.s. | n.s. | 2.2% |
| **WORLD** | **465** |  | **10%** |  | **100%** |

Note: The growth rate represents the percentage increase in number of papers over the course of the study period. The growth index (GI) compares the increase in the number of papers to that of the world. Note that growth indicators are less reliable when the scientific output is small.

Source: Calculated by Science-Metrix using the Scopus database

As shown in Table VI, only four countries have contributed to more than 30 papers each on sea lice research, and thus only these four can be examined using the positional analysis graph. This graph shows that the Canada, the UK and Norway occupy roughly the same space in the top right quadrant: in other words, all three are specialized and have a scientific impact score above the world level (Figure 4). Meanwhile, the US is less specialized and has an impact score less than the world level in sea lice research.

Figure 4 Positional analysis of leading countries in sea lice research, 1996–2008




Note: Only countries that published more than 30 papers in this subtopic are included.
Source: Calculated by Science-Metrix using the Scopus database

# 4 Leading Institutions in Aquaculture Research

Leading institutions in aquaculture research were identified based on their number of papers published in this research area; world institutions having contributed to more than 150 papers from 1996 to 2008 are listed in Table VII, whereas the Canadian institutions having contributed to more than 10 papers during the same period are listed in Table VIII. These tables indicate that DFO is ranked forth at the world level in terms of number of papers published in aquaculture research and occupies the first rank in Canada. Note that all acronyms used for institutions are listed at the front of this report, and countries in which non-Canadian institutions are located are listed in Table VII.

At the world level, IFREMER contributes to the highest number of papers, followed by the USDA, the University of Stirling (UK), DFO and the Chinese Academy of Sciences (Table VII). IFREMER (*Institut français de recherche pour l'exploitation de la mer*), the USDA (US Department of Agriculture), DFO and the Chinese Academy of Sciences are all government-led science-based agencies with multiple research centres across their respective countries, whereas the University of Stirling established an Institute of Aquaculture over 35 years ago.

Seeing China's high level of growth in this research area (see Table III), it is not surprising that two Chinese institutions – the Chinese Academy of Sciences and the Ocean University of China – also have the two highest growth rates in this list, at 567% and 433%, respectively (Table VII). Other institutions with high growth rates (i.e., greater than 200%) include ICAR, the Universidade do Algarve, and TAFI (Tasmanian Aquaculture and Fisheries Institute). Note that very few institutions saw their output decline, which confirms that aquaculture research is a growing field at the international level.

Table VII also presents data on the ARC. Similar to how the ARC is used in the positional analysis to compare the scientific impact of an entity (i.e., an country or an institution) with the world level, an ARC score of 1 or greater indicates a scientific impact above the world level, whereas an ARC of 1 or less means the reverse. Four of the five international institutions that are most cited in aquaculture research are located in Norway: AKVAFORSK, NIFES, the Universitetet i Tromsø and the Universitetet i Bergen, whereas Universiteit Gent (in Belgium) rounds out the top five. Along with the University of Washington, these institutions are cited, on average at lest 50% more frequently than the average world paper in aquaculture research (i.e., ARC of 1.50 or greater).

Several other institutions are cited more frequently than the world average in aquaculture research, including all four Canadian institutions that appear in the ranking for world-leading institutions: Dalhousie University (ARC of 1.36), DFO (ARC of 1.35), the University of British Columbia (ARC of 1.30), the University of Guelph (ARC of 1.27). In fact, the list of leading Canadian institutions indicates that all of the institutions that contributed to at least 30 papers in aquaculture research have an impact above that of the average world paper (Table VIII). Moreover, while many of the Asian institutions in this list have impact scores that are below the world average, the National Taiwan University (ARC of 1.11) and Japan's Fisheries Research Agency (ARC 1.0) are notable exceptions.

Table VII Leading world institutions in aquaculture research, 1996–2008

| Institution | Country | Papers | Trend | Growth rate | GI | ARC |
|---|---|---|---|---|---|---|
| IFREMER | France | 474 |  | 37% |  | 1.36 |
| USDA | USA | 462 |  | 163% |  | 1.05 |
| U of Stirling | UK | 444 |  | 8% |  | 1.33 |
| DFO | Canada | 431 |  | 49% |  | 1.35 |
| Chinese Academy of Sciences | China | 422 |  | 433% |  | 0.92 |
| Institute of Marine Research | Norway | 366 |  | 108% |  | 1.49 |
| U of Tasmania | Australia | 330 |  | 59% |  | 1.38 |
| U i Bergen | Norway | 309 |  | 87% |  | 1.59 |
| USGS | USA | 307 |  | 33% |  | 1.37 |
| Ocean U of China | China | 278 |  | 567% |  | 0.87 |
| Auburn U | USA | 270 |  | 38% |  | 0.77 |
| Fisheries Research Agency | Japan | 268 |  | 98% |  | 1.10 |
| CSIRO | Australia | 257 |  | 74% |  | 1.27 |
| INRA | France | 255 |  | 41% |  | 1.24 |
| NOAA | USA | 253 |  | 68% |  | 1.36 |
| AKVAFORSK | Norway | 243 |  | 58% |  | 1.73 |
| Tokyo U of Marine Sci. & Technol. | Japan | 237 |  | 86% |  | 1.05 |
| CIBNOR | Mexico | 237 |  | 109% |  | 0.77 |
| NIFES | Norway | 237 |  | 108% |  | 1.62 |
| U of California, Davis | USA | 226 |  | 23% |  | 1.49 |
| Mississippi State U | USA | 221 |  | 93% |  | 0.66 |
| ICAR | India | 213 |  | 415% |  | 0.72 |
| SEAFDEC | Thailand* | 208 |  | -10% |  | 0.73 |
| CSIC | Spain | 207 |  | 116% |  | 1.37 |
| Wageningen U & Research Centre | Netherlands | 200 |  | 133% |  | 1.31 |
| TAFI | Australia | 192 |  | 227% |  | 1.39 |
| IOLR | Israel | 188 |  | 6% |  | 1.22 |
| U of Tokyo | Japan | 185 |  | 68% |  | 0.95 |
| U i Tromsø | Norway | 183 |  | 79% |  | 1.59 |
| U de Santiago de Compostela | Spain | 176 |  | 174% |  | 1.34 |
| Marine Scotland | UK | 172 |  | 4% |  | 1.49 |
| Hellenic Centre for Marine Research | Greece | 172 |  | 52% |  | 1.42 |
| National Taiwan Ocean U | Taiwan | 170 |  | 35% |  | 0.94 |
| Pukyong National U | Rep. of Korea | 170 |  | 50% |  | 0.79 |
| James Cook U | Australia | 168 |  | 57% |  | 1.09 |
| U Gent | Belgium | 166 |  | 104% |  | 1.69 |
| U of British Columbia | Canada | 166 |  | 192% |  | 1.30 |
| U of Guelph | Canada | 162 |  | 3% |  | 1.27 |
| Louisiana State U | USA | 159 |  | -3% |  | 0.65 |
| U do Algarve | Portugal | 157 |  | 284% |  | 1.22 |
| National Taiwan U | Taiwan | 155 |  | 27% |  | 1.11 |
| U of Washington | USA | 154 |  | 44% |  | 1.55 |
| Hokkaido U | Japan | 153 |  | 108% |  | 0.78 |
| Oregon State U | USA | 152 |  | 47% |  | 1.40 |
| U of Idaho | USA | 152 |  | 136% |  | 1.04 |
| Dalhousie U | Canada | 151 |  | 121% |  | 1.36 |

Notes: *SEAFDEC is an intergovernmental body based in Thailand but has facilities in several countries. The growth rate represents the percentage increase in number of papers over the course of the study period. The growth index (GI) compares the increase in the number of papers to that of the world.

Source: Calculated by Science-Metrix using the Scopus database

Table VIII Leading Canadian institutions in aquaculture research, 1996–2008

| Institution | Papers | Trend | Growth rate | GI | ARC |
|---|---|---|---|---|---|
| DFO | 431 |  | 49% |  | 1.35 |
| U of British Columbia | 166 |  | 192% |  | 1.30 |
| U of Guelph | 162 |  | 3% |  | 1.27 |
| Dalhousie U | 151 |  | 121% |  | 1.36 |
| NRC Canada | 134 |  | 203% |  | 1.61 |
| Memorial U of Newfoundland | 132 |  | 64% |  | 1.17 |
| U of Prince Edward Island | 115 |  | 37% |  | 1.48 |
| U of New Brunswick | 87 |  | 68% |  | 1.11 |
| U Laval | 67 |  | 40% |  | 1.25 |
| U of Victoria | 63 |  | 77% |  | 1.66 |
| Simon Fraser U | 63 |  | 111% |  | 1.69 |
| U of Waterloo | 52 |  | 55% |  | 1.08 |
| UQAR | 51 |  | 529% |  | 1.28 |
| Environment Canada | 31 |  | 283% |  | 1.64 |
| McGill U | 28 |  | n.s. | n.s. | n.s. |
| U of Alberta | 28 |  | n.s. | n.s. | n.s. |
| Ontario Min. of Natural Resources | 25 |  | n.s. | n.s. | n.s. |
| U of Toronto | 25 |  | n.s. | n.s. | n.s. |
| U of Saskatchewan | 25 |  | n.s. | n.s. | n.s. |
| U de Montréal | 22 |  | n.s. | n.s. | n.s. |
| McMaster U | 20 |  | n.s. | n.s. | n.s. |
| Queen's U | 19 |  | n.s. | n.s. | n.s. |
| U de Moncton | 18 |  | n.s. | n.s. | n.s. |
| U of Ottawa | 17 |  | n.s. | n.s. | n.s. |
| U of Manitoba | 17 |  | n.s. | n.s. | n.s. |
| U of Windsor | 16 |  | n.s. | n.s. | n.s. |
| GIROQ | 16 |  | n.s. | n.s. | n.s. |
| Wilfrid Laurier U | 15 |  | n.s. | n.s. | n.s. |
| Huntsman Marine Science Centre | 14 |  | n.s. | n.s. | n.s. |
| U of Western Ontario | 12 |  | n.s. | n.s. | n.s. |
| York U | 12 |  | n.s. | n.s. | n.s. |
| U of Calgary | 11 |  | n.s. | n.s. | n.s. |
| Raincoast Research | 11 |  | n.s. | n.s. | n.s. |
| Trent U | 10 |  | n.s. | n.s. | n.s. |
| U of Northern British Columbia | 10 |  | n.s. | n.s. | n.s. |
| Mount Allison U | 10 |  | n.s. | n.s. | n.s. |

Note: The growth rate represents the percentage increase in number of papers over the course of the study period. The growth index (GI) compares the increase in the number of papers to that of the world. Note that growth indicators are less reliable when the scientific output is small.

Source: Calculated by Science-Metrix using the Scopus database

In addition to the four Canadian institutions discussed among the world leaders, NRC Canada, the Memorial University of Newfoundland and the University of Prince Edward Island all published at least 100 aquaculture research papers during 1996–2008 period (Table VIII). The GI indicator shows that, among Canadian institutions, only the University of Guelph is lagging behind the world growth level in this research area, as it has a growth rate of 3% (compared to 53% at the world level).

In contrast, NRC Canada, the University of British Columbia and Dalhousie University all increased their output by 120% or more over the study period. Note that the growth index is less reliable when the total number of papers is small (e.g., less than 100 papers), as it is subject to a high degree of variability. Nonetheless, the steady increase in the number of papers by UQAR in the second half of the period, as illustrated by the trend column, suggests that the growth rate and growth index are justifiably high for this institution.

Finally, as mentioned above, all Canadian institutions that contributed to 30 or more aquaculture research papers between 1996 and 2008 have an impact score that is greater than the world average (Table VIII). The highest scores among these institutions are observed for Simon Fraser University, the University of Victoria, Environment Canada and NRC Canada, all of which are cited at least 60% more than the world average (i.e., ARC of 1.6 or greater).

## 4.1 Inter-institutional collaboration in aquaculture research

Collaboration between international institutions in aquaculture research over the 1996–2008 period is illustrated in Figure 5. In this collaboration network, the size of the nodes (which represent institutions) is proportional to the number of papers published by the institution. The width of the links between institutions represent the number of papers authored in collaboration by each pair; links are only displayed when 13 or more collaborations have been observed (i.e., a threshold of one per year). All institutions that co-authored 13 or more papers during the study period have been included in the network, even if they published fewer than 150 papers. This explains why some institutions may appear in Figure 5 but not in Table VII.

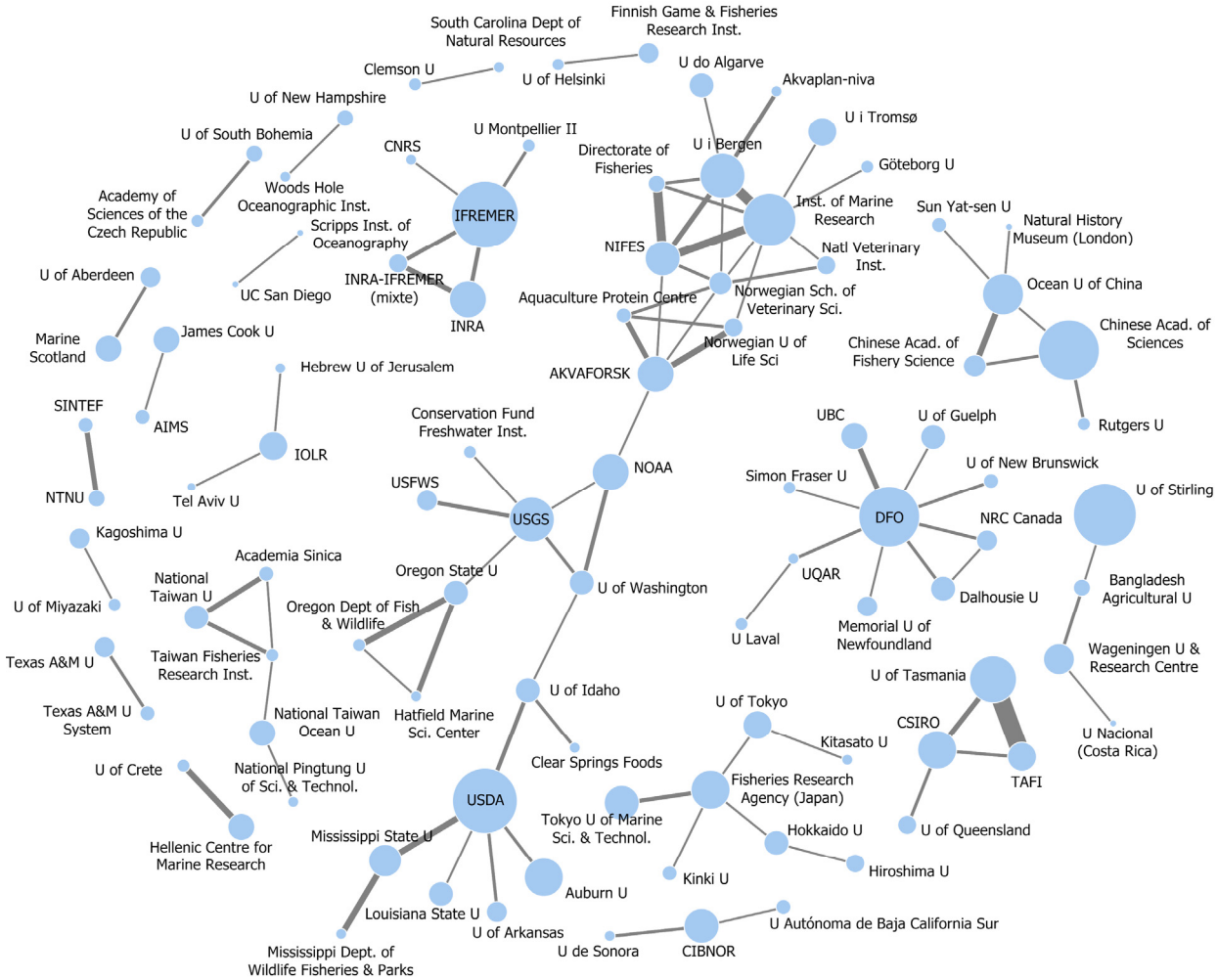
As shown in Figure 5, aquaculture research is quite fragmented at the international institutional level. More specifically, few links exist between institutions of different countries, with isolated clusters almost always involving countries from a single country. For example, all of the French institutions appearing in this network (i.e., IFREMER, INRA, the mixed INRA-IFREMER centres, CNRS, and Université de Montpellier II) are joined in a cluster that does not involve any institution from another country. Exceptions to this trend include a link between NOAA and AKVAFOSK, effectively linking the main Norwegian cluster and one of the US clusters. One truly international cluster (on the right edge of the network) involves the University of Stirling, Bangladesh Agriculture University, Wageningen University and Research Centre (in the Netherlands) and the Universidad Nacional of Costa Rica. Moreover, as seen in the main Chinese cluster, the Natural History Museum (London, UK) collaborates with the Ocean University of China.

Canada is no exception to the trend of partnering primarily within national borders: no Canadian institution has co-authored 13 or more aquaculture research papers with a non-Canadian institution during the study period. However, DFO is shown to play a central role in the Canadian cluster, partnering with several universities as well as with NRC Canada. The Canadian national collaboration network is shown in greater detail (i.e., with a threshold set at six papers over the 1996–2008 period) in Figure 6.

At the international level, the most substantial collaborations in terms of number of co-authored papers are observed between TAFI and the University of Tasmania; this is not surprising as TAFI is a

joint venture between the Tasmanian State Government and the University of Tasmania, and has facilities located on this University's campus. The other most prolific collaborations are observed in Norway, which also has one of the most inter-linked national clusters: many Norwegian institutions collaborated with more than two partners in their country, and several institutions are located at the centre of the cluster, particularly the Institute of Marine Research, the Universitetet i Bergen, NIFES and the Norwegian School of Veterinary Science. Note that before 2003, NIFES (National Institute of Nutrition and Seafood Research) was known as the Institution of Nutrition and was part of the Directorate of Fisheries, which explains the strong linkage between these two institutions. Finally, note also the presence of several US institutions in this network, many of which are linked to two government agencies: the USDA and the USGS. Indeed, government agencies such as these (or DFO) often act as central hubs among national clusters.

Figure 5 Collaboration network of world institutions in aquaculture research, 1996–2008

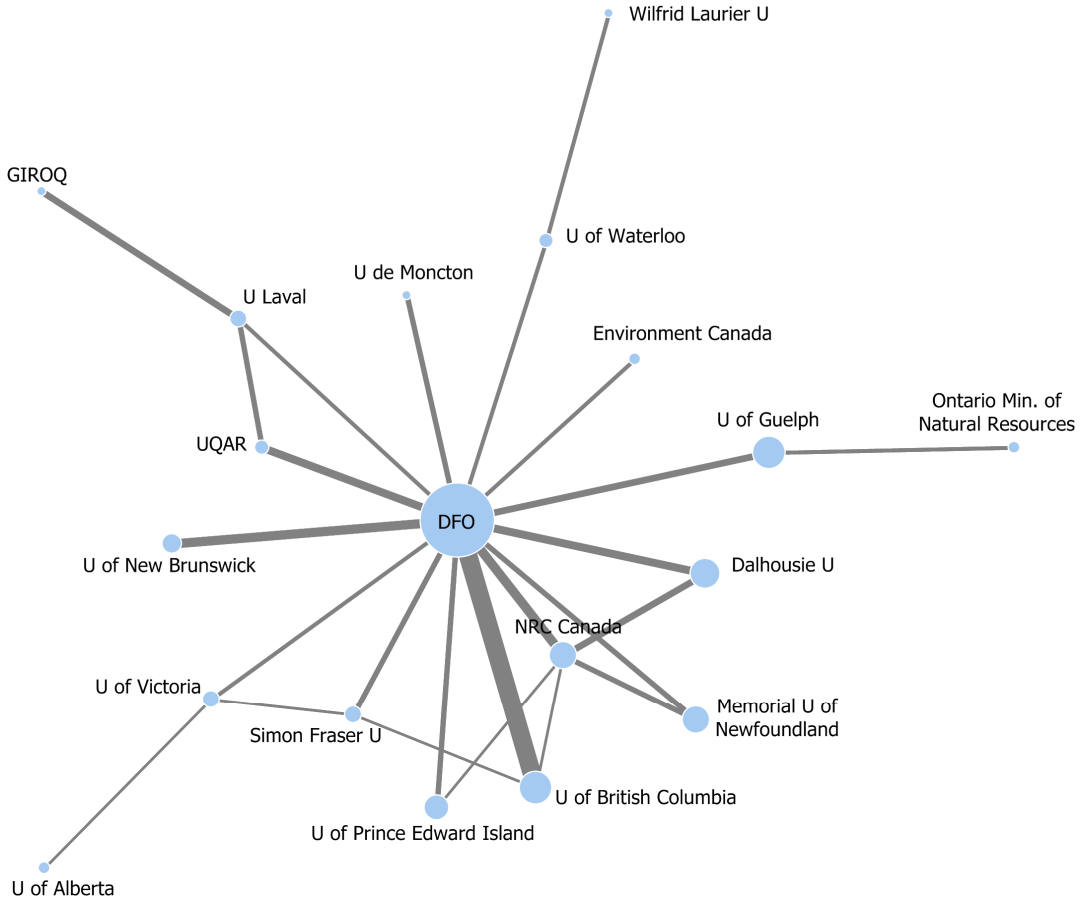



Note: The size of nodes is proportional to total number of papers published by the institution over the period, and the width of the links is proportional to the number of collaborations between country pairs. Links are only displayed when country pairs co-authored an average of at least 1 paper per year over the period (i.e., 13 co-authored papers between 1996 and 2008).

Source: Calculated by Science-Metrix using the Scopus database

Figure 6 confirms DFO's central role in the collaboration network of Canadian institutions in aquaculture research. NRC Canada is the only other Canadian institution to partner with more than three other institutions on more than six papers during the 1996–2008 period. Note that certain universities, such as Université Laval, the University of Waterloo, the University of Guelph and the University of Victoria, act to bring other institutions into the network. The most substantial national partnership in this research area involves DFO and the University of British Columbia. This and other DFO collaborative partnerships are also examined in more detail in Section 5.2.

Figure 6 Collaboration network of leading Canadian institutions in aquaculture research, 1996–2008




Note: The size of nodes is proportional to total number of papers published by the institution over the period, and the width of the links is proportional to the number of collaborations between country pairs. Links are only displayed when country pairs co-authored at least six papers between 1996 and 2008.
Source: Calculated by Science-Metrix using the Scopus database

## 4.2 Habitat impacts

At the world level, DFO is the most productive institution in the subtopic of habitat impacts (Table IX). Indeed, only IFREMER publishes 30 papers of more in this subtopic; note that several indicators become unreliable when the total number of papers is small, including impact indicators, and so these are said to be non-significant. Compared to IFREMER, DFO has the greater ARC score (1.10),

which is also higher than the world level: it indicates that DFO's papers are cited 10% more frequently than the average world paper in this subtopic.

Table IX Leading institutions in habitat impacts research (within aquaculture), 1996–2008

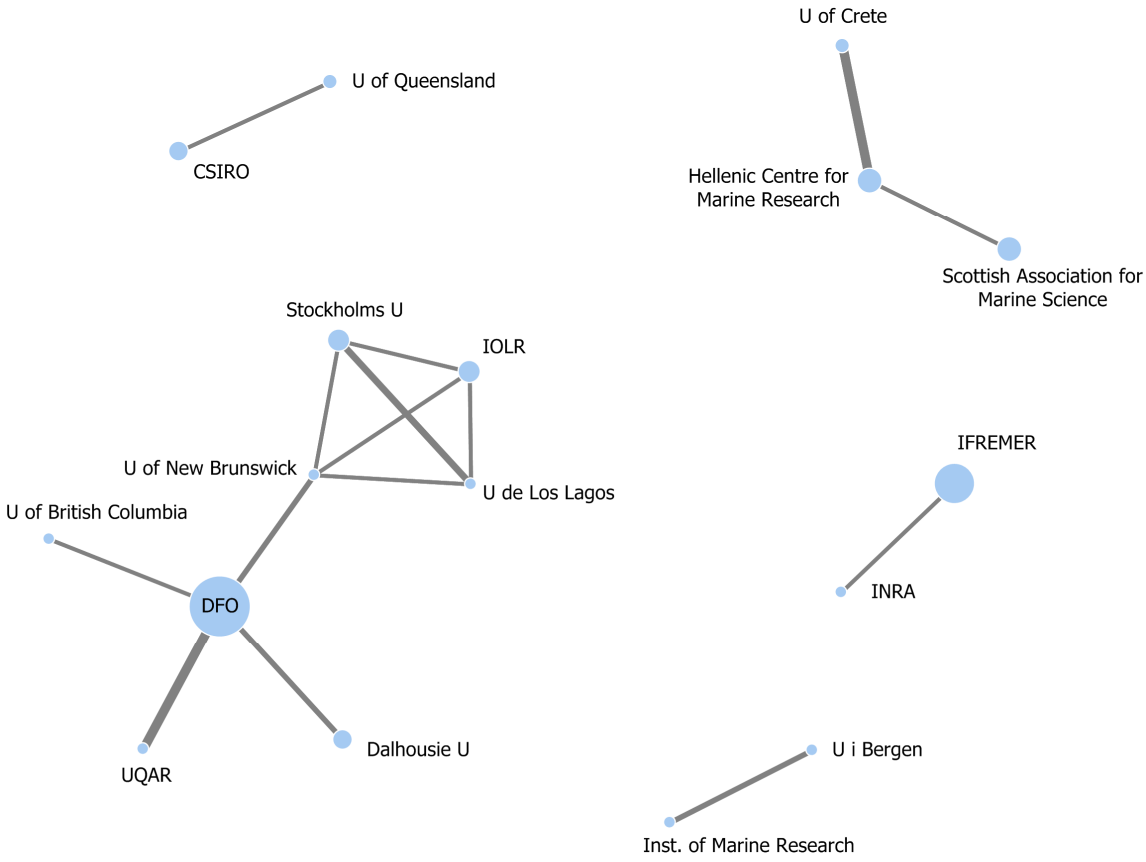
| Institution | Country | Papers | Trend | ARC |
|---|---|---|---|---|
| DFO | Canada | 44 |  | 1.10 |
| IFREMER | France | 30 |  | 0.98 |
| Hellenic Centre for Marine Research | Greece | 19 |  | n.s. |
| Scottish Association for Marine Science | UK | 18 |  | n.s. |
| IOLR | Israel | 17 |  | n.s. |
| Stockholms U | Sweden | 16 |  | n.s. |
| CSIRO | Australia | 15 |  | n.s. |
| U of Tasmania | Australia | 15 |  | n.s. |
| U of Stirling | UK | 14 |  | n.s. |
| Dalhousie U | Canada | 14 |  | n.s. |
| TAFI | Australia | 13 |  | n.s. |
| U di Genova | Italy | 13 |  | n.s. |
| U di Palermo | Italy | 13 |  | n.s. |
| U of Crete | Greece | 11 |  | n.s. |
| Auburn U | USA | 11 |  | n.s. |
| U of Hawaii at Manoa | USA | 11 |  | n.s. |
| National U of Ireland | Ireland | 11 |  | n.s. |
| U of Queensland | Australia | 10 |  | n.s. |
| U de Murcia | Spain | 10 |  | n.s. |
| Chinese Academy of Sciences | China | 10 |  | n.s. |
| Marine Scotland | UK | 9 |  | n.s. |
| City U of Hong Kong | China | 9 |  | n.s. |
| U of British Columbia | Canada | 9 |  | n.s. |
| INRA | France | 9 |  | n.s. |
| Texas A and M U | USA | 9 |  | n.s. |
| U of New Brunswick | Canada | 9 |  | n.s. |
| Wageningen U & Research Centre | Netherlands | 9 |  | n.s. |
| UQAR | Canada | 9 |  | n.s. |
| Asian Institute of Technology | Thailand | 9 |  | n.s. |
| Ocean U of China | China | 9 |  | n.s. |
| U do Algarve | Portugal | 8 |  | n.s. |
| CNRS | France | 8 |  | n.s. |
| U de Los Lagos | Chile | 8 |  | n.s. |
| Institute of Marine Research | Norway | 8 |  | n.s. |
| U i Bergen | Norway | 8 |  | n.s. |
| AIMS | Australia | 7 |  | n.s. |
| U of Idaho | USA | 7 |  | n.s. |
| Fisheries Research Agency | Japan | 7 |  | n.s. |
| U of the Philippines - Diliman | Philippines | 7 |  | n.s. |
| Griffith U | Australia | 7 |  | n.s. |
| Kasetsart U | Thailand | 7 |  | n.s. |
| U of Victoria | Canada | 7 |  | n.s. |
| Russian Academy of Sciences | Russian Fed. | 7 |  | n.s. |
| USDA | USA | 7 |  | n.s. |

Source: Calculated by Science-Metrix using the Scopus database

Other international institutions that contributed to 15 or more papers relating to this subtopic include the Hellenic Centre for Marine Research, the Scottish Association for Marine Science, IOLR, Stockholms universitet, CSIRO and the University of Tasmania (Table IX). It is worth noting that among these leaders and within the larger list, there is a large proportion of government departments or agencies and other government-based organizations (e.g., DFO, IFREMER, Hellenic Centre for Marine Research, Scottish Association for Marine Science, IOLR, and CSIRO).

Other than DFO, five Canadian institutions published at least seven papers relating to habitat impacts of aquaculture between 1996 and 2008: Dalhousie University, the University of British Columbia, the University of New Brunswick, UQAR and the University of Victoria (Table IX). Not unexpectedly, all of these universities (or at least one of their campuses) are located in a coastal city adjacent to a major body of water (i.e., Atlantic Ocean, Pacific Ocean or Gulf of St. Lawrence). The collaboration network in habitat impacts research, which features both international and Canadian institutions, is shown in Figure 7.

Figure 7 Collaboration network of leading institutions in habitat impacts research, 1996–2008




Note: The size of nodes is proportional to total number of papers published by the institution over the period, and the width of the links is proportional to the number of collaborations between country pairs. Links are only displayed when country pairs co-authored at least three papers between 1996 and 2008.

Source: Calculated by Science-Metrix using the Scopus database

The collaboration network of world-leading institutions in habitat impacts research (Figure 7) shows links above a threshold of three co-authored papers between 1996 and 2008.[5] As with aquaculture research overall, the international network is in fact comprised of fragmented clusters. However, more international collaborations are observed in this subtopic at this collaboration threshold, such as between the Hellenic Centre for Marine Research and the Scottish Association for Marine Science, and more significantly, in the cluster that involves the Canadian institutions. Indeed, through the University of New Brunswick, the Canadian cluster is linked to the Universidad de Los Lagos (Chile), the IOLR (Israel Oceanographic and Limnological Research) and Stockholms universitet. Otherwise, the central Canadian institution remains DFO, which is linked to four Canadian universities.

## 4.3 Wild/farmed interactions

As seen for habitat impacts research, DFO was the most productive institution in the subtopic of wild/farmed interactions at the world level during the 1996–2008 period (Table X). Only one other institution, NINA (Norwegian Institute for Nature Research) publishes 30 papers of more in this subtopic. NINA performs applied ecological research relating to terrestrial, freshwater and coastal ecosystems and is funded mainly by commissioned projects (by management authorities, private and industrial sectors), as well as through government grants and research funding. NINA has a greater scientific impact than does DFO in wild/farmed interactions research, as shown by their ARC scores of 1.54 and 0.89, respectively.

Six other institutions contributed to 15 or more papers relating to this subtopic during the study period, two of which are Canadian: the six institutions are the University of Washington, NOAA, the Institute of Marine Research (Norway), the USGS, the University of British Columbia and Dalhousie University (Table X). The other Canadian institutions that published at least six papers relating to wild/farmed interactions are the University of New Brunswick, Université Laval and the University of Alberta.

Figure 8 presents the collaboration network in wild/farmed interactions research at the international level, including the main Canadian collaborations that involved at least three co-authored papers during the 1996–2008 period. A Canadian university, Université Laval, and NINA are involved in the only collaboration of three or more co-authored papers seen between two institutions from different countries. The largest cluster in wild/farmed interactions research collaboration involves six US institutions, four of which are government agencies. Once again, DFO plays a central role among collaboration between Canadian institutions in this subtopic, linking to the University of British Columbia and the University of New Brunswick.

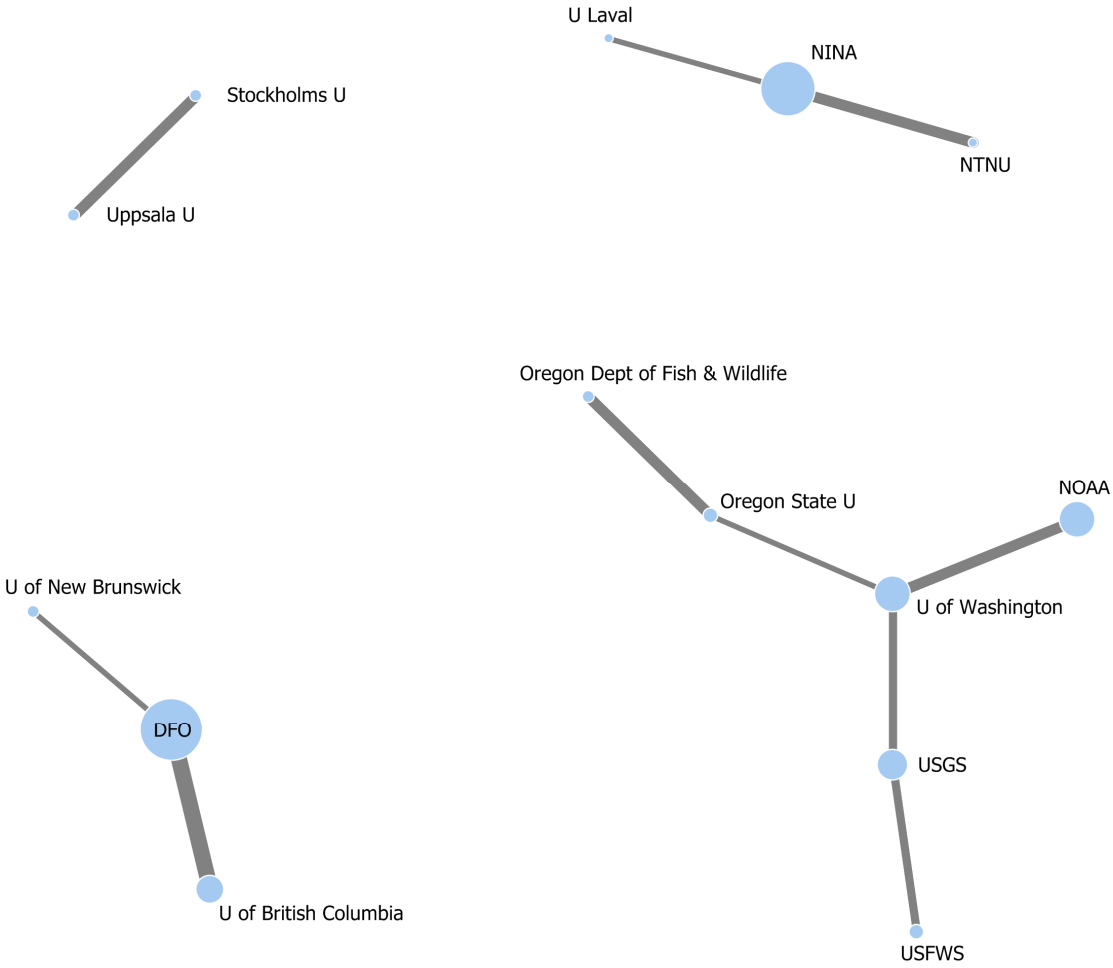
[5] Note that certain collaborations appear in this network and that for other subtopics, but not in the main network for aquaculture research. This is because of the different threshold used for each network: 13 co-authored papers for aquaculture research, 6 co-authored papers for the Canadian network, and 3 co-authored papers for each of the subtopics.

Table X Leading institutions in wild/farmed interactions research (within aquaculture), 1996–2008

| Institution | Country | Papers | Trend | ARC |
|---|---|---|---|---|
| DFO | Canada | 39 |  | 0.89 |
| NINA | Norway | 34 |  | 1.54 |
| U of Washington | USA | 23 |  | n.s. |
| NOAA | USA | 22 |  | n.s. |
| Institute of Marine Research | Norway | 21 |  | n.s. |
| USGS | USA | 20 |  | n.s. |
| U of British Columbia | Canada | 18 |  | n.s. |
| Dalhousie U | Canada | 15 |  | n.s. |
| Washington Dept. Fish & Wildlife | USA | 13 |  | n.s. |
| National U of Ireland | Ireland | 12 |  | n.s. |
| Marine Scotland | UK | 12 |  | n.s. |
| IFREMER | France | 11 |  | n.s. |
| USFWS | USA | 9 |  | n.s. |
| U of California, Davis | USA | 9 |  | n.s. |
| INRA | France | 9 |  | n.s. |
| Game & Fisheries Research Inst. | Finland | 9 |  | n.s. |
| Oregon State U | USA | 9 |  | n.s. |
| Chinese Academy of Sciences | China | 8 |  | n.s. |
| U of Tasmania | Australia | 8 |  | n.s. |
| Stockholms U | Sweden | 7 |  | n.s. |
| USDA | USA | 7 |  | n.s. |
| Oregon Dept. Fish & Wildlife | USA | 7 |  | n.s. |
| Göteborg U | Sweden | 7 |  | n.s. |
| U of New Brunswick | Canada | 7 |  | n.s. |
| U of Stirling | UK | 7 |  | n.s. |
| U de Oviedo | Spain | 7 |  | n.s. |
| U Austral de Chile | Chile | 7 |  | n.s. |
| Uppsala U | Sweden | 7 |  | n.s. |
| U of Tokyo | Japan | 6 |  | n.s. |
| CIBNOR | Mexico | 6 |  | n.s. |
| U of New Hampshire | USA | 6 |  | n.s. |
| U of California, Santa Barbara | USA | 6 |  | n.s. |
| Kasetsart U | Thailand | 6 |  | n.s. |
| U of Idaho | USA | 6 |  | n.s. |
| Deakin U | Australia | 6 |  | n.s. |
| U Laval | Canada | 6 |  | n.s. |
| U of Alberta | Canada | 6 |  | n.s. |
| NTNU | Norway | 6 |  | n.s. |
| Hellenic Centre for Marine Research | Greece | 6 |  | n.s. |
| Shanghai Ocean U | China | 6 |  | n.s. |

Source: Calculated by Science-Metrix using the Scopus database

Figure 8 Collaboration network of leading institutions in wild/farmed interactions research, 1996–2008




Note: The size of nodes is proportional to total number of papers published by the institution over the period, and the width of the links is proportional to the number of collaborations between country pairs. Links are only displayed when country pairs co-authored at least three papers between 1996 and 2008.

Source: Calculated by Science-Metrix using the Scopus database

## 4.4 Sea lice

As observed in Section 3.3, sea lice research is primarily conducted in four countries: the UK, Norway, Canada and the US. Not surprisingly, the largest scientific output in sea lice research occurs from institutions located in these countries (Table XI). In fact, the Universidad Austral de Chile is the only institution that is not located in these four countries to publish more than 10 papers on sea lice. Marine Scotland, the lead marine management organisation in Scotland (and which comprises the former Scottish Government Marine Directorate, the Fisheries Research Services and the Scottish Fisheries Protection Agency), contributed to the most papers in sea lice research (38) between 1996 and 2008. Next is Norway's Institute of Marine Research – Norway's largest centre of marine science whose activities are about fifty percent financed by the Ministry of Fisheries and Coastal Affairs – followed by DFO and the University of Stirling.

DFO has the highest level of scientific impact among these four leading institutions in sea lice research, as indicated by the ARC column: an ARC score of 1.46 indicates that DFO's papers in this subtopic are cited, on average, 46% more than the average world sea lice paper (Table XI). Marine Scotland also has an impact above the world level (ARC of 1.11), whereas sea lice papers from the Institute of Marine Research (Norway) are cited, average at the same frequency as the world level. Finally, the University of Stirling has less scientific impact that the world level (ARC of 0.78).

Table XI Leading institutions in sea lice research (within aquaculture), 1996–2008

| Institution | Country | Papers | Trend | ARC |
|---|---|---|---|---|
| Marine Scotland | UK | 38 |  | 1.11 |
| Institute of Marine Research | Norway | 34 |  | 1.01 |
| DFO | Canada | 32 |  | 1.46 |
| U of Stirling | UK | 31 |  | 0.78 |
| U of Aberdeen | UK | 28 |  | n.s. |
| U of Prince Edward Island | Canada | 21 |  | n.s. |
| California State U, Long Beach | USA | 18 |  | n.s. |
| National Veterinary Institute | Norway | 18 |  | n.s. |
| U of Oslo | Norway | 17 |  | n.s. |
| U i Bergen | Norway | 16 |  | n.s. |
| NINA | Norway | 16 |  | n.s. |
| Marine Harvest (Scotland) Ltd. | UK | 13 |  | n.s. |
| NRC Canada | Canada | 12 |  | n.s. |
| U of Strathclyde | UK | 11 |  | n.s. |
| School of Veterinary Science | Norway | 11 |  | n.s. |
| U Austral de Chile | Chile | 11 |  | n.s. |
| National Chiayi U | Taiwan | 10 |  | n.s. |
| Schering-Plough | USA/UK | 10 |  | n.s. |
| Raincoast Research | Canada | 10 |  | n.s. |
| U of British Columbia | Canada | 9 |  | n.s. |
| NOFIMA | Norway | 9 |  | n.s. |
| Simon Fraser U | Canada | 9 |  | n.s. |
| U of Alberta | Canada | 9 |  | n.s. |
| U of Tromsø | Norway | 8 |  | n.s. |
| National U of Ireland | Ireland | 8 |  | n.s. |
| Rothamsted Research | UK | 8 |  | n.s. |
| U de Los Lagos | Chile | 8 |  | n.s. |
| U of St. Andrews | UK | 8 |  | n.s. |
| Natural History Museum (London) | UK | 8 |  | n.s. |
| Marine Institute | Ireland | 7 |  | n.s. |
| Scottish Association for Marine Science | UK | 7 |  | n.s. |
| Nutreco | Norway | 7 |  | n.s. |
| AQUAFACT International Services Ltd | Ireland | 7 |  | n.s. |
| U of Dublin | Ireland | 7 |  | n.s. |
| Dalhousie U | Canada | 6 |  | n.s. |
| U of Maine | USA | 6 |  | n.s. |
| U of Victoria | Canada | 6 |  | n.s. |
| U of Limpopo | South Africa | 6 |  | n.s. |

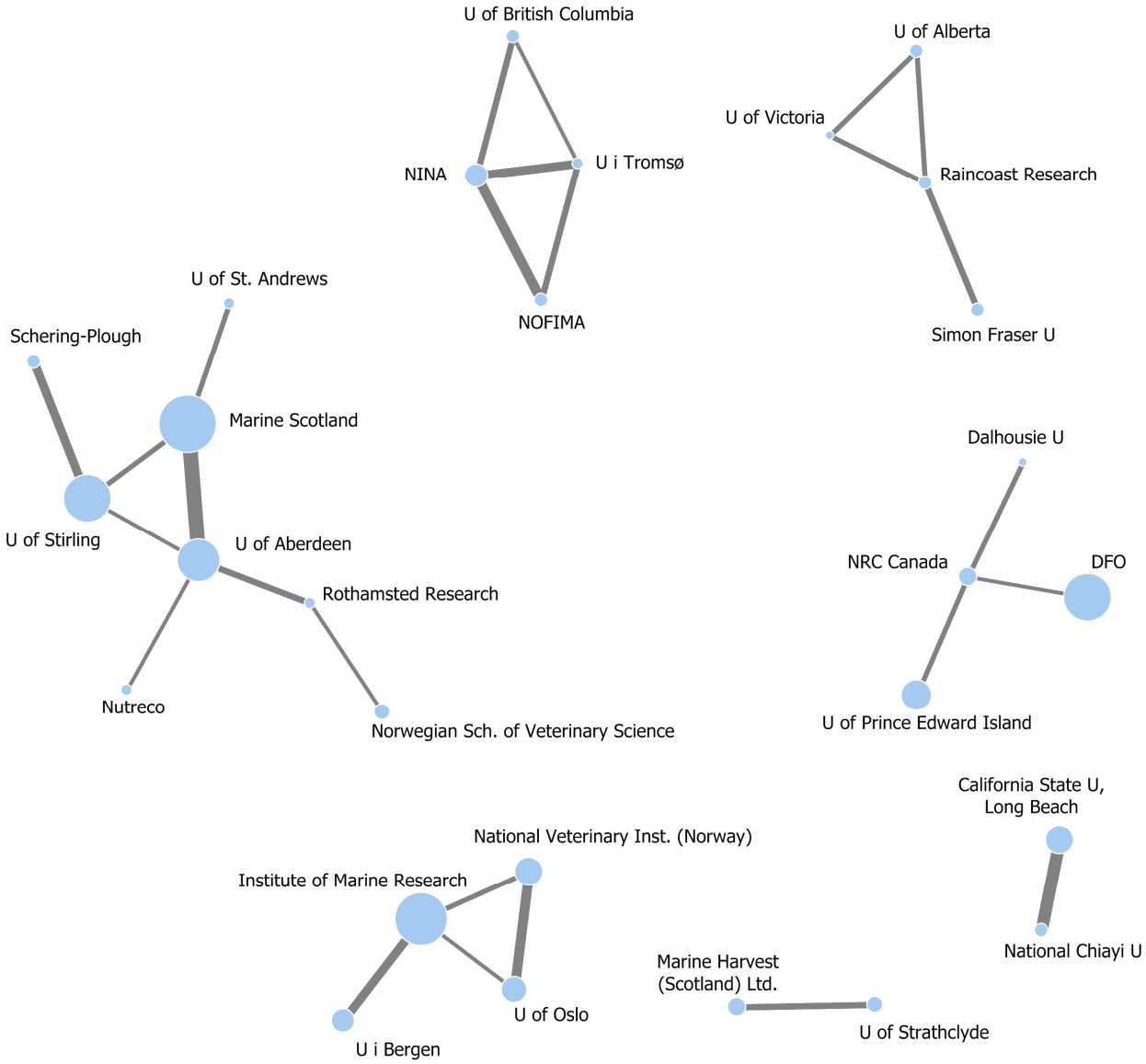
Source: Calculated by Science-Metrix using the Scopus database

The "Trend" column suggests that both the Institute of Marine Research and DFO have increased their scientific output in sea lice research over the latter half of the study period, as have most of the Canadian institutions appearing on this list (Table XI). The Canadian institutions that have contributed to at least six papers in sea lice research are the University of Prince Edward Island, NRC Canada, Raincoast Research, the University of British Columbia, Simon Fraser University, the University of Alberta, Dalhousie University and the University of Victoria. Note that Raincoast Research is a non-profit research organization located in British Columbia that conducts collaborative research on marine mammals and on the impacts of salmon farming.

Not surprisingly, collaboration in sea lice research mainly involves institutions from Norway, Canada and the UK (Figure 9). This network displays links between institutions that have co-authored three or more sea lice papers between 1996 and 2008. Several clusters are observed, the largest being the main Scotland-based cluster, which also includes two Norwegian institutions (Nutreco and the Norwegian School of Veterinary Science). Norwegian institutes are scattered among three isolated clusters in sea lice research, and do not form an integrated cluster like the one observed in aquaculture research. The most substantial collaboration, in terms of number of co-authored papers, is between Marine Scotland and the University of Aberdeen. Note also a partnerships between National Chiayi University (Taiwan) and California State University at Long Beach.

Like the Norwegian institutions, Canadian institutions are split among a number of clusters: one involves mainly institutions from Western Canada (Raincoast Research, Simon Fraser University, the University of Victoria and the University of Alberta) and one involves government agencies (DFO and NRC Canada) and two universities from the Maritimes (Dalhousie University and the University of Prince Edward Island). Finally, the University of British Columbia has collaborated with both NINA and the Universitetet i Tromsø, and thus joins a Norway-based cluster.

Figure 9 Collaboration network of leading institutions in sea lice research, 1996–2008




Note: The size of nodes is proportional to total number of papers published by the institution over the period, and the width of the links is proportional to the number of collaborations between country pairs. Links are only displayed when country pairs co-authored at least three papers between 1996 and 2008.

Source: Calculated by Science-Metrix using the Scopus database

# 5 Scientific Collaboration by DFO and Canada

In this section, the numbers of scientific collaborations are examined in more detail for DFO and for Canada over the 1996–2008 period. As stated previously, certain indicators are less reliable when numbers are small, as is particularly the case in the subtopics of aquaculture research. Thus, for the subtopics, only the number and percentage of collaborations across countries and institutions are presented.

## 5.1 Scientific collaboration by Canada

Of the 1,705 aquaculture papers by Canadian researchers between 1996 and 2008, 653 – or 38% – involved one or more international co-author (Table I and Table XII). This collaboration rate varies among the three subtopics, from 28% in sea lice research (27 out of 95 papers) to 42% (42 out of 100 papers) in wild/farmed interactions research; 35% of habitat impacts papers also involved international collaboration (35 out of 99 papers) (Table II and Table XII).

At the country level, the US is Canada's most frequent international partner for scientific collaboration in aquaculture research, as well as in the three subtopics (Table XII). Indeed, the US is involved in 35% to 49% of Canada's international collaborations in these subtopics. In aquaculture research overall, Canada also collaborates frequently with Norway (76 papers, or about 12% of international collaborations), the UK (57 papers, about 9%) and France (38 papers, about 6%).

This pattern varies somewhat across the three subtopics over the 1996–2008 period:

- In habitat impacts research, Canada collaborates most frequently with the US (14 papers), Sweden (7 papers) and Israel (4 papers).
- In wild/farmed interactions research, Canada collaborates most frequently with the US (15 papers), Norway (11 papers) and Ireland (5 papers).
- In sea lice research, Canada collaborates most frequently with the US (13 papers), Norway and the UK (8 papers each).

Table XII Scientific collaborations of Canada by country in aquaculture research and its subtopics, 1996–2008

| | Aquaculture | | Habitat impacts | | Wild/farmed interactions | | Sea lice | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **Number** | **%** | **Number** | **%** | **Number** | **%** | **Number** | **%** |
| United States | 241 | 36.9% | 14 | 40.0% | 15 | 35.7% | 13 | 48.1% |
| Norway | 76 | 11.6% | 2 | 5.7% | 11 | 26.2% | 8 | 29.6% |
| United Kingdom | 57 | 8.7% | 1 | 2.9% | 4 | 9.5% | 8 | 29.6% |
| France | 38 | 5.8% | 3 | 8.6% | 2 | 4.8% | | |
| China | 29 | 4.4% | 1 | 2.9% | 1 | 2.4% | | |
| Australia | 26 | 4.0% | 3 | 8.6% | 2 | 4.8% | | |
| Sweden | 24 | 3.7% | 7 | 20.0% | 2 | 4.8% | | |
| Germany | 22 | 3.4% | 1 | 2.9% | 2 | 4.8% | | |
| Brazil | 21 | 3.2% | | | 2 | 4.8% | | |
| Japan | 21 | 3.2% | | | 1 | 2.4% | 1 | 3.7% |
| Spain | 18 | 2.8% | | | | | | |
| Chile | 18 | 2.8% | 3 | 8.6% | | | 1 | 3.7% |
| Italy | 16 | 2.5% | 1 | 2.9% | 1 | 2.4% | | |
| Denmark | 14 | 2.1% | 1 | 2.9% | | | 1 | 3.7% |
| Venezuela | 14 | 2.1% | | | | | | |
| Mexico | 13 | 2.0% | 1 | 2.9% | | | | |
| Ireland | 12 | 1.8% | 1 | 2.9% | 5 | 11.9% | | |
| Israel | 12 | 1.8% | 4 | 11.4% | | | | |
| Thailand | 12 | 1.8% | 1 | 2.9% | 1 | 2.4% | | |
| New Zealand | 12 | 1.8% | 3 | 8.6% | | | 1 | 3.7% |
| Republic of Korea | 11 | 1.7% | 1 | 2.9% | 1 | 2.4% | | |
| Philippines | 9 | 1.4% | | | | | | |
| Netherlands | 9 | 1.4% | | | | | | |
| Greece | 8 | 1.2% | | | | | | |
| Belgium | 8 | 1.2% | | | 1 | 2.4% | | |
| Malaysia | 8 | 1.2% | | | 1 | 2.4% | | |
| Egypt | 7 | 1.1% | | | | | | |
| Finland | 6 | 0.9% | | | | | | |
| **WORLD** | **653** | **100%** | **35** | **100%** | **42** | **100%** | **27** | **100%** |

Note: The sum of collaborations with individual countries may be more than the world total because Canadian sometimes co-authors papers with more than one country.
Source: Calculated by Science-Metrix using the Scopus database

Among international institutions, Canada collaborates most often with NINA, for a total of 25 co-authored papers over the 1996–2008 period (Table XIII). Next are the USGS and IFREMER, with 15 collaborations each. Note that 12 of the 30 international institutions listed in Table XIII are located in the US. For the three subtopics of aquaculture research, considering the small number of papers involved, few trends can be inferred. In the habitat impacts subtopic (Table XIV), note the presence of institutions from five different countries with which Canada has authored at least three papers: Stockholms universitet (Sweden), the IOLR (Israel), the Universidad de Los Lagos (Chile), the University of Auckland (New Zealand) and the University of Connecticut (USA). NINA is the top international collaborator for Canada in both wild/farmed interactions research (nine papers) and sea lice research (five papers).

Table XIII International scientific collaborations of Canada by institution in aquaculture research, 1996–2008

| Institution | Country | Number |
|---|---|---|
| NINA | Norway | 25 |
| USGS | USA | 15 |
| IFREMER | France | 15 |
| UC Davis | USA | 13 |
| Cornell U | USA | 13 |
| USDA | USA | 12 |
| U de Oriente | Venezuela | 12 |
| NOAA | USA | 11 |
| U of Maine | USA | 11 |
| Oregon State U | USA | 11 |
| U of Connecticut | USA | 10 |
| U Austral de Chile | Chile | 10 |
| IOLR | Israel | 9 |
| U of Stirling | UK | 8 |
| Norwegian U of Life Sciences | Norway | 8 |
| Stockholms U | Sweden | 7 |
| Institute of Marine Research | Norway | 7 |
| Ghent U | Belgium | 7 |
| U of Tromsø | Norway | 7 |
| State U of New York at Albany | USA | 7 |
| Indiana U, Bloomington | USA | 7 |
| U of Washington | USA | 6 |
| U of Tasmania | Australia | 6 |
| AKVAFORSK | Norway | 6 |
| CSIRO | Australia | 6 |
| Norwegian Sch. of Veterinary Sci. | Norway | 6 |
| Texas A and M U | USA | 6 |
| Chinese Academy of Sciences | China | 6 |
| U of Oslo | Norway | 6 |
| Shanghai Ocean U | China | 6 |

Source: Calculated by Science-Metrix using the Scopus database

Table XIV International scientific collaborations in subtopics of aquaculture research of Canada by institution, 1996–2008

| Habitat impacts | | Wild/farmed interactions | | Sea lice | |
|---|---|---|---|---|---|
| Institution | Number | Institution | Number | Institution | Number |
| Stockholms U | 4 | NINA | 9 | NINA | 5 |
| IOLR | 4 | U of Washington | 3 | U of Tromsø | 3 |
| U de Los Lagos | 3 | | | SUNY, Stony Brook | 3 |
| U of Auckland | 3 | | | | |
| U of Connecticut | 3 | | | | |

Source: Calculated by Science-Metrix using the Scopus database

## 5.2 Scientific collaboration by DFO

DFO produces about 26% of its aquaculture research papers with at least one international co-author (111 out of 430 papers) (Table I and Table XV).[6] This percentage varies only slightly (between 25% and 28%) among the three subtopics. However, seeing how relatively few papers have been produced by DFO in the three subtopics (see Table II), very few conclusions can be drawn in terms of DFO's collaboration patterns in these subtopics.

At the country level, the US is DFO's most frequent international collaborator in aquaculture research and all three subtopics (Table XV). Note that DFO has also collaborated on three papers with New Zealand in habitat impacts research.

Table XV Scientific collaborations of DFO by country in aquaculture research and its subtopics, 1996–2008

| | Aquaculture | | Habitat impacts | | Wild/farmed interactions | | Sea lice | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **Number** | **%** | **Number** | **%** | **Number** | **%** | **Number** | **%** |
| United States | 49 | 44.1% | 4 | 36.4% | 4 | 36.4% | 5 | 62.5% |
| Norway | 10 | 9.0% | | | 1 | 9.1% | | |
| Sweden | 9 | 8.1% | 1 | 9.1% | 2 | 18.2% | | |
| France | 9 | 8.1% | 1 | 9.1% | 1 | 9.1% | | |
| United Kingdom | 7 | 6.3% | | | 2 | 18.2% | 2 | 25.0% |
| Germany | 6 | 5.4% | 1 | 9.1% | 1 | 9.1% | | |
| New Zealand | 5 | 4.5% | 3 | 27.3% | | | 1 | 12.5% |
| Japan | 5 | 4.5% | | | | | 1 | 12.5% |
| Denmark | 4 | 3.6% | | | | | | |
| Ireland | 3 | 2.7% | | | 1 | 9.1% | | |
| Australia | 3 | 2.7% | 1 | 9.1% | | | | |
| Italy | 3 | 2.7% | | | | | | |
| Israel | 3 | 2.7% | 1 | 9.1% | | | | |
| Kenya | 3 | 2.7% | | | | | | |
| **WORLD** | **111** | **100%** | **11** | **100%** | **11** | **100%** | **8** | **100%** |

Note: The sum of collaborations with individual countries may be more than the world total because DFO sometimes co-authors papers with more than one country.
Source: Calculated by Science-Metrix using the Scopus database

Both Canadian and international institutions with whom DFO collaborates in aquaculture research are presented in Table XVI. Not surprisingly, most of these institutions are Canadian, as are the top 13 most frequent DFO collaborators. As mentioned in Section 4.1, DFO has a substantial national partnership in aquaculture research with University of British Columbia, which represents a total of 45 co-authored papers over the 1996–2008 period. DFO also collaborates frequently with the University of New Brunswick (25 papers), NRC Canada (21 papers), Dalhousie University (20 papers) and UQAR (19 papers).

[6] This finding is consistent with a previous study conducted for DFO by Science-Metrix found that DFO's international collaboration rate is 38% overall and 28% in the "Sustainability of Aquaculture" priority research area over the 1996–2007 period. Source: Picard-Aitken, M., Campbell, D. and Côté, G. 2009. *Bibliometric Study in Support of DFO's International Science Strategy*. Prepared for DFO by Science-Metrix.

Table XVI National and international scientific collaborations of DFO by institution in aquaculture research, 1996–2008

| Institution | Country | Number |
|---|---|---|
| U of British Columbia | Canada | 45 |
| U of New Brunswick | Canada | 25 |
| NRC Canada | Canada | 21 |
| Dalhousie U | Canada | 20 |
| UQAR | Canada | 19 |
| U of Guelph | Canada | 16 |
| Memorial U of Newfoundland | Canada | 14 |
| Simon Fraser U | Canada | 14 |
| U of Prince Edward Island | Canada | 12 |
| U de Moncton | Canada | 12 |
| U of Waterloo | Canada | 9 |
| U of Victoria | Canada | 9 |
| Environment Canada | Canada | 9 |
| USGS | USA | 8 |
| Université Laval | Canada | 8 |
| USDA | USA | 6 |
| Vancouver Island U | Canada | 6 |
| NOAA | USA | 5 |
| U of Manitoba | Canada | 5 |
| U of Maine | USA | 5 |
| U of Auckland | New Zealand | 5 |
| U of Saskatchewan | Canada | 4 |
| Oregon State U | USA | 4 |
| IFREMER | France | 4 |
| Queen's U | Canada | 4 |
| Aalborg U | Denmark | 3 |
| UC Davis | USA | 3 |
| Göteborg U | Sweden | 3 |
| Institute of Marine Research | Norway | 3 |
| U of Idaho | USA | 3 |
| IOLR | IOLR | 3 |
| GIROQ | Canada | 3 |
| Natural Resources Canada | Canada | 3 |
| Huntsman Marine Science Centre | Canada | 3 |
| Wilfrid Laurier U | Canada | 3 |
| Stockholms U | Sweden | 3 |

Source: Calculated by Science-Metrix using the Scopus database

Among top international collaborators, note the USGS (8 co-authored papers), the USDA (6 papers), NOAA (5 papers), the University of Maine (5 papers) and the University of Auckland (5 papers) (Table XVI). Based on the fact that no international collaborative relationship was observed for DFO in Figure 5, which had a threshold of 13 co-authored papers in aquaculture research over the study

period, it is not surprising that these numbers are relatively low. In terms of collaborations in the three subtopics (Table XVII), the most productive collaborative partnerships are seen with UQAR in habitat impacts (7 papers) and the University of British Columbia in wild/farmed interactions (7 papers).

Table XVII Scientific collaborations in subtopics of aquaculture research of Canada by institution, 1996–2008

| Habitat impacts | | Wild/farmed interactions | | Sea lice | |
|---|---|---|---|---|---|
| **Institution** | **Number** | **Institution** | **Number** | **Institution** | **Number** |
| UQAR | 7 | U of British Columbia | 7 | NRC Canada | 3 |
| Dalhousie U | 4 | U of Prince Edward Island | 4 | | |
| U of New Brunswick | 4 | U of New Brunswick | 3 | | |
| U of British Columbia | 3 | | | | |
| U of Auckland | 3 | | | | |
| Université de Moncton | 3 | | | | |

Source: Calculated by Science-Metrix using the Scopus database

# 6 Leading Researchers in Aquaculture Research

Leading researchers, both at the international level and within Canada, were identified based on their total number of papers in aquaculture research and in the three subtopics over the 1996–2008 period. Note that these researchers may have published additional papers in other areas of research; the papers reported here are only the ones contained within the aquaculture dataset (or subtopic datasets, when specified). As the numbers of papers for many researchers are quite small, particularly in the subtopics, it should be stressed that these lists may fluctuate substantially over time. Finally, efforts were made to identify the institution to which each researcher was affiliated during the study period based on author addresses; it is possible that some researchers may have since left the institutions identified in this section.

## 6.1 Aquaculture research overall

Leading world researchers in aquaculture research are listed in Table XVIII according to their scientific output; only researchers who have published 50 or more papers between 1996 and 2008 are included in this list. No Canadian researchers published more papers than 35 papers in aquaculture research during the study period; leading Canadian researchers are therefore listed in Table XIX.

If Table XVIII is compared with Table VII (leading institutions in aquaculture research), it becomes clear that certain researchers are responsible for a significant proportion of their institution's aquaculture papers, particularly for universities. This is the case for the top-ranked researcher, Patrick Sorgeloos of Universiteit Gent: he contributed to 126 of the 166 aquaculture papers published by this university. Also, Delbert Gatlin of Texas A&M University is third in the list with 78 aquaculture papers but Texas A&M University published fewer than 150 aquaculture papers during the study period and so is not listed in Table VII. Other institutions, particularly those which have multiple research centres or institutes, such as IFREMER, DFO, the Chinese Academy of Sciences, and Norway's Institute of Marine Research, are ranked highly in Table VII but feature no researchers in Table XVIII. Note that the USDA's Agricultural Research Service has an Aquatic Animal Health Research laboratory, to which are affiliated both USDA researchers in the list below. Also, Kangsen Mai from the Ocean University of China is affiliated with the Key Laboratory of Mariculture located at this institution, but which is overseen by the Ministry of Education.

Several researchers affiliated with US institutions published 50 or more aquaculture papers between 1996 and 2008 (Table XVIII). Interestingly, many of these researchers also have the lowest scientific impact, represented in the ARC column. Indeed, seven US-based researchers obtained ARC scores that are below the world level (i.e., below 1.0). The researchers whose papers have the highest scientific impact are Sadasivam J. Kaushik from INRA (or more specifically, from the Fish Nutrition Laboratory, a unit which is also affiliated with IFREMER), who has an ARC score of 2.1, Albert K. Imsland from the Universitetet i Bergen (ARC of 2.00), Barbara F. Nowak from the University of Tasmania (ARC of 1.99) and Scott E. LaPatra from Clear Springs Foods (ARC of 1.98). All of these researchers published papers that were cited, on average, more than twice as often as the average world paper in aquaculture research.

Table XVIII Leading international researchers in aquaculture research, number of papers and ARC,1996–2008

| Researcher | Institution | Country | Number | ARC |
|---|---|---|---|---|
| Patrick Sorgeloos | Universiteit Gent | Belgium | 126 | 1.51 |
| Phillip H. Klesius | USDA | USA | 92 | 1.05 |
| Delbert M. Gatlin III | Texas A and M University | USA | 78 | 1.10 |
| Claude E. Boyd | Auburn University | USA | 73 | 0.88 |
| Konrad Dabrowski | Ohio State University | USA | 71 | 0.90 |
| Barbara F. Nowak | University of Tasmania | Australia | 68 | 1.99 |
| Toshio Takeuchi | Tokyo University of Marine Sci. & Technol. | Japan | 65 | 1.09 |
| Sadasivam J. Kaushik | INRA (Unité Mixte IFREMER) | France | 62 | 2.15 |
| Ronald W. Hardy | University of Idaho | USA | 58 | 0.91 |
| Addison L. Lawrence | Texas A and M University | USA | 58 | 0.88 |
| Gro-Ingunn Hemre | NIFES | Norway | 58 | 1.88 |
| Paul C. Southgate | James Cook University | Australia | 57 | 0.96 |
| Pascal Divanach | Hellenic Center for Marine Research | Greece | 57 | 1.31 |
| Donald V. Lightner | University of Arizona | USA | 56 | 1.92 |
| Johan A. J. Verreth | Wageningen University & Research Center | Netherlands | 56 | 0.97 |
| Kangsen Mai | Ocean University of China | China | 55 | 1.67 |
| Sigurd Stefansson | Universitetet i Bergen | Norway | 55 | 1.86 |
| D. Allen Davis | Auburn University | USA | 55 | 0.76 |
| Menghe H. Li | Mississippi State University | USA | 55 | 0.79 |
| Sena S. De Silva | Deakin Universty | Australia | 53 | 1.35 |
| Edwin H. Robinson | Mississippi State University | USA | 53 | 0.81 |
| Albert K. Imsland | Universitetet i Bergen | Norway | 52 | 2.00 |
| Peter R. Smith | National University of Ireland (Galway) | Ireland | 51 | 1.03 |
| Marc C. J. Verdegem | Wageningen University & Research Center | Netherlands | 51 | 1.41 |
| Craig A. Shoemaker | USDA | USA | 50 | 1.20 |
| Scott E. LaPatra | Clear Springs Foods | USA | 50 | 1.98 |

Source: Calculated by Science-Metrix using the Scopus database

Leading Canadian researchers in aquaculture research, as presented in Table XIX, are considered to be those who contributed to at least 10 papers in the research area during the 1996–2008 period. All of the institutions listed in Table VIII (leading Canadian institutions in aquaculture research) are well represented in the table below, including 12 researchers who were affiliated with DFO during the study period. In fact, DFO researchers make up one third of the list of leading Canadian researchers in aquaculture research. Other institutions whose researchers have a strong presence in the list include the University of Prince Edward Island (due largely to the presence of the Atlantic Veterinary College at this university), the University of British Columbia, the University of Guelph and NRC Canada (more specifically the Institute for Marine Biosciences).

Table XIX Leading Canadian researchers in aquaculture research, 1996–2008

| Researcher | Institution | Number |
|---|---|---|
| Dominique P. Bureau | University of Guelph | 35 |
| Joseph A. Brown | Memorial University of Newfoundland | 34 |
| Santosh P. Lall | NRC Canada (Institute for Marine Biosciences) | 33 |
| David J. Speare | University of Prince Edward Island | 32 |
| R. Scott McKinley | University of British Columbia | 31 |
| David A. Higgs | DFO (CEAR) | 29 |
| Robert H. Devlin | DFO (CEAR) | 28 |
| Simon R.M. Jones | DFO (Pacific Biological Station) | 26 |
| Richard D. Moccia | University of Guelph | 26 |
| Stewart C. Johnson | NRC Canada (Institute for Marine Biosciences) | 25 |
| Christopher C. Parrish | University of Victoria | 24 |
| Neil W. Ross | NRC Canada (Institute for Marine Biosciences) | 24 |
| Jonathan Grant | Dalhousie University | 22 |
| Niels C. Bols | University of Waterloo | 19 |
| Michael L. Kent | DFO (Pacific Biological Station) | 19 |
| K. Larry Hammell | University of Prince Edward Island | 19 |
| John D. Castell | DFO (St. Andrews Biological Station) | 18 |
| Patrick T.K. Woo | University of Guelph | 18 |
| Tillmann J. Benfey | University of New Brunswick | 18 |
| G. Jay Parsons | DFO/Memorial University of Newfoundland | 17 |
| Shawn M. C. Robinson | DFO (St. Andrews Biological Station) | 16 |
| Katsuji Haya | DFO (St. Andrews Biological Station) | 16 |
| Deborah J. Martin-Robichaud | DFO (St. Andrews Biological Station) | 15 |
| Les E. Burridge | DFO (St. Andrews Biological Station) | 15 |
| John F. Burka | University of Prince Edward Island | 14 |
| Ian R. Dohoo | University of Prince Edward Island | 14 |
| Thomas Landry | DFO (Gulf Fisheries Centre) | 14 |
| Frederick S.B. Kibenge | University of Prince Edward Island | 13 |
| Fereidoon Shahidi | Memorial University of Newfoundland | 13 |
| Royann J. Petrell | University of British Columbia | 13 |
| George K. Iwama | University of British Columbia | 13 |
| Shannon K. Balfry | University of British Columbia | 13 |
| Réjean Tremblay | UQAR | 13 |
| Christopher M. Pearce | DFO (Pacific Biological Station) | 13 |
| Alexandra B. Morton | Raincoast Research Society | 13 |
| Matthew K. Litvak | University of New Brunswick | 13 |

Source: Calculated by Science-Metrix using the Scopus database

## 6.2 Subtopics of aquaculture research

The assessment of leading researchers in each of the three subtopics is limited by the size of these research areas; as the numbers are relatively small (at most 20 papers by a single researcher in habitat impacts and sea lice research, and at most 10 papers in wild/farmed interactions research), they are subject to more variability over time and should be considered with caution. The fact that the maximum number of papers published by individual researchers is smaller for wild/farmed interactions than for the other two subtopics might be explained by a lack of specialization in this

subtopic; in other words, researchers may be less likely to focus a large proportion of their research program on wild/farmed interactions than on the other two subtopics.

In all subtopics, it should be highlighted that the dataset design favoured precision (the absence of errors, or false positives) over recall (the extensiveness of the dataset, or the absence of false negatives), which often exist in an inverse relationship (i.e., increasing one is done at the cost of reducing the other). This design approach means that a modest number relevant papers may have been left out of the datasets (i.e., false negatives) in order to limit the number of irrelevant or non-specific papers (i.e., false positives) and so ensure a high level of precision of the final dataset. As a result, the number of papers listed in the tables below may slightly underestimate the total scientific output of researchers in these subtopics, but the approach ensures that those researchers who are presented published high numbers of papers that are specific in these subtopics.

In habitat impacts research (Table XX), a large number of researchers from Italian universities appear in the list of international leaders. Other researchers from European universities, namely Crete and South Denmark (Syddansk Universitet), as well as from the Scottish Association for Marine Science, are also highly ranked in this subtopic. No Canadian researcher contributed to more than 10 papers in the habitat impacts dataset and so the leading Canadian researchers are presented below the dotted line in Table XX; note that non-Canadian researchers who published fewer than 10 papers in this subtopic are not presented. Two DFO-affiliated researchers contributed to 5 or more papers in habitat impacts research, as did one researcher from the University of Victoria, one from Dalhousie University and one from UQAR.

Table XX Leading researchers in habitat impacts research, 1996–2008

| Researcher | Institution | Country | Number |
|---|---|---|---|
| Ioannis Karakassis | University of Crete | Greece | 19 |
| Marianne Holmer | Syddansk Universitet | Denmark | 14 |
| Simone Mirto | Università di Palermo | Italy | 14 |
| Antonio Mazzola | Università di Palermo | Italy | 14 |
| Roberto Danovaro | Università di Bari/Università di Ancona | Italy | 14 |
| Kenneth D. Black | Scottish Association for Marine Science | UK | 14 |
| Pierluigi Viaroli | Università di Parma | Italy | 11 |
| Mauro Fabiano | Università di Genova | Italy | 11 |
| Marco Bartoli | Università di Parma | Italy | 10 |
| Dror L. Angel | IOLR | Israel | 10 |
| Claude E. Boyd | Auburn University | USA | 10 |
| Daniele Nizzoli | Università di Parma | Italy | 10 |
| Peter R. Smith | National University of Ireland (Galway) | Ireland | 10 |
| Luigi Vezzulli | Università di Genova | Italy | 10 |
| Barry T. Hargrave | DFO (Bedford Institute of Oceanography) | Canada | 8 |
| Mark Flaherty | University of Victoria | Canada | 6 |
| Jonathan Grant | Dalhousie University | Canada | 6 |
| Christopher W. McKindsey | UQAR | Canada | 5 |
| Katsuji Haya | DFO (St. Andrews Biological Station) | Canada | 5 |

Source: Calculated by Science-Metrix using the Scopus database

In contrast, Canadians feature prominently among the list of world-leading researchers in wild/farmed interactions research; these researchers have published between ten and five papers in

this subtopic (Table XXI). Ian A. Fleming, currently professor with the Ocean Sciences Centre at the Memorial University of Newfoundland, contributed to ten papers in this subtopic. Other leading Canadian researchers include two from the Atlantic Salmon Federation, four researchers from DFO, and one researcher from the University of Victoria. Several Norwegian researchers also feature in Table XXI, and are mainly affiliated to the Institution of Marine Research and NINA. Additionally, researchers from Ireland, Denmark, the UK, Sweden and Finland published at least six papers on wild/farmed interactions between 1996 and 2008.

Table XXI Leading researchers in wild/farmed interactions research, 1996–2008

| Researcher | Institution | Country | Number |
|---|---|---|---|
| Ian A. Fleming | Memorial University of Newfoundland | Canada* | 10 |
| Frederick G. Whoriskey | Atlantic Salmon Federation | Canada | 9 |
| Øystein Skaala | Institute of Marine Research | Norway | 9 |
| Kjetil Hindar | NINA | Norway | 8 |
| Robert H. Devlin | DFO (CEAR) | Canada | 8 |
| Thomas F. Cross | National University of Ireland (Cork) | Ireland | 8 |
| Jonathan W. Carr | Atlantic Salmon Federation | Canada | 8 |
| Lars P. Hansen | NINA | Norway | 8 |
| Michael M. Hansen | Danish Institute for Fisheries Research | Denmark | 7 |
| Philip McGinnity | Marine Institute | Ireland | 7 |
| Pål Arne Bjørn | NOFIMA | Norway | 7 |
| Andy Ferguson | Queen's University of Belfast | UK | 7 |
| Jörgen I. Johnsson | Göteborg University | Sweden | 7 |
| Erik Petersson | Uppsala University | Sweden | 6 |
| John P. Volpe | University of Victoria | Canada | 6 |
| Torbjörn Järvi | Stockholm University | Sweden | 6 |
| Marja-Liisa Koljonen | Finnish Game and Fisheries Research Institute | Finland | 6 |
| Sigurd Einum | NINA | Norway | 6 |
| Martin Krkošek | University of Alberta | Canada | 5 |
| Ricardo Perez-Enriquez | CIBNOR | Mexico | 5 |
| John B. Taggart | University of Stirling | UK | 5 |
| Ruth E. Withler | DFO (Pacific Biological Station) | Canada | 5 |
| Frédérique Viard | CNRS (Station Biologique de Roscoff) | France | 5 |
| Thomas P. Quinn | University of Washington | USA | 5 |
| Jan A. Jacobsen | Fisheries Laboratory of the Faroes | Faroe Islands | 5 |
| Tiit Paaver | Estonian Agricultural University | Estonia | 5 |
| Fred Utter | University of Washington | USA | 5 |
| Knut E. Jørstad | Institute of Marine Research | Norway | 5 |
| Roar A. Lund | NINA | Norway | 5 |
| Gilles L. Lacroix | DFO (St. Andrews Biological Station) | Canada | 5 |
| Eva Garcia-Vazquez | Universidad de Oviedo | Spain | 5 |
| Jose Luis, Garcia-Marin | Universitat de Girona | Spain | 5 |
| Thomas Landry | DFO (Gulf Fisheries Centre) | Canada | 5 |
| Karen-Lise D. Mensberg | Danish Institute for Fisheries Research | Denmark | 5 |
| Kevin A. Glover | Institute of Marine Research | Norway | 5 |
| Uthairat Na-Nakorn | Kasetsart University | Thailand | 5 |

Note: *Ian Fleming has also held positions at Oregon State University, the University of Waterloo, and the Norwegian Institute for Nature Research (NINA) during the study period.
Source: Calculated by Science-Metrix using the Scopus database

In sea lice research, the leading international researchers hail primarily from the four countries who dominate this subtopic: the UK, Norway, Canada and the US (Table XXII). These researchers contributed to between 10 and 20 papers on sea lice; Canadian researchers who published at least 5 papers on sea lice are also listed in the table below. UK-based researchers are mainly affiliated with universities, although some are affiliated with government agencies, private firms and trade organizations. In Norway, government-led agencies (e.g., National Veterinary Institute, Institute of Marine Research, NINA, NOFIMA) host most of their leading sea lice researchers. Leading Canadian researchers in this subtopic are affiliated with DFO, NRC Canada, several universities, as well as the Raincoast Research Society.

Table XXII Leading researchers in sea lice research, 1996–2008

| Researcher | Institution | Country | Number |
|---|---|---|---|
| Christina Sommerville | University of Stirling | UK | 20 |
| Ju-Shey Ho | California State University (Long Beach) | USA | 18 |
| Peter Andreas Heuch | National Veterinary Institute | Norway | 17 |
| Stewart C. Johnson | NRC Canada (Institute for Marine Biosciences) | Canada | 16 |
| Frank Nilsen | Institute of Marine Research | Norway | 16 |
| James W. Treasurer | Marine Harvest (Scotland) Ltd. | UK | 15 |
| Bengt Finstad | NINA | Norway | 14 |
| Pål Arne Bjørn | NOFIMA | Norway | 14 |
| Les E. Burridge | DFO (St. Andrews Biological Station) | Canada | 13 |
| John F. Burka | University of Prince Edward Island | Canada | 13 |
| Crawford W. Revie | University of Strathclyde | UK | 12 |
| George Gettinby | University of Strathclyde | UK | 12 |
| Alexandra B. Morton | Raincoast Research Society | Canada | 12 |
| Ian M. Davies | Marine Scotland | UK | 12 |
| Thomas A. Schram | University of Oslo | Norway | 12 |
| Gordon H. Rae | Scottish Salmon Producers' Organisation* | UK | 11 |
| Simon R. M. Jones | DFO (Pacific Biological Station) | Canada | 11 |
| Michael G. Ritchie | University of St. Andrews | UK | 11 |
| Ching-Long Lin | National Taiwan University | Taiwan | 11 |
| Tor E. Horsberg | Norwegian School of Veterinary Science | Norway | 10 |
| Alan W. Pike | University of Aberdeen | UK | 10 |
| Juan Carvajal | Universidad de Los Lagos | Chile | 10 |
| Kevin A. Glover | Institute of Marine Research | Norway | 10 |
| Mark D. Fast | Stony Brook University | USA | 10 |
| Martin Krkošek | University of Alberta | Canada | 9 |
| Neil W. Ross | NRC Canada (Institute for Marine Biosciences) | Canada | 8 |
| K. Larry Hammell | University of Prince Edward Island | Canada | 8 |
| Susan L. Waddy | DFO (St. Andrews Biological Station) | Canada | 8 |
| Katsuji Haya | DFO (St. Andrews Biological Station) | Canada | 8 |
| R. Scott McKinley | University of British Columbia | Canada | 7 |
| Ahmed Mustafa | University of Prince Edward Island | Canada | 7 |
| Mark A. Lewis | University of Alberta | Canada | 6 |
| Richard D. Routledge | Simon Fraser University | Canada | 5 |
| Ian R. Dohoo | University of Prince Edward Island | Canada | 5 |
| Barbara M. Mackinnon | University of New Brunswick | Canada | 5 |

Note: *Formerly Scottish Quality Salmon and the Scottish Salmon Growers Association
Source: Calculated by Science-Metrix using the Scopus database

# 7 Conclusions

The goal of the current study was to assess the scientific production in aquaculture research and three subtopics for the 1996–2008 period using bibliometric analysis. Particular attention was paid to DFO's contributions to this research area, leading researchers, as well as collaborative relationships observed at the country and institution level. Note that the three subtopics (habitat impacts, wild/farmed interactions and sea lice) were found to involve a relatively small number of papers (approximately 500–1000 papers each), which implies that indicators and trends on these subtopics are limited by the sample size; areas where findings must be interpreted with caution are indicated throughout the text. This conclusion reviews the key findings of this study.

A total of almost 27,000 aquaculture research papers that were produced between 1996 and 2008 were found in the Scopus database, of which 1,700 had at least one Canadian author and 430 had at least one author from DFO. The overview of aquaculture research also indicated that the scientific output in this research area is growing at all levels examined: at the world level, in Canada and at DFO. Indeed, the world's output increased by 53% in the second half of the study period, with Canada increasing by 56% and DFO increasing by 48%. In the three subtopics, both Canada and DFO also increased their output over the study period; for Canada, the growth in sea lice and habitat impacts research was greater than that of the world. Note that DFO contributes to a large share of Canada's aquaculture research (25% overall), especially in the three subtopics (34–44%).

### Leading countries

The examination of leading countries in aquaculture research confirms that aquaculture research is a growing field, with the US having the largest scientific output, representing 22% of world papers. The US is followed by Japan, the UK, Norway and Canada, each of which contributed to between 6% and 8% of the world's aquaculture papers. All of these countries, as well as Australia and Spain, exhibited growth over the study period at a rate that is in the same range as that of the world (20% to 80%). However, notable increases in production were seen for China (377% growth rate), Brazil (194%), Portugal (189%), Turkey (258%), Bangladesh (161%), Vietnam (192%), and Iran (1633%).

When indicators of scientific impact and specialization are taken into account along with output, countries which demonstrate strengths in aquaculture research include Norway, Canada, Spain, Australia, the UK and France, while several countries with a small output also have a high level of scientific impact, such as Denmark, Belgium, New Zealand, Ireland, Portugal, Greece, and Iceland. Despite its very large output in aquaculture research, the US has a level of scientific impact that is barely above that of the world, and it is not specialized in this area of research. Finally, the only Asian country to have an impact above the world level in aquaculture research is Singapore: China, Japan, India and the Republic of Korea, while contributing to at least 500 aquaculture papers each, are not cited frequently enough to be positioned above the world level in this area of research.

Countries that demonstrate research strengths based on a combination of indicators (number of papers, scientific impact and specialisation) in each of the subtopics are as follows:

- Habitat impacts: Greece, Israel, Sweden, Italy, Canada, the UK, France and Spain. Like in many research areas, the US is not specialized in habitat impacts research but has an impact that is

higher than the world level in this subtopic. In addition, growth of the scientific output in this subtopic has been strongest in Greece, Italy, China, Spain and Canada.

- Wild/farmed interactions: Canada, Norway, the US, the UK and France; note that the first four countries produce over 60% of the papers related to this subtopic. Moreover, high growth in this subtopic is observed for the US, Canada, Australia, Japan and Spain.
- Sea lice: Canada, Norway and the UK. Along with the US (which has a scientific impact below the world level in this subtopic), only these four countries have contributed to more than 30 papers each on sea lice research. The highest growth in sea lice research is demonstrated by Canada, whereas the UK's growth has actually become negative over the study period.

### Leading institutions in aquaculture research

The analysis of leading international and Canadian institutions in aquaculture research indicates that DFO is ranked forth at the world level in terms of number of papers published in aquaculture research; DFO is also ranked first in Canada. Many of the world-leading institutions are government-led science-based agencies with multiple research centres or institutes, such as four of the top five producers: IFREMER (France), the USDA, DFO and the Chinese Academy of Sciences (the University of Stirling, in the UK, rounds out the top five).

Very few leading institutions have negative growth rates, which suggests that aquaculture research is a growing field at the international level; the highest growth were seen for the Chinese Academy of Sciences and the Ocean University of China, at 567% and 433%, respectively. At the world level, the most frequently cited institutions – and so the ones with the highest scientific impact based on the ARC indicator – are mostly located in Norway: AKVAFORSK, NIFES, the Universitetet i Tromsø and the Universitetet i Bergen, plus Belgium's Universiteit Gent.

All leading Canadian institutions (i.e., those that contributed to at least 30 papers in aquaculture research) have an impact above the world level. Note that several of these institutions (other than DFO) also appeared in the list of top world institutions as they had contributed to over 150 papers in aquaculture research (the University of British Columbia, the University of Guelph and Dalhousie University), whereas NRC Canada, the Memorial University of Newfoundland and the University of Prince Edward Island each contributed to 100 or more papers. NRC Canada, the University of British Columbia and Dalhousie University all increased their output by 120% or more over the study period, whereas only the University of Guelph is lagging behind the world growth level in this research area.

### Inter-institutional collaboration in aquaculture research

The collaboration network in aquaculture research is quite fragmented at the international institutional level. More specifically, few links exist between institutions of different countries, with isolated clusters almost always involving countries from a single country. Exceptions include a link between NOAA and AKVAFOSK, effectively linking the main Norwegian cluster and one of the US clusters. Norway also has one of the most inter-linked national clusters: many Norwegian institutions collaborated with more than two partners in their country, and several institutions are located at the centre of the cluster. There are also several US institutions in this network, many of

which are linked to two government agencies: the USDA and the USGS. Indeed, government agencies such as these (e.g., DFO) often act as central hubs among national clusters.

Canada is no exception to the trend of partnering primarily within national borders, as none of its institutions were found to co-author 13 or more papers with a foreign institution. DFO plays a central role in the collaboration network of Canadian institutions in aquaculture research, acting as the main hub to which most others link. In fact, NRC Canada is the only other Canadian institution to partner with more than three other institutions (with a threshold of more than six papers during the study period), whereas certain universities act to bring another institution into the network. The most substantial national partnership in this research area involves DFO and the University of British Columbia, which represents a total of 45 co-authored papers. DFO also collaborates frequently with the University of New Brunswick (25 papers), NRC Canada (21 papers), Dalhousie University (20 papers) and UQAR (19 papers).

### Leading institutions and scientific collaboration in aquaculture research subtopics

As seen in aquaculture research overall, research collaboration among leading institutions occurs in isolated clusters in each of the three subtopics. However, there is more collaboration between institutions from different countries in these contexts (note that the threshold was lowered to three or more co-authored papers between institution pairs). Key findings from the three subtopics are the following:

- Habitat impacts: DFO is the most productive institution and has a scientific impact above the world level. Only IFREMER publishes 30 papers of more in this subtopic but has below world-level scientific impact. Links between Canada and other countries exist through the University of New Brunswick, whereas DFO is at the centre of the collaboration cluster of Canadian institutions.
- Wild/farmed interactions: DFO is the most productive institution but has a scientific impact below the world level. NINA also published more than 30 papers and has above world-level scientific impact. The largest collaboration cluster is in the US. As for leading Canadian institutions, Université Laval collaborates with Norway cluster, DFO links two other Canadian universities and Dalhousie University is also productive but does not collaborate with other institutions.
- Sea lice: Marine Scotland and the Institute of Marine Research (Norway) are the most productive institutions. DFO ranks third but has the highest scientific impact score. The collaboration network indicates that the largest cluster is mainly based in the UK. The University of British Columbia links with one of Norway's clusters, whereas DFO links only with NRC Canada. The latter also collaborates with the University of Prince Edward Island and Dalhousie University; a separate Canadian cluster links institutions from Western Canada.

### Scientific collaboration of Canada

Of the 1,705 aquaculture papers by Canadian researchers between 1996 and 2008, 38% involved one or more international co-author. This collaboration rate varies in the three subtopics, from 28% in sea lice research to 42% in wild/farmed interactions research. At the country level, the US is Canada's

most frequent international partner for scientific collaboration in aquaculture research (37%), as well as in the three subtopics (35% to 49%). In aquaculture research overall, Canada also collaborates frequently with Norway (12% of international collaborations), the UK (9%) and France (6%).

Among international institutions, Canada collaborates most often with Norway's NINA, for a total of 25 co-authored papers over the 1996–2008 period. Next are the USGS and IFREMER, with 15 collaborations each. Note that 12 of the 30 international institutions with whom Canada collaborates most often are located in the US.

### Scientific collaboration of DFO

DFO produces about 26% of its aquaculture research papers with at least one international co-author; this percentage is about the same in the three subtopics (between 25% and 28%). At the country level, the US is DFO's most frequent international collaborator in aquaculture research and all three subtopics. The top 13 most frequent DFO collaborators and most of the other institutions with whom DFO collaborates in aquaculture research are Canadian. Among top international collaborators, note the USGS (8 co-authored papers), the USDA (6 papers), NOAA (5 papers), the University of Maine (5 papers) and the University of Auckland (5 papers).

### Leading researchers

The names and affiliated institutions of leading world and Canadian researchers in aquaculture research and its three subtopics are listed in Section 6. A number of trends can be observed from these lists:

- Certain university-based researchers are responsible for a significant proportion of their institution's aquaculture papers, whereas institutions that have multiple research centres or institutions (such as DFO) often have a larger total output but few individual researchers that publish more than 50 papers in aquaculture research.
- Several researchers affiliated with US institutions published 50 or more aquaculture papers between 1996 and 2008 but many of these researchers also have the lowest scientific impact.
- All of the leading Canadian institutions in aquaculture research are well represented in the list of leading Canadian researchers (who contributed to at least 10 papers) in this research area. DFO-affiliated researchers make up one third of this list (12 out of 36 researchers).
- In habitat impacts research, a relatively large number of researchers from Italian universities appear in the list of international leaders. No Canadian researcher contributed to more than 10 papers in the habitat impacts dataset.
- Canadians feature prominently among the list of world-leading researchers in wild/farmed interactions research, as do researchers from Norway.
- In sea lice research, the leading international researchers hail primarily from the four countries who dominate this subtopic: the UK, Norway, Canada and the US. Leading Canadian researchers in this subtopic are affiliated with DFO, NRC Canada, several universities, as well as the Raincoast Research Society.

# Appendix A – Bibliometric Methods

Access to a database containing the most complete bibliographic information on scientific journals published worldwide is essential for the production of bibliometric data. In this study, the Scopus database (by Elsevier) was used to produce statistics on aquaculture research for DFO. Scopus currently indexes some 33 million records in more than 18,000 peer-reviewed journals (i.e., articles that are peer reviewed prior to publication), covering various fields of science (e.g., natural sciences and engineering (NSE), and social sciences and humanities).

Scopus was chosen over other databases because it lists the references cited by each document it includes, allowing for internal coverage monitoring of the database and analysis of scientific impact based on citations and impact factors. Also, compared to databases that only provide information on the first author of a publication, Scopus includes all authors and their institutional affiliations, which allows collaboration rates between various entities (e.g., countries, institutions and researchers) to be analysed.

In producing bibliometric data, only four document types published in refereed scientific journals — articles, conference papers, notes and reviews — were retained, as all have undergone the peer-review process prior to being accepted for publication. The peer-review process ensures that the research is of good quality and constitutes an original contribution to scientific knowledge. In this report, these documents are collectively referred to as "papers".

## Constitution of datasets

A set of publications on aquaculture research were retrieved from the Scopus database by performing a query in titles, author keywords and abstracts using specific keywords; this constituted the main aquaculture dataset. The resulting dataset was tested for recall (i.e., an estimate of the proportion of relevant papers that were extracted from Scopus using the keywords) and precision (i.e., the number of relevant papers divided by the total number of papers retrieved by the query), and found to limit the number of false negatives (high recall) as well as false positives (high precision). Using a similar approach, datasets were constituted for the subtopics of sea lice, wild/farmed interactions and habitat impacts from the set of papers on aquaculture science. Additional keywords suggested by DFO were added after being tested for relevance and specificity in relation to the subtopics in question.

## Bibliometric indicators

Bibliometric indicators were computed on the four datasets described above, covering the period between 1997 and 2008. Note when an entity contributed to fewer than 30 papers during this period, certain indicators cannot be reliably calculated and most others are subject to rapid fluctuations.

**Number of papers:** Number of scientific papers written by authors located in a given geographical or organizational entity (e.g., a country or an institution).

**Growth:** A measure of growth is used to quantify change in the number of papers published over time. In the present report, the growth rate is expressed as a percentage increase in number of papers over the course of the study period, according to the following calculation:

$$\textbf{Growth rate (\%)} = \left( \frac{X_b}{X_a} - 1 \right) \textbf{x } 100$$

Where:
$X_a$ = Papers from entity X in a given research area (e.g., papers by Norway in aquaculture research) published between 1997–2002;
$X_b$ = Papers from entity X in the same research area published between 2003–2008

Note: The values for $X_a$ and $X_b$ are normalized to take into account the growth of the database.

**Growth Index (GI):** The GI compares the growth of a given entity (e.g., a country or an institution) in a given area with that of a reference entity (e.g., the world, as represented by the database). In other words, the GI is a measure of the increase in the number of papers in a particular field or research area relative to the increase in the number of papers in this field or research area in the database overall.

$$\textbf{GI} = \frac{(X_b/X_a)}{(R_b/R_a)}$$

Where:
$X_a$ = Papers from entity X in a given research area (e.g., papers by France in aquaculture research) published between 1997–2002;
$X_b$ = Papers from entity X in a given research area published between 2003–2008;
$R_a$ = Papers in a given research area published in Scopus between 1997–2002;
$R_a$ = Papers in a given research area published in Scopus between 2003–2008.

A GI value above 1 means that a given entity experienced greater growth in this research area relative to the reference entity, whereas an index value below 1 means the reverse.

**Specialization Index (SI):** The SI is an indicator of *research intensity* in a given entity (e.g., a country or an institution) for a given research area, relative to the intensity in a reference entity (e.g., the world, or the entire output as measured by the database) for the same research area. In other words, when a country is specialized in a research area, it places more emphasis on that area at the expense of other research areas. Specialization is therefore said to be a zero sum game: the more one specializes somewhere, the less it does elsewhere.

The SI is formulated as follows:

$$\textbf{SI} = \frac{(X_S/X_T)}{(N_S/N_T)}$$

Where:
$\mathbf{X_S}$ = Papers from entity X in a given research area (e.g., papers by Sweden in aquaculture research);
$\mathbf{X_T}$ = Papers from entity X in a reference set of papers (e.g., total papers by Sweden);

$\mathbf{N_s}$ = Papers from reference entity N in a given research area (e.g., world papers in aquaculture research);

$\mathbf{N_T}$ = Papers from reference entity N in a reference set of papers (e.g., total world papers).

An SI value above 1 means that a given entity is specialized relative to the reference entity, whereas an index value below 1 means the reverse. For example, if a country publishes 4% of its papers in biology, compared to the world level of 2%, this country has an SI of 2, because the percentage of its papers in biology is twice as high as the percentage at the world level (4%/2%=2). Conversely, if a country publishes 1% of its papers in biology, then its SI would be 0.5, as its research intensity in biology is only half as high as at the world level (1%/2% = 0.5).

**Average of Relative Citations (ARC):** The ARC is an indicator of the *observed scientific impact* of papers produced by a given entity (e.g., a country or an institution) based on the number of citations they received. The number of citations received by each paper is counted for the year in which it was published and for the two subsequent years. For papers published in 1997, for example, citations received in 1997, 1998 and 1999 are counted. Papers published in 2007 and 2008 are not considered in the ARC calculations, because citation data are not yet available for the full window. To account for different citation patterns across fields and subfields of science (e.g., there are more citations in biomedical research than in mathematics), each paper's citation count is divided by the average citation count of the papers in its subfield to obtain a relative citation count (RC). The ARC of a given entity is the average of the RCs of the papers belonging to it. An ARC value above 1 means that a given entity is cited more frequently than the world average in this research area, while a value below 1 means the reverse.

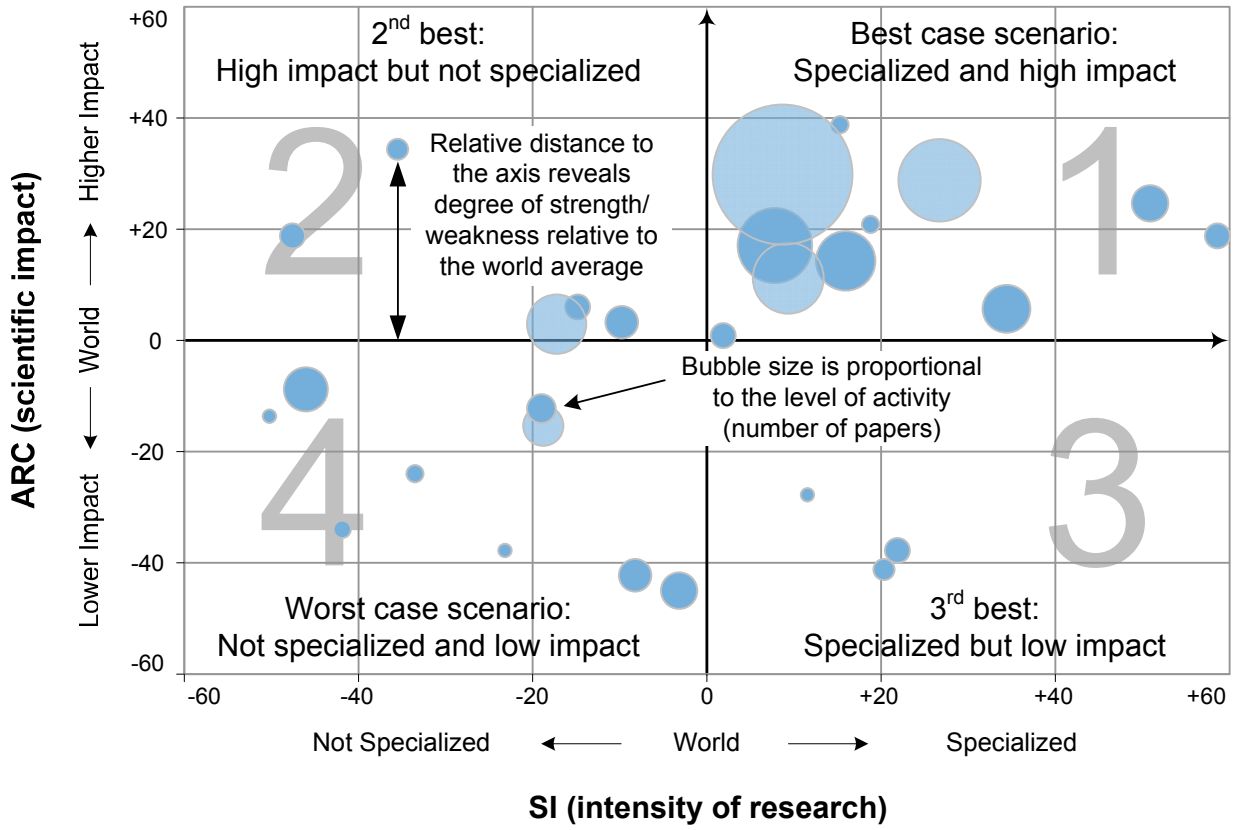
**Positional analysis:** To more easily interpret the strengths and weaknesses of an entity (e.g., a country or an institution) through the use of several separate indicators, Science-Metrix uses a graphical representation called positional analysis (see Example 1). This graphical representation logically combines three of the previously mentioned indicators (number of papers, SI and ARC).

The horizontal axis of this positional graph corresponds to the SI, and the vertical axis to the ARC. These data are transformed to obtain a symmetrical distribution of possible values between -100 and +100, with zero representing the world level. The size of the bubbles is proportional to the number of papers produced by the country or institution.

The position of a country or institution in one of four quadrants can therefore be interpreted as follows:

- **Quadrant 1**: Located at the top right of the graph, this quadrant is synonymous with excellence. Countries in this quadrant specialize in the given research area and their activities have a high impact, meaning that their papers are more frequently cited than the world average in this field.
- **Quadrant 2**: Located at the top left of the graph, this quadrant is synonymous with high-impact scientific production, but the countries are not specialized in this research area.
- **Quadrant 3**: Located at the bottom right of the graph, this quadrant signals specialization in the given research area, whereas the entity's impact is below the world average.

- **Quadrant 4**: Located at the bottom left of the graph, this quadrant represents the worst case scenario, as both the specialization and impact levels are below the world average in this research area.




Example 1: Positional Analysis Graph

**Collaboration network:** Scientific collaboration between entities (e.g., countries or institutions) is depicted by Science-Metrix using a collaboration network. Based on a square matrix cross-linking the number of papers co-authored by the relevant entities, the software programs UCINET and NetDraw (Analytic Technologies) produce a visual representation of the strength of the relationships between top entities.

In the networks, each node corresponds to an entity, represented by a circle of a size proportional to the total number of papers it published in collaboration with other entities in a given research area. Links (lines) between nodes represent collaborations between entities. The width of each link is proportional to the number of collaborations between two entities. For a link to be displayed between two entities in the network, researchers from the entities must have co-authored more than a specified number of papers over the period (e.g., 12 or more papers during 1996–2008).

A 'spring-embedding' algorithm with node repulsion and equal edge length is used to establish the relative locations of the entities in the graphic representation. Although the algorithm attempts to place entities that share a greater number of collaborations closer together on a two-dimensional plane, the length of the links cannot be used as an objective measurement of their relationship as minor manual adjustments are sometimes made to increase readability.

**Number of collaborations:** Number of collaborations between two countries (or DFO and another country). For example, if a paper is co-signed by researchers from DFO and researchers from CSIRO (Australia), the paper will count as one international collaboration for Canada and one for Australia, or as one inter-institutional collaboration between DFO and CSIRO.