Science-Metrix

25 Years of Canadian Environmental Research

A Scientometric Analysis (1980–2004)

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Executive summary

This report presents a detailed quantitative profile of Canada's contributions to environmental research. An overview of environmental research on an international scale is provided by identifying global trends in environmental research. Canada's output is compared to that of other leading countries, and its position in international networks of collaboration is subsequently examined. The report then turns to output in environmental research by province and sector of activity and identifies the most productive Canadian institutions.

Indicators presented in this study draw on three types of documents representing original contributions to science: articles, notes, and reviews, which will be referred to jointly as "papers". In building a dataset of papers published in environmental research-related journals, 434 peer-reviewed journals indexed in the Science Citation Index (SCI) and the Social Sciences Citation Index (SSCI) from ISI Thomson Scientific were selected and classified according to seven environmental areas:

- *Climate, Meteorology & Atmospheric Sciences*
- *Ecology & Biological Resources*
- *Environmental Engineering, Chemistry & Biotechnology*
- *Environmental Planning, Management & Conservation*
- *Environmental Sciences - General*
- *Pollution, Environmental Toxicology & Health*
- *Water Resources*

The scientometric indicators applied to 580,446 papers published in these journals were: growth; national and international collaboration rates; impact factor; and specialization index (research effort dedicated to the field and particular areas).

Canada's position in environmental science research relative to other countries is very strong. Among 13 leading countries, Canada ranks third in the world in number of papers published in environmental research and second in number of papers per capita. It is also second in the world in terms of scientific impact and level of specialization measures. Canada tops the list when a multicriteria analysis is performed.

During the first half of the 1990s, the levels of Canadian scientific collaboration at the national and international levels were roughly equal. Since 1997, the international collaboration rate has exceeded that of national collaboration. In 2004, there were 28% more papers co-authored with international partners than with national partners. However, the international collaboration rate in environmental research is similar to that observed for all Canadian scientific papers.

Canada's position as a global leader is likely to change in the coming years. Canadian environmental research represented, on average, 8% of the world's total output over the last 25 years, but the level of output began a decline in 1998. Several countries experienced significant growth in their scientific production over the last decade (between 1995–1999 and 2000–2004); these include China (110%), Spain (50%), Switzerland (46%), Italy (44%), and Japan (40%).

Concerning environmental research areas, Canada has consistently ranked first in the area of *Ecology & Biological Resources* and is expected to continue having a relatively high impact in that area (10% more than the world level).

However, since 1998, Canada has not improved its position in *Climate, Meteorology & Atmospheric Science*. The Canadian annual scientific output remained at the same level (300 papers per year) and, like its scientific impact, is comparable to the world level in this field. Canada's impact in *Environmental Engineering, Chemistry & Biotechnology* has fallen considerably since the mid-1990s.

After the US, which has 31 institutions in the top 50 most productive institutions in the world, Canada has the second highest number of institutions in environmental research in the last 10 years. These four institutions—Environment Canada (7th place), Fisheries & Oceans Canada (25th place), the University of British Columbia (28th place), and the University of Toronto (47th place)—also account for the highest percentage of international collaborations. Ontario represents most of the scientific output in environmental science and 44.4% of Canadian production over the last 25 years. Canada's university sector dominates environmental research.

Environment Canada (EC), which ranks among the top 10 leading institutions in the world, is also the first among the top 25 most active institutions in environmental research in Canada, producing approximately 14% of Canadian papers in the field.

The annual scientific production of the department increased three-fold over the last 25 years, from 100 to 300 papers. In addition, EC has positioned itself strongly among the international networks of the most collaborative institutions in the field (Figure page iv). On the Canadian scene, EC is the most important source of research collaborators for 10 of the 14 other most productive institutions, making it the central hub of the Canadian network in environmental science. ■

Key findings

A. International level

- At the world level, the number of scientific papers related to environmental research increased steadily over the 25-year period, from slightly over 15,000 papers in 1980 to roughly 35,000 papers in 2004.
- This growth represents an annual average increase of 4% over the period, which is greater than the average annual increase in scientific output generally (2.3%) and greater than the increase in most established fields of research.
- Canada ranks third in papers in environmental research over the last 25 years. The annual output of Canada rose from 1,175 papers in 1980 to 2,316 in 2004 (100%). However, it has not shown substantial growth since 1996 (7%), and Germany and China may soon overtake Canada's position.
- When the number of papers is calculated per capita, Canada ranks second in the world. At the beginning of the period (1980–1984), however, Canada was ranked first, but has not continued to increase as quickly as other countries. Canada has one of the lowest levels of output growth between the 1995–1999 and 2000–2004 periods (5.8%).
- Canada also ranks second in scientific relative effort (specialization index) and scientific impact (ARIF).
- When ranked according to a multicriteria analysis using four indicators, Canada consistently ranks first across the 25-year period.
- Among environmental areas, Canada specializes in *Ecology & Biological Resources* (10% more specialized than the world) and, to a lesser extent, in *Pollution, Environmental Toxicology & Health*.
- Canada shows a scientific impact between 1% and 5% higher than the world level in all environmental areas with the exception of *Environmental Engineering, Chemistry & Biotechnology*.
- According to a multicriteria ranking of Canada's performance in different specialties, Canada has remained in the top position in *Ecology & Biological Resources* for each 5-year period and, with the exception of 1995–1999, in *Water Resources*.
- Canada also ranks first for the entire period in *Pollution, Environmental Toxicology & Health*. Canada has also performed well in *Environmental Sciences—General*, improving from fifth place in 1985–1989 to first place in the two most recent periods, averaging at second place for the whole period.
- Canada comes in ninth in the world in international collaboration over the last 25 years, and 35.9% of Canadian publications in the field were co-authored with international partners over the 2000–2004 period. The US is Canada's most important collaborator, followed by the UK, Germany and France. In addition, the annual number of papers co-authored by Canada and China has increased rapidly.
- Over the last decade, 16 Canadian institutions figure in the world's top 200 most productive institutions and four among the top 50 in environmental research.

B. Canadian level

- Ontario accounts for most of the scientific output in environmental science and represents 44.4% of Canadian production over the last 25 years. Quebec and British Columbia also experienced steady growth in terms of output (particularly Quebec).
- The university sector dominates environmental research, having authored 76.5%* of the Canadian scientific papers published between 2000 and 2004. The federal government, which contributed 33% of the national output, places second. The industry sector ranks third (7%), and provincial governments fell from 6.1% in 1995–1998 to 4.9% in 2000–2004.
- In terms of scientific impact, universities and the federal government have a slightly higher impact than Canada as a whole and than the world level in the field.
- Between 1980 and 2004, the proportion of publications co-authored with partners from other Canadian institutions rose from 14.4% to 32.0%. While the international and national collaboration rate stayed at about the same level, collaborations with international researchers surpassed national collaborations from 2001 to reach 41% in 2004.
- Provincial and industry sector collaborations took place primarily at the national level, while the federal sector's rate of collaboration with other Canadian institutions has accelerated since the beginning of 1990s. In 2004, more than 50% of the federal government's output in the field was the result of collaboration with Canadian partners.

C. Institutional level

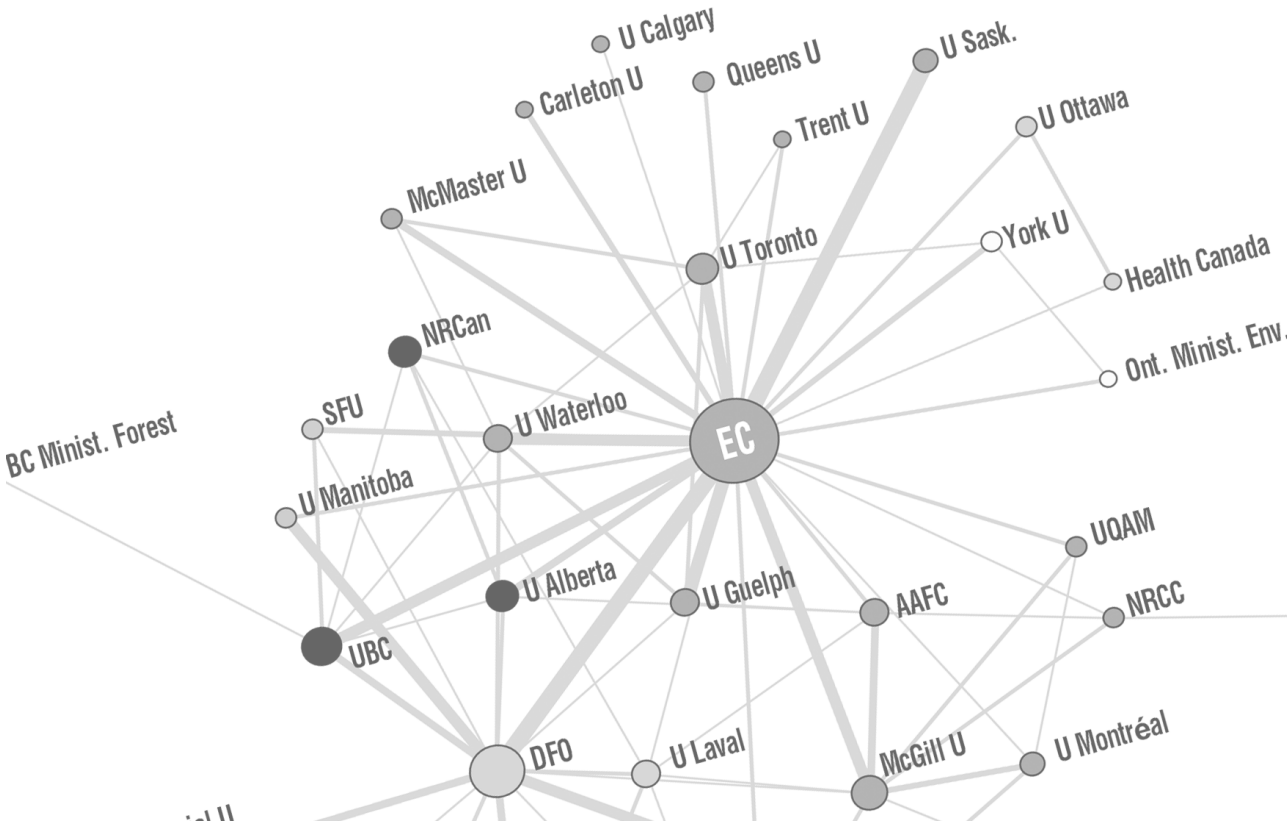
- The most productive institutions in environmental research in terms of number of papers between 1995 and 2004 were Environment Canada (3,033 papers), Fisheries and Oceans Canada (1,826), the University of British Columbia (1,761), the University of Toronto (1,327), McGill University (1,262), and the University of Alberta (1,149).
- Between the 1995–1999 and 2000–2004 periods, the institutions that increased their output in environmental research the most (by more than 25%) were the University of Ottawa (41%), the University of Toronto (33%), the University of Saskatchewan (31%), the University of Victoria (29%), Queens University (27%), and Trent University (25%).

** The sum of the percentages of papers from each sector is higher than 100% because a number of papers are subject to inter-sectoral collaborations.*

- In measures of the top 10 Canadian institutions by environmental research areas between 1995 and 2004, Environment Canada ranked first in four specialties: *Climate, Meteorology & Atmospheric Science* (935 papers); *Pollution, Environmental Toxicology & Health* (587 papers); *Environmental Sciences - General* (431); and *Water Resources* (379 papers). Fisheries and Oceans Canada ranked first for *Ecology & Biological Resources* (956), the University of Alberta for *Environmental Engineering, Chemistry & Biotechnology* (164), and the University of British Columbia for *Environmental Planning, Management & Conservation* (218).
- Two important clusters of collaboration between Canadian institutions are built around Environment Canada and Fisheries and Oceans Canada. Apart from these, collaborative links between academic institutions are relatively weak.

D. Environment Canada

- Environment Canada (EC) accounted for 15.7% of Canadian output in environmental research papers in 2003 and 12.7% in 2004. The Department was responsible for 41% of the federal government's output in the field in 2004.
- Between the 1995–1999 and 2000–2004 periods, the Department increased its output by about 9.5%. The increase began in 1994 with 230 papers and reached 300 papers in 1997, remaining fairly constant since.
- Over the last 25 years, EC published more papers in *Climate, Meteorological & Atmospheric* related-science than any other environmental area (1,450 papers). The Department's other areas of importance are *Pollution, Environmental Toxicology & Health* (978 papers), *Ecology and Biological Resources* (915 papers) and *Water Resources* (912 papers).
- The total collaboration rate of the Department was about 32% in 1980 and is now 81% (in 2004). International collaboration rate remained at around 34% over the last 10 years; concurrently, the national collaboration rate increased. Environment Canada's national collaboration rate increased from 26% in 1980 to 61% in 2004.
- Most of Environment Canada's collaborators are from Canadian institutions. In 2004, 60% of the Department's scientific output was co-authored with Canadian researchers, and 35% was co-authored with international researchers. EC has the strongest links with American institutions, despite the fact that this institution collaborates more with other Canadian institutions than with foreign institutions.
- However, the Department collaborates more at the international level in *Climate, Meteorological & Atmospheric Science* than at the national level. In 2000–2004, 46% of papers were coauthored with international counterparts, and 37% were with Canadians.
- EC is the principal collaborator with the other most productive Canadian institutions; EC constitutes the main hub of environmental research in Canada. ■



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Disclaimer

This report was prepared by Science-Metrix Inc. for Environment Canada. Information contained in this report consists of findings and opinion expressed by the authors; consequently, the views expressed herein are those of the originators and do not necessarily represent the opinions of Environment Canada or the government of Canada. ■

1 Introduction

1.1 Context

The environmental state of the planet is a growing concern for both the global population and scientific communities. Recognition of the impact of human activities on natural and constructed environments as well as on human health is exemplified by intensified debate surrounding global climate change in public, political, and industrial arenas. Though widespread consensus does not appear to exist among these stakeholder groups, these debates help to influence research and development (R&D), technological efforts, policy, and the dedication of funds to environmental protection and care. When the environmental performances of countries are examined in conjunction with their scientific and technological capacities, it becomes clear that there is no direct relationship between scientific effort and environmental protection. In fact, the more industrialized a country is, the more likely it will devote resources to environmental research, but also the more threatening its environmental activity is likely to be. Therefore, knowledge of the scientific and political structures of countries is critical to solving complex environmental issues.

Since the early 1980s, R&D funding has been increasing worldwide. In OECD countries, the amount of R&D funds dedicated to the protection and care of the environment has also increased (Figure 1). However, the share of environmental R&D funding among all R&D expenditure has grown only very slightly over the last 25 years. According to government budget appropriations or outlays for R&D (GBAORD)[1], the proportion dedicated to environmental protection and care accounted for 1.1% in 1980 and 1.4% in 2004.

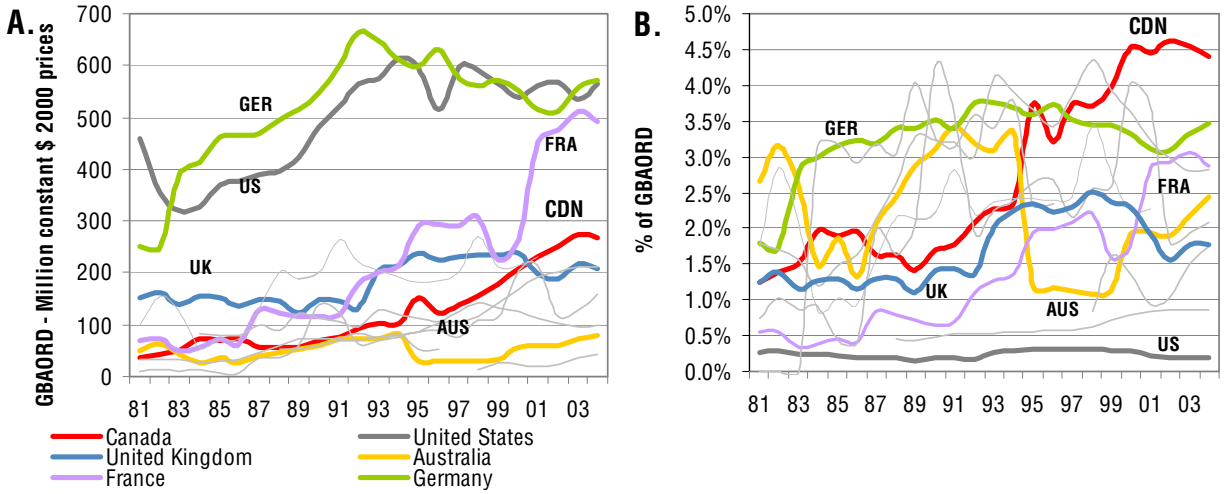

Figure 1 Government budget appropriations or outlays for R&D (GBAORD) for control and care of the environment: **(A)** Million dollars and **(B)** % of total GBAORD

Source: Data compiled by Science-Metrix from OECD

[1] No comparable statistics on total environmental R&D spending are readily available for countries. Government budget appropriations or outlays for R&D (GBAORD) by socio-economic objective compiled by the OECD are a proxy measurement of countries' R&D spending for the control and care of the environment.

Between 1980 and 1990, governments increased their financial contributions in order to better reach environmental protection and care objectives. After 1990, the majority of governments slowed or stabilized their levels of funding towards this socio-economic objective. However, Canada and France are exceptions, as both continued to increase GBAORD dedicated to environment. Among OECD countries, Canada's federal government dedicates the highest proportion of its total R&D spending to the control and care of the environment; Canada spent $37 million (in 2000 constant dollars) in 1980 and more than $268 million in 2004, equalling nearly 4.5% of total government R&D expenditures. No detailed statistics are available on the total R&D spending dedicated to environmental research in Canada[2].

The purpose of this report is not to establish a causal relation between funding and scientific output, but rather to provide an up-to-date, detailed quantitative profile of Canada in environmental research. Canada's scientific output in environmental research between 1980 and 1998 was shown to be very significant[3] in a 2002 study for Environment Canada conducted by the *Observatoire des sciences et des technologies* (OST)[4]. In fact, according to field experts, Canada's research funding system demonstrates evidence of success compared to that of the US: given its size, Canada produces far more high-quality environmental research than would be expected[5].

The present report, in particular, attempts to answer the following questions: How has Canada's scientific output evolved in recent years? Has Canada increased its leadership, or is it losing ground? What are the leading Canadian institutions, and how do Canadian institutions compare to the world's leading institutions in terms of the scientific impact of their work? What are Canada's strengths and weaknesses in the field of environmental research? In order to answer these questions, the present report examines the evolution of Canadian output compared to world output through the use of scientometric[6] indicators. The report follows the bibliometric profile established in 2002 for Environment Canada, which provided indicators up to 1998, and aims to provide an update that includes data up to 2004.

The first part of the report begins with a general overview of environmental research at the world level. The most productive countries, including Canada, are benchmarked according to four indicators, and strengths and weaknesses by environmental speciality are examined at the country level. The first part also presents the leading institutions in the world and the major international collaboration networks. The second part of the report focuses on the Canadian output in the field, first by describing its distribution by province and by sector of activity, and then by identifying the most active Canadian institutions in the field, their areas of specialization, and the collaborative networks to which they belong.

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[2] Without having systematically surveyed the total spending on environmental research, Environment Canada's Science Policy Branch has previously used bibliometric data as a basis to approximate R&D expenditures. Total R&D spending is estimated to be 900 million for 2005–2006.

[3] Bertrand F., Robitaille J.-P., Côté G. and Godin B. 2002. *Bibliometric Profile of Environmental Science in Canada, 1980-1998*. Prepared for Environment Canada by the *Observatoire des sciences et des technologies* (OST).

[4] *L'Observatoire des sciences et des technologies* (OST) is an academic organization associated with the *Centre interuniversitaire de recherche sur la science et la technologie* (CIRST) at the Université du Québec à Montréal (UQAM). The OST is devoted to the measurement of science, technology, and innovation (www.ost.qc.ca).

[5] Pelly J. 2005. Canada's research funding system shows success in *Environmental Science and Technology*, Business & Education News – June 1, 2005.

[6] Scientometrics is the production and analysis of statistics on scientific publications.

1.2 Methods

1.2.1 The journal approach

This study uses the *Science Citation Index* (SCI) and the *Social Sciences Citation Index* (SSCI) from Thomson Scientific to obtain statistics on scientific output in environmental research. The study draws on three types of documents representing original contributions to science: articles, notes, and reviews, which will be referred to jointly as "papers". SCI and SSCI provide extensive coverage of high-quality scientific journals in the natural sciences and engineering (NSE) and ample coverage of social science journals. They index approximately 3,700 and 1,700, respectively, of the world's leading scholarly science and technical journals in more than 150 disciplines. These publications are considered to be the most important peer-reviewed journals in their respective fields. They reflect significant scientific achievements and are published in the world's most widely cited journals (receiving over 80% of the world's citations).

Environmental research encompasses multidisciplinary and interdisciplinary areas of science and technology (S&T). Measurement of the scientific output of different environment-related fields and subfields using scientometric techniques is therefore complex, particularly when a mutually exclusive journal classification is used to identify multidisciplinary and interdisciplinary areas[7]. Although use of a set of journals is imperfect, this method was the only solution given the time and budget available and is sufficiently robust to support a comparative study. An alternative to this journal-based method is to construct the paper dataset using a keyword search of papers' titles. This querying method was not originally employed for the production of the 2002 OST study because of the complexity of delineating all research topics covering environmental research by only using terms in titles.

1.2.2 Journal dataset and classification update

Two main tasks were performed to update the environmental journal dataset used in the OST 2002 bibliometric study. First, the journals indexed in the bibliographic databases were reviewed to identify[8] new or additional environment-related research journals. This updating was performed within the parameters and definitions of the OST 2002 study's classifications with a view to maintaining the study's rationale and method of analysis.

Second, the original journal classification by specialty was revised. In the course of the revision, it became clear that the original OST classifications could be modified so as to provide more appropriate descriptions of environmental research specialties. Without invalidating the original classification, we made three modifications: 1) creating a new category, *Environmental Planning, Management & Conservation*; 2) withdrawing the category *Social Science*; and 3) explicitly including pollution issues in the original classification P*ollution, Environmental Toxicology & Healt*h.

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[7] Mutually exclusive classification means that any journal can belong to only one category or specialty.

[8] The aims and scopes of these new or additional journals, as well as samples of article titles, were examined in the update process.

Because the first study concluded that journals dedicated to environmental issues were under-represented within the category of *Social Science*, the category was removed for this study. Instead, in this update these journals were classified under other categories according to their particular scope and contribution to environmental research.

Three minor adaptations that did not have any affect on the categories but that clarified the scope of the classifications and allowed for more precise classification of some of the journals that were in the general category were also incorporated in the present study: 1) *Meteorology & Atmospheric Sciences* was changed to *Climate, Meteorology & Atmospheric Sciences*; 2) *Environmental Engineering* was changed to *Environmental Engineering, Chemistry & Biotechnology*; and 3) *Ecology* was changed to *Ecology & Biological Resources*.

This new set of journal classifications includes seven environmental research specialities. The 2002 study covered 306,746 papers and 317 journals, while the updated dataset comprises a total of 580,446 scientific papers from 432 journals (Table I). The names of the journals are listed, by specialty, in Appendix A.

Originally, the journal dataset covered 59% of Environment Canada's total production, while the updated dataset covers slightly more than 70% of the Department's output over the same period.

Table I Number of journals and papers by environmental research specialty, 1980–2004

Specialty	No. of journals	No. of papers
Climate, Meteorology & Atmospheric Sciences	52	77,563
Ecology & Biological Resources	105	147,979
Environmental Engineering, Chemistry & Biotechnology	39	60,388
Environmental Planning, Management & Conservation	77	52,788
Environmental Sciences - General	52	67,805
Pollution, Environmental Toxicology & Health	73	102,685
Water Resources	36	71,238
TOTAL	**434**	**580,446**

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

1.2.3 Scientometric indicators

The Thomson Scientific databases (including SCI and SSCI) provide the addresses of all authors listed in scientific papers; this enables the precise computation of a number of statistics and scientometric indicators that would otherwise be difficult or, in some cases, impossible to perform. In particular, national and international collaboration rates and collaboration networks between countries can only be analysed when all addresses are compiled. For the present study, statistics were produced based on the following indicators:

- Number of papers: The number of scientific papers with authors that are associated to geographic areas (as based on author addresses; e.g., countries and cities), sectors, or organizations.

- **Growth:** This is calculated based on countries' percentages of growth between the total outputs achieved during two 5-year periods: 1995–1999 and 2000–2004. This indicates the appreciation of countries' growth during the last decade.
- **Collaboration rate:** This is an indicator of the relative importance of inter-institutional collaboration (both national and international). The rate is computed by dividing the number of papers with at least two institutions in the address field by the country's total papers.
- **National collaboration rate:** This is an indicator of the relative intensity of collaboration within a country. The rate is calculated by dividing the number of papers with at least two institutional author addresses within the country by the country's total number of papers.
- **International collaboration rate:** This is an indicator of the relative intensity of collaboration between and among countries. The rate is calculated by dividing the number of papers with at least one author address in a foreign country by the entity's total number of papers.
- **Average relative impact factor (ARIF):** This indicator is a proxy for the quality of the journals in which an entity publishes. Each journal has an impact factor (IF) which is calculated annually by Thomson Scientific based on the number of citations it receives relative to the number of papers it publishes. The IF of papers is calculated by ascribing to them the IF of the journals in which they are published. In order to account for different citation patterns across fields and subfields of science (e.g., there are more citations in biomedical research than mathematics), each paper's IF is then divided by the average IF of the papers in its particular subfield in order to obtain a Relative Impact Factor (RIF). The ARIF of a given entity is computed using the average RIF of each paper belonging to it. When the ARIF is above 1, it means that an entity scores better than the world average; when it is below 1, an entity publishes in journals that are not cited as often as the world average.
- **Specialization index (SI):** This is an indicator of the intensity of research of a given geographic or organizational entity (e.g., a country) in a given research area (domain, field) relative to the intensity of the reference entity (e.g., the world) in the same research area. The SI can be formulated as follows:

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

$\mathbf{X_S}$ = Papers from entity X in a given research area (e.g., Canada in agriculture)

$\mathbf{X_T}$ = Papers from entity X in a reference set of papers (e.g., Canada in the whole database)

$\mathbf{N_S}$ = Papers from the reference entity N in a given research area (e.g., the world in agriculture)

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

An index value above 1 means that a given entity is specialized relative to the reference entity, while an index value below 1 means the opposite.

- **Visualization of collaboration networks:** A square matrix was built from the number of papers co-authored by all pairs of the top 50 institutions in the period 1995–2004. The software programs UCINET and NetDraw (Analytic Technologies) were used to process data and produce a representation of the strengths of the relationships between the top institutions in environmental research. A "spring-embedding" algorithm was used to establish the relative locations of the institutions in the visual representation. Each node is an institution, represented by a circle with a size proportional to its number of papers in environmental research. Links between nodes represent collaboration between institutions with a minimum of 25 papers for the 10-year period. The width of the links is proportional to the number of collaborations between the two institutions. Because the algorithm attempts to closely position those countries that have stronger collaboration patterns in the two-dimensional representation, the length of the links (lines) cannot be used as an objective measurement of their relation. Groups of institutions were identified using faction analysis, and the resulting cluster was represented by assigning group members the same color. In fact, institutions of the same color have more similar patterns of collaboration than other institutions that may be closer in a two-dimensional representation. Manual adjustments were made to increase readability. ■

2 Environmental Research at the International Level

This section analyzes trends in world environmental research over the last 25 years. Based on selected scientometric indicators, Canada is benchmarked against other leading countries to provide a comprehensive picture of its relative position in the field. Finally, the world's most active institutions in the field are listed to highlight the relative position of Canadian institutions.

2.1 Global trends in environmental research

The number of scientific papers related to environmental research that are published annually in the world increased steadily over the 25-year period, from slightly over 15,000 papers in 1980 to roughly 35,000 papers in 2004 (Figure 2). This represents an annual average increase of 4% over the period. This increase is greater than the average annual increase in scientific output generally (2.3%) and greater than the increase in most established fields of research. However, it is smaller than the increase in other, more recent fields, such as biotechnology, nanotechnology, and genomics. As is generally the case for scientific papers, the majority of environment-related papers come from a small group of countries. Over the 25-year period, 13 countries authored or co-authored 86% of all scientific papers in the field.

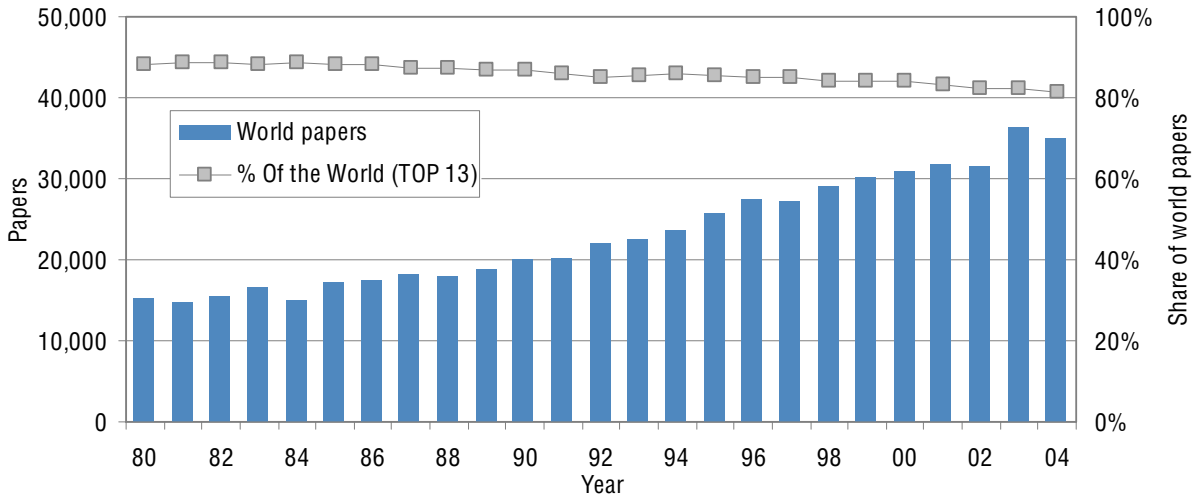

Figure 2 World scientific papers and share of the TOP 13 countries in environmental research, 1980–2004

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

As Figure 2 shows, the predominance of these 13 countries has been slowly decreasing over the period. This is related to the generally slow growth of the most important countries, most notably the US, and the rapid growth of many newcomers, such as the Republic of Korea, Turkey, Mexico, Argentina, Brazil, and other, smaller countries that are not included in the graph (Figure 3). Nevertheless, these 13 countries still clearly lead the field and will thus be used to contextualize Canadian output.

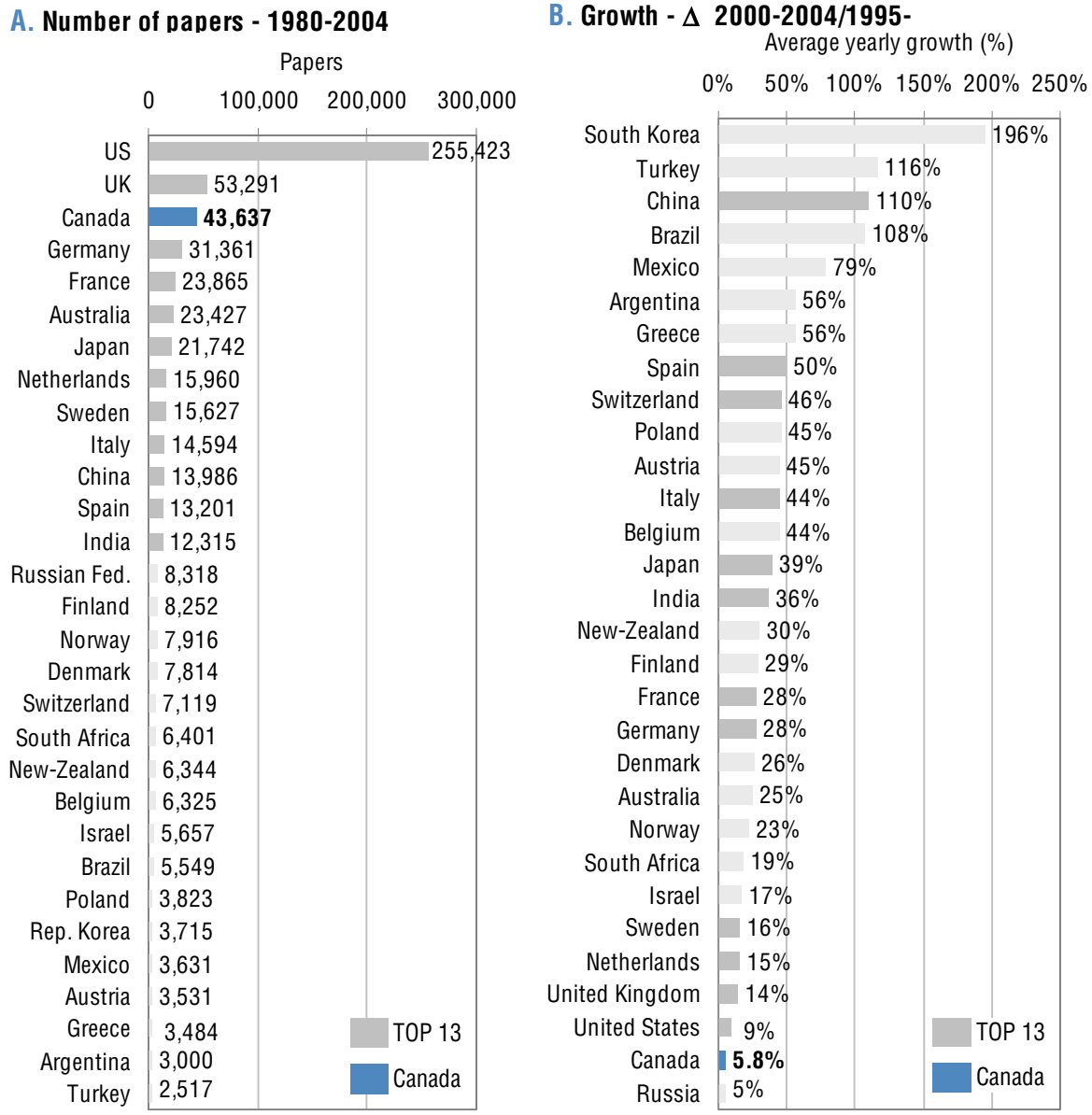

Figure 3 Number of papers (A) and annual average growth* (B) in environmental research by country, 1980–2004

Note: *Growth has been calculated from the ratio between the output of the five-year period 2000–2004 and the total output of the five-year period 1995–1999.

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

Canada is a major player in environmental research. It ranked third, behind the US and the UK and ahead of Germany, during the 25-year period. However, since 2003, Germany has been closing the gap, and China is also threatening Canada's position. China had 14% fewer papers than Canada in 2004, but has shown an average annual increase of 110% between the 1995–1999 and 2000–2004 periods compared to Canada's 5.8%. If these trends continue, China will probably have overtaken Canada at the time of writing this report (2006).

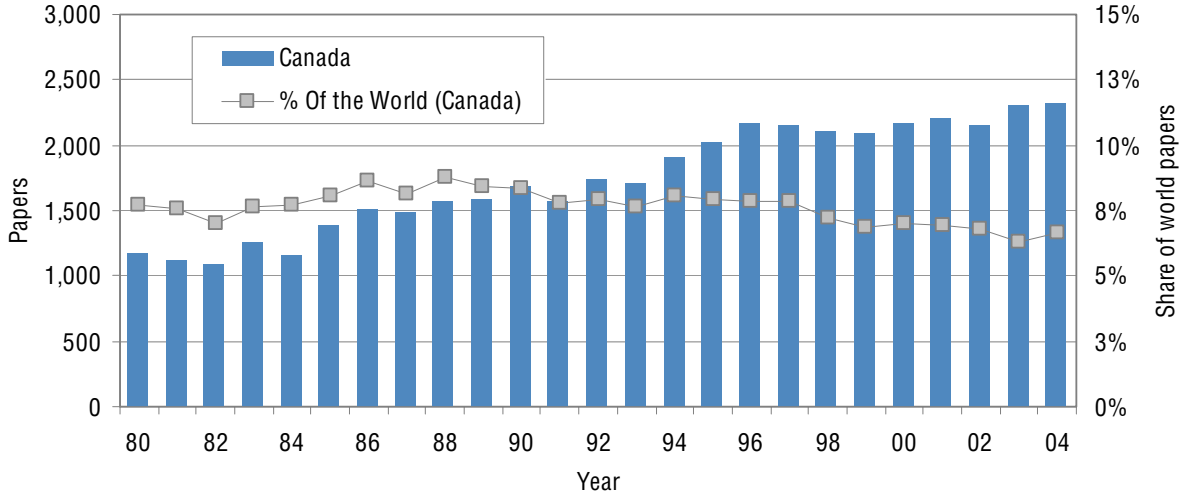

Figure 4 Number and share of Canadian papers in environmental research, 1980–2004

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

As shown in Figure 4, after 1996 Canada's scientific output in environmental research stopped growing as exponentially as it had been, with only a small net increase since that year. The actual data do not allow for the precise forecasting of future output, but it is unlikely that there will be a period of major growth in papers in Canada unless there are significant transformations in the Canadian scientific system. Moreover, when computed against the total amount of Canadian papers, the percentage of papers in environmental research is shown to have been slowly decreasing since 1988.

2.2 Benchmarking environmental research

The number of scientific papers published by a country in a given field provides a valuable indication of its research activity in that field. But this indicator is correlated with other scientific production factors, including number of researchers, R&D expenditure, and even gross domestic product, and does not take into account the impact or the quality of the papers surveyed. In order to obtain a synthesized metric for the ranking of Canada among the 13 leading countries, four indicators were computed and combined in a multicriteria analysis. The number of papers was used as a first indicator, but was also relativized by population (the second indicator) and by the country's general scientific output (or the SI, the third indicator). A fourth indicator, based on the number of citations to journals in which the papers are published, was also included in the analysis to provide a proxy for the impact of the papers (ARIF).

2.2.1 Number of papers

Table II presents the number of papers in environmental research for the selected countries. The US is the clear leader, with almost five times more papers than the second most highly ranked country. Although the US lead is much smaller when it is weighted per capita (Section 2.2.2) or if the intensity of the US output in science (in general) is taken into account (Section 2.2.3), almost one in two

scientific papers in environmental research has a US author. The UK, Canada, and Germany are also important in the field. Canada ranked third for number of papers, which is a relatively strong ranking considering its seventh position in science. With the exception of China, a country in which the number of papers is increasing very rapidly, the positions of the remaining countries remained fairly stable over the period[9].

Table II Papers by 13 leading countries, 1980–2004

Rank	Country	1980-1984 Papers (Rk)	1985-1989 Papers (Rk)	1990-1994 Papers (Rk)	1995-1999 Papers (Rk)	2000-2004 Papers (Rk)	1980-2004 Papers (Rk)
1	US	41,020 (1)	44,704 (1)	49,476 (1)	57,427 (1)	62,796 (1)	255,423 (1)
2	UK	7,207 (2)	7,825 (2)	9,098 (2)	13,614 (2)	15,547 (2)	53,291 (2)
3	**Canada**	**5,803 (3)**	**7,547 (3)**	**8,609 (3)**	**10,531 (3)**	**11,147 (3)**	**43,637 (3)**
4	Germany	2,994 (4)	3,664 (4)	5,514 (4)	8,426 (4)	10,763 (4)	31,361 (4)
5	France	1,859 (7)	2,613 (7)	4,160 (5)	6,688 (5)	8,545 (5)	23,865 (5)
6	Australia	2,759 (5)	3,397 (5)	4,140 (6)	5,824 (6)	7,307 (8)	23,427 (6)
7	Japan	1,895 (6)	2,646 (6)	3,746 (7)	5,618 (7)	7,837 (6)	21,742 (7)
8	Netherlands	1,182 (11)	1,905 (10)	3,144 (8)	4,517 (8)	5,212 (11)	15,960 (8)
9	Sweden	1,473 (9)	2,371 (8)	2,982 (9)	4,070 (9)	4,731 (12)	15,627 (9)
10	Italy	1,274 (10)	1,488 (11)	2,482 (10)	3,830 (11)	5,520 (10)	14,594 (10)
11	China	325 (13)	819 (13)	1,480 (13)	3,669 (12)	7,693 (7)	13,986 (11)
12	Spain	326 (12)	842 (12)	2,207 (12)	3,933 (10)	5,893 (9)	13,201 (12)
13	India	1,826 (8)	2,177 (9)	2,324 (11)	2,536 (13)	3,452 (13)	12,315 (13)
	World	**76,881**	**89,716**	**108,273**	**139,780**	**165,796**	**580,446**

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

2.2.2 Number of papers per capita

When the population of countries is taken into consideration, the representation of environmental research changes appreciably. Very populous countries tend to rank much lower, while smaller countries move up in the ranking. Based on population size, Sweden ranked first in number of papers, with an average of roughly 72 papers per million inhabitants per year over the period (Table III). Canada was a fairly close second, with just over 61 papers per million inhabitants per year. Australia ranked third, with nearly 54 papers, followed by the Netherlands (42 papers), the US (40 papers) and the UK (37 papers). It is not surprising that, due to their enormous populations, India and China ranked very low. This picture stayed quite constant over the period, with some exceptions. Sweden's number of papers per million inhabitants tripled over the period, and this trend will likely continue. Sweden was already well ahead in the 2000–2004 period and had more than twice as many papers per capita in 2004 than the next ranked country, Canada (data not shown). Canada ranked first at the beginning of the period, but its research output has not continued to grow as fast as that of Sweden and Australia. The Netherlands' output is also increasing rapidly, and the country is expected to overtake Canada in the future.

[9] Although China was 13th among the 13 leaders in the first three 5 year periods, it was in fact 23rd, 18th and 14th respectively in the world.

Table III Papers per capita by 13 leading countries, 1980–2004

Rank	Country	1980-1984 Papers/ 10^6 inhab. (Rk)	1985-1989 Papers/ 10^6 inhab. (Rk)	1990-1994 Papers/ 10^6 inhab. (Rk)	1995-1999 Papers/ 10^6 inhab. (Rk)	2000-2004 Papers/ 10^6 inhab. (Rk)	1980-2004 Papers/ 10^6 inhab. (Rk)
1	Sweden	35.4 (3)	56.2 (2)	67.0 (1)	91.5 (1)	105.7 (1)	72.1 (1)
2	**Canada**	**46.1 (1)**	**56.8 (1)**	**56.8 (2)**	**69.5 (2)**	**69.9 (3)**	**61.3 (2)**
3	Australia	36.4 (2)	41.8 (3)	44.6 (3)	62.8 (3)	74.8 (2)	53.9 (3)
4	Netherlands	16.5 (6)	26.0 (6)	40.3 (4)	57.8 (4)	64.7 (4)	42.1 (4)
5	US	35.3 (4)	36.8 (4)	36.3 (5)	42.1 (6)	43.7 (6)	39.5 (5)
6	UK	25.6 (5)	27.5 (5)	30.9 (6)	46.3 (5)	51.9 (5)	36.8 (6)
7	France	6.8 (8)	9.4 (8)	14.2 (7)	22.8 (7)	28.5 (8)	16.7 (7)
8	Germany	7.7 (7)	9.4 (7)	13.5 (8)	20.6 (8)	26.1 (9)	15.6 (8)
9	Spain	1.7 (11)	4.3 (11)	11.1 (9)	19.7 (9)	29.4 (7)	13.4 (9)
10	Italy	4.5 (9)	5.2 (9)	8.6 (10)	13.3 (10)	19.1 (10)	10.2 (10)
11	Japan	3.2 (10)	4.3 (10)	5.9 (11)	8.9 (11)	12.3 (11)	7.0 (11)
12	India	0.5 (12)	0.5 (12)	0.5 (12)	0.5 (13)	0.7 (13)	0.6 (12)
13	China	0.1 (13)	0.1 (13)	0.2 (13)	0.6 (12)	1.2 (12)	0.5 (13)
	World	**3.3**	**3.6**	**4.0**	**4.8**	**5.3**	**4.3**

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

2.2.3 Specialization Index

Another way to relativize papers in environmental research is to consider them within the context of countries' outputs in science generally, which indicates the level of specialization of a country in environmental research. The SI is computed by dividing the percentage of a country's papers in the field by the percentage of papers the country contributes to world science in general. A country that has an SI of 2 has a share of papers in environmental research twice that of its papers in science in the reference database. Table IV presents the SI of the benchmarked countries both by 5-year period and over the entire 25-year period. With this indicator, Sweden ranked first over the entire period, but its score (1.542) was more or less the same as that of Canada, which ranked second (1.541). Australia was third, with a score of 1.41. Again, India and China ranked lowest, with SIs of 0.69 and 0.46, respectively, indicating that these countries were producing very little in the field of environmental research compared to their general output in science. This pattern was fairly stable over time, with the exception of the US and Germany, which slowly traveled downward in measures of SI, and the UK, which had a steadily increasing SI.

Table IV SI of 13 leading countries, 1980–2004

Rank	Country	1980-1984 SI (Rk)	1985-1999 SI (Rk)	1990-1994 SI (Rk)	1995-1999 SI (Rk)	2000-2004 SI (Rk)	1980-2004 SI (Rk)
1	Sweden	1.52 (2)	1.59 (2)	1.56 (1)	1.48 (2)	1.52 (1)	1.54 (1)
2	**Canada**	**1.61 (1)**	**1.64 (1)**	**1.53 (2)**	**1.56 (1)**	**1.47 (2)**	**1.54 (2)**
3	Australia	1.14 (4)	1.44 (3)	1.48 (3)	1.42 (3)	1.39 (3)	1.41 (3)
4	Netherlands	0.89 (6)	1.03 (6)	1.21 (4)	1.23 (4)	1.19 (4)	1.17 (4)
5	US	1.30 (3)	1.22 (4)	1.14 (5)	1.11 (5)	1.08 (6)	1.14 (5)
6	UK	0.57 (10)	0.77 (8)	1.06 (7)	1.07 (6)	1.15 (5)	1.10 (6)
7	France	0.85 (7)	1.15 (5)	1.13 (6)	1.03 (7)	1.05 (7)	1.03 (7)
8	Germany	1.04 (5)	0.98 (7)	0.94 (8)	1.02 (8)	1.01 (8)	1.00 (8)
9	Spain	0.63 (9)	0.73 (9)	0.64 (12)	0.77 (9)	0.81 (10)	0.83 (9)
10	Italy	0.72 (8)	0.64 (10)	0.70 (9)	0.70 (12)	0.76 (11)	0.74 (10)
11	Japan	0.48 (12)	0.57 (11)	0.68 (10)	0.76 (10)	0.83 (9)	0.72 (11)
12	India	0.53 (11)	0.56 (12)	0.68 (11)	0.72 (11)	0.76 (12)	0.69 (12)
13	China	0.39 (13)	0.41 (13)	0.42 (13)	0.44 (13)	0.50 (13)	0.46 (13)
	World	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

2.2.4 Average relative impact factor - ARIF

The ARIF is a proxy for the quality of scientific production and is an indicator of expected scientific impact. It is computed using the number of citations to the journals in which papers are published. Table V presents ARIF scores for the 13 countries. The US led for most of the period; however, in the last 5-year period, it was matched by the UK. Canada ranked second on average for the entire period, but it alternated between the second and third positions between 5-year periods.

Table V ARIF of 13 leading countries, 1980-2004

Rank	Country	1980-1984 ARIF (Rk)	1985-1999 ARIF (Rk)	1990-1994 ARIF (Rk)	1995-1999 ARIF (Rk)	2000-2004 ARIF (Rk)	1980-2004 ARIF (Rk)
1	US	1.09 (1)	1.09 (1)	1.11 (1)	1.10 (1)	1.08 (2)	1.09 (1)
2	**Canada**	**1.02 (3)**	**1.07 (2)**	**1.08 (2)**	**1.08 (3)**	**1.07 (3)**	**1.07 (2)**
3	Netherlands	1.08 (2)	1.01 (4)	1.03 (3)	1.08 (2)	1.06 (4)	1.06 (3)
4	UK	1.01 (4)	0.98 (6)	1.00 (4)	1.03 (5)	1.08 (1)	1.03 (4)
5	Sweden	1.01 (5)	1.01 (3)	0.99 (5)	1.00 (6)	1.04 (6)	1.01 (5)
6	France	0.87 (9)	0.85 (12)	0.97 (6)	1.04 (4)	1.05 (5)	1.00 (6)
7	Spain	0.70 (13)	0.93 (8)	0.92 (9)	0.99 (7)	0.99 (8)	0.97 (7)
8	Australia	0.95 (8)	0.95 (7)	0.97 (7)	0.95 (9)	0.99 (9)	0.97 (8)
9	Japan	0.99 (6)	1.00 (5)	0.92 (10)	0.92 (10)	0.97 (10)	0.96 (9)
10	Germany	0.82 (10)	0.90 (9)	0.87 (11)	0.97 (8)	0.99 (7)	0.94 (10)
11	China	0.97 (7)	0.90 (10)	0.94 (8)	0.90 (12)	0.94 (11)	0.92 (11)
12	Italy	0.78 (12)	0.86 (11)	0.86 (12)	0.90 (11)	0.92 (12)	0.89 (12)
13	India	0.81 (11)	0.84 (13)	0.79 (13)	0.77 (13)	0.82 (13)	0.81 (13)
	World	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

India, at 0.81, had the lowest ARIF for the entire period. Italy performed worse in environmental research than in science generally, while Japan, even with an SI below 1, was doing better than in science generally (comparative data are not presented). Although the positions of some countries changed across the period, the global picture has remained fairly stable, with the exception of France, which had an ARIF that increased considerably (from 0.87 in 1980–84 to 1.05 in 2000–2004).

2.2.5 Multicriteria analysis

Ranks for the multicriteria analysis are calculated using the average of ranks for all four indicators, each indicator having the same weight. When all of these indicators are combined, it is revealed that Canada consistently ranked 1st across the period, followed by the US, which was consistently 2nd (Table VI). The next four positions were varyingly occupied by the UK, Australia, Sweden, and the Netherlands; Italy, India, and China lagged behind, occupying the last three spots. Although the positions of some countries fluctuated over the period, only the Netherlands (which went from the 6th to the 4th position in the last 15 years), Japan (which fell from 8th to 10th in the same period), and China (which went from 13th to 10th in the last 5 years) demonstrated significant movement.

Table VI Multicriteria ranking of 13 leading countries, 1980–2004

Rank	1980-1984	1985-1999	1990-1994	1995-1999	2000-2004	1980-2004
1	**Canada**	**Canada**	**Canada**	**Canada**	**Canada**	**Canada**
2	US	US	US	US	US	US
3	Australia	UK	Sweden	Australia	UK	UK
4	UK	Australia	Australia	Sweden	Netherlands	Australia
5	Sweden	Sweden	UK	Netherlands	Australia (5)	Sweden
6	Netherlands	Netherlands	Netherlands	UK	Sweden (5)	Netherlands
7	Germany	Germany	Germany	France	France	France
8	France	Japan	Japan	Germany	Germany (8)	Germany (8)
9	Japan	France	France	Spain	Spain (8)	Spain (8)
10	Spain	India	Spain	Japan	China (10)	Japan
11	India (11)	Italy	Italy	Italy	Japan (10)	Italy
12	Italy (11)	China	India	India	Italy	China
13	China	Spain	China	China	India	India

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

2.3 Specialties of environmental research

Environmental research is a vast interdisciplinary research field covering many topics. This section uses the classification[10] developed for Environment Canada to identify Canada's strengths and weaknesses compared to other countries. This classification is based on the journals' aims and scopes, and is thus less precise than would be a classification based on article content; however, it is adequate for a general analysis. Figure 5 provides positional representations for the 13 leading

[10] Please see the section on methods for more information on this classification.

countries in seven specialties of environmental research during the 1995-2004 period. The scientometric positional analysis combines number of papers (area of circle), expected scientific impact as measured by the ARIF (*y*-axis), and specialization[11] as measured by the SI (*x*-axis). Countries in the upper right quadrant are specialized and have higher expected impacts in the specialty. In the lower right quadrant are the countries that are specialized but that have lower expected impacts than the world average. The upper left quadrant includes countries that are not specialized but that have high expected impacts. Finally, countries in the lower left quadrant are not specialized and do not have much expected impact. The position of the 13 countries for each specialty is described below.

2.3.1 Climate, Meteorology & Atmospheric Sciences

Germany, France, the US, and the UK are specialized and have good expected impacts in research related to climate, meteorology, and atmospheric sciences (Figure 5 A). Germany is the most specialized, with a share of papers in this specialty almost 50% above the word average. The US has a slightly higher impact than the other four countries. Countries with better-than-average expected impacts, but without specialization in this area, are the Netherlands and Sweden. Japan and India are specialized in the field but have the lowest expected impacts among the top 13. Canada has an average expected impact and is not specialized in this branch of research.

2.3.2 Ecology & Biological Resources

Canada, Sweden, and the UK have very good expected impacts and good specializations in research related to ecology and biological resources, with Sweden having the highest expected impact of the 13 countries (Figure 5 B). The Netherlands also has a high expected impact but is not specialized. Australia is the most specialized in this area and has an expected impact similar to the world average. China and India are not specialized in the field and have low expected impacts.

2.3.3 Environmental Engineering, Chemistry & Biotechnology

Japan leads in research related to engineering, chemistry, and biotechnology with a fairly high level of specialization and the highest expected impact. Spain and France also have good expected impacts and are specialized (Figure 5 C). The Netherlands has the second highest expected impact of the 13 countries but it is not specialized. India is the most specialized country in this area, with a share of papers more than twice that of the world, but it has a small expected impact. China and Italy are both specialized in this branch of research, China having an average expected impact and Italy having the lowest expected impact in the group. Canada is not specialized in this area and has an expected impact slightly under the world average.

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[11] SI is calculated on the countries' own totals for environmental science and thus a country cannot be specialized in every specialty.

2.3.4 Environmental Planning, Management & Conservation

The UK is second in both specialization and impact, making it the best positioned country in this area of environmental research (Figure 5 D). The US has a good expected impact and is specialized. Australia is the most specialized in this area, but it has the lowest expected impact. The Netherlands has the highest expected impact but is slightly under-specialized. France, Spain, and Germany have good expected impacts but are not specialized in this area. In fact, within the leading 13 countries, only Australia, the US, and the UK are specialized in this branch of environmental research. Japan, Italy, Germany, and France are not very specialized in this area, with two-to-three times fewer papers than might be expected given their general output in environmental research. Canada has an expected impact just over the world average and an SI just under the world score.

2.3.5 Environmental Sciences – General

No country combines high expected impact with specialization in science journals dedicated to multiple and broad environmental issues (Figure 5E). The US has a very high impact but a share of papers in this specialty similar to that of the world. France also has a good expected impact but is not specialized in this area. China and Sweden are relatively highly specialized in this specialty, but they have low expected impacts. Canada is third in terms of impact, but it is not specialized in this branch.

2.3.6 Pollution, Environmental Toxicology & Health

Sweden, Canada, and the Netherlands are specialized in this area and have good expected impacts—Canada with the highest expected impact of the selected countries, and Sweden showing the highest specialization (Figure 5 F). China, India, and Japan are also highly specialized but have low expected impact—particularly India, which has the lowest impact among the top 13 countries. Australia has a good ARIF but is clearly not specialized in this area.

2.3.7 Water Resources

France is very specialized in research related to water resources and has a good scientific impact. Italy is less specialized, but it has a higher impact. China is also specialized and has a higher expected impact than the world average in this specialty (Figure 5 G). The US and Canada have the highest expected impact in the group but are not specialized. The Netherlands is the most specialized, but it has an expected impact in this area below the world level.

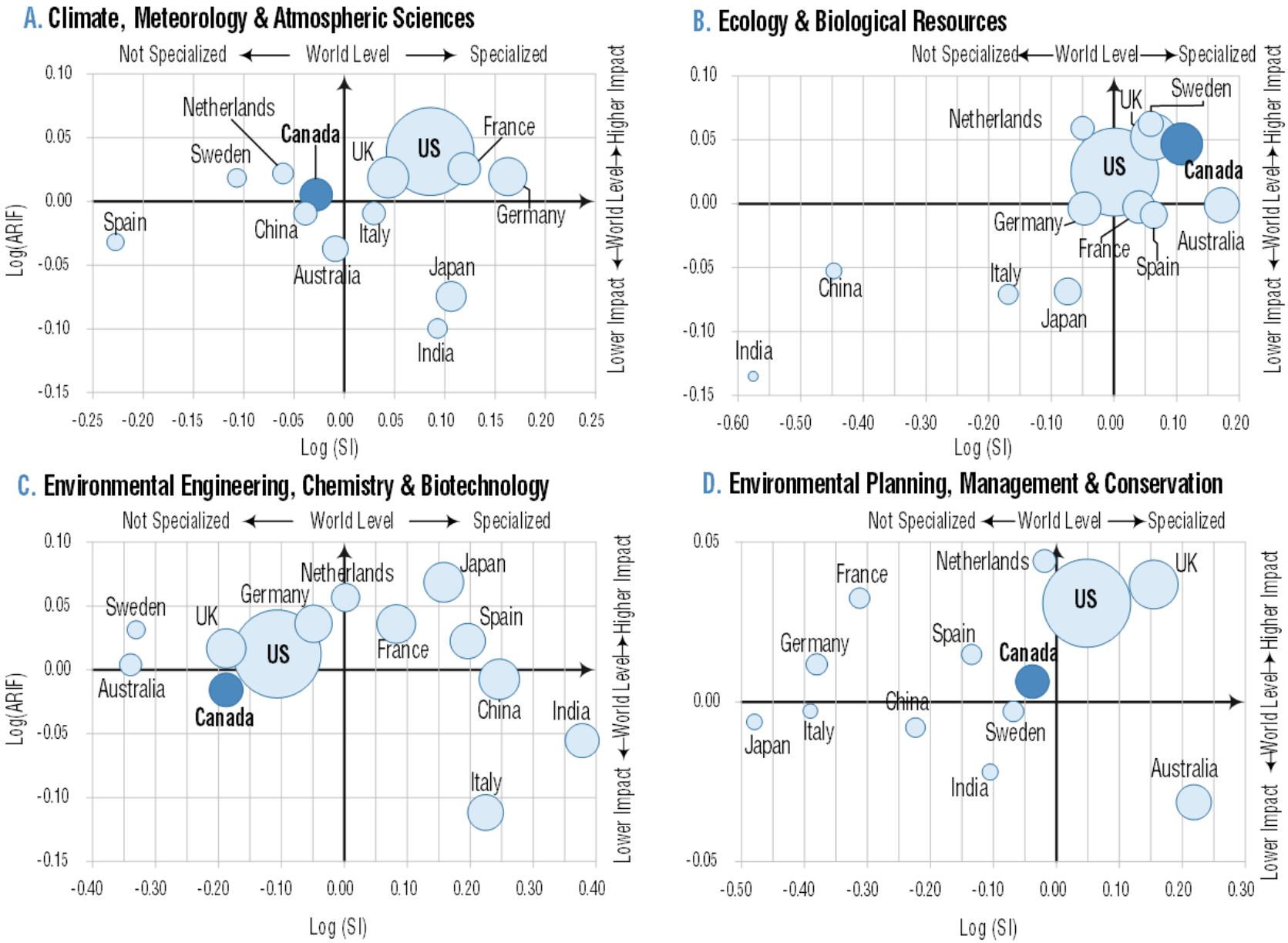

Figure 5 Scientometric positional analysis: countries' specialization and scientific impact by specialty, 1995–2004

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

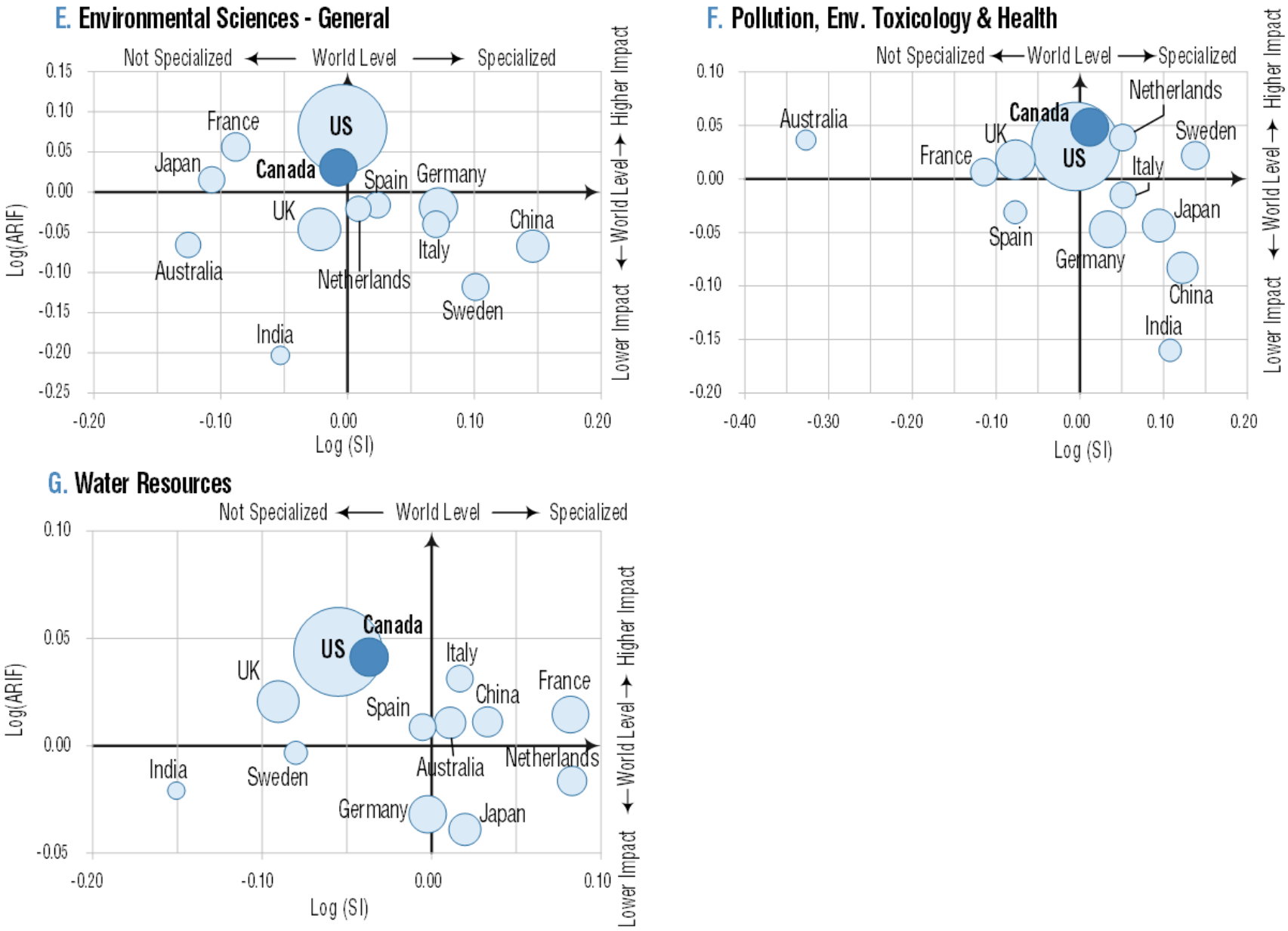

Figure 5 (cont'd) Scientometric positional analysis: countries' specialization and scientific impact by specialty, 1995–2004

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

Table VII presents Canada's evolution in the various specialties using a multicriteria analysis. Canada ranked first for the entire 25-year period in environmental research. It was first in *Ecology & Biological Resources* for each 5-year period and, with the exception of 1995–1999, was first in *Water Resources*. Over the entire period, Canada ranked first in *Pollution, Environmental Toxicology & Health*. Canada also performed well in *Environmental Sciences – General*, a specialty for which its position improved from fifth place in 1985–1989 to first place in the two last periods, achieving an overall second position for the whole period. Canada ranked fifth overall for the three remaining specialties. In *Environmental Engineering, Chemistry & Biotechnology*, Canada's ranking fell between the third and fourth 5-year periods to ninth position for the last 5-year period.

Table VII Multicriteria ranking of Canada in the different specialties of environmental research by five years period and overall, 1980-2004

Specialty	1980-1984	1985-1999	1990-1994	1995-1999	2000-2004	1980-2004
Climate, Meteorology & Atmospheric Sciences	3	4	4	5	2	**5**
Ecology & Biological Resources	1	1	1	1	1	**1**
Environmental Engineering, Chemistry & Biotechnology	2	2	3	8	9	**5**
Environmental Planning, Management & Conservation	5	3	3	5	5	**5**
Environmental Sciences - General	3	5	3	1	1	**2**
Pollution, Environmental Toxicology & Health	3	2	1	2	1	**1**
Water Resources	1	1	1	2	1	**1**
Environmental science (Total)	**1**	**1**	**1**	**1**	**1**	**1**

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

2.4 International collaboration

In general, scientific collaboration between countries is on the rise. The percentage of papers co-authored by researchers from two countries is lower in environmental research than in science in general, though it has been growing. The rate of international collaboration is often perceived as indicative of quality of research and is thus encouraged by government programs and other funding bodies. However, there is a scale effect[12] in international collaboration rates—large countries usually collaborate less than smaller countries. Table VIII presents collaboration rates for the 13 leading countries between 1980 and 2004. France had the highest rates in each 5-year period and for the entire 25 years. During the last 5-year period, 47.1% of France's papers were co-authored with at least

[12] Everything being equal, the larger the scientific population of a country is, the more likely researchers will find peers to collaborate within that country.

one foreigner, a score similar to that of Germany (46.3%), the Netherlands (46.8%), and Sweden (43.7%). Canada was not far behind, with 35.9% of international collaboration during the last 5 years. The US and India were at the tail end, with 22.1% and 18.5%, respectively, during the last 5 years.

Table VIII International collaboration rates of the 13 leading countries, 1980–2004

Rank	Country	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	1980-2004
1	France	15.5%	20.4%	30.0%	38.4%	47.1%	36.3%
2	Germany	13.4%	20.4%	25.7%	36.3%	46.3%	33.8%
3	Netherlands	10.7%	17.1%	24.5%	34.9%	46.8%	32.8%
4	Sweden	15.9%	17.5%	25.8%	36.8%	43.7%	31.9%
5	China	31.7%	35.8%	37.0%	29.4%	31.6%	31.8%
6	Italy	10.7%	15.8%	24.6%	31.6%	37.3%	29.1%
7	Spain	9.5%	16.5%	19.7%	29.8%	33.0%	28.2%
8	United Kingdom	10.8%	14.8%	22.6%	29.7%	39.7%	26.6%
9	**Canada**	**12.5%**	**15.1%**	**20.9%**	**29.9%**	**35.9%**	**24.8%**
10	Australia	10.5%	13.2%	18.3%	24.9%	32.5%	22.7%
11	Japan	6.6%	12.4%	15.4%	23.1%	29.5%	21.3%
12	United States	5.1%	7.8%	11.3%	16.6%	22.1%	13.5%
13	India	5.5%	7.5%	12.4%	14.0%	18.5%	12.6%
	Top 13	**12.2%**	**16.5%**	**22.2%**	**28.9%**	**35.7%**	**26.6%**

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

Table IX presents the number of Canadian collaborations and the main collaborators in environmental research. The US is Canada's most important collaborator, as almost one in two international collaborations were with US researchers (6,173 papers in 25 years). The UK is the next most important, with 1,056 papers co-authored by Canada and the UK, followed by Germany (716 papers) and France (702 papers). The picture has remained the same over time, with the exception of Australia, which was the 3rd most important collaborator in 1980–2004 but was only the 5th most important in the last 5 years. Germany went from the 6th position to the 3rd, and China moved upward, from 15th to 7th most important country in this measure.

The number of papers coauthored by Canada and China has increased rapidly. In general, the number of collaborations with a given country is correlated with that country's output in the field and its propensity for collaboration. However, there are reasons, such as geographical proximity and common language, that lead to some countries collaborating more with one another than might be expected based on their overall rate of collaborations in the field. An indicator—the preference index (PI)—was designed to measure these privileged patterns of collaboration.

The PI is computed by dividing the number of observed collaborations between two countries with the number that would be expected if collaborators were selected randomly. Table IX presents PIs for Canada and its most important collaborators. A score over 1 denotes a preference, while a score under 1 denotes a relatively weak linkage between the countries. The US and Canada were strongly linked, more than twice what would be expected if collaborators were selected at random. New Zealand, with a PI of 1.26, was also preferred for collaboration by Canadian researchers. Australia

and Japan had a PI score higher than 1 and thus collaborated more often with Canada than would be expected if there were no organized patterns of collaborations. The PI of 0.99 for Canada and China is quite remarkable given the geographical and cultural differences between the two countries, and this index value has increased over time. At the other end of the scale, Canada had weak relationships with Italy (0.41) and Spain (0.41), two countries that ranked relatively low in the multicriteria analysis.

Table IX Number of collaboration and preference index of Canada with its main collaborators, 1980–2004

	Collaborative papers						Preference Index
Collaborator	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	1980-2004	1980-2004
US	462	703	1,026	1,780	2,202	6,173	2.09
UK	69	91	166	296	434	1,056	0.80
Germany	11	33	97	254	321	716	0.68
France	32	51	107	208	304	702	0.84
Australia	39	27	88	142	181	477	1.06
Japan	18	37	51	156	157	419	1.02
China	3	28	55	101	155	342	0.99
Sweden	9	23	45	107	145	329	0.65
Norway	9	24	48	75	127	283	0.92
Netherlands	6	21	53	87	112	279	0.53
New-Zealand	11	27	36	74	84	232	1.28
Denmark	10	8	22	79	111	230	0.70
Switzerland	11	10	38	46	98	203	0.70
Russia	2	4	33	76	83	198	0.76
Italy	3	20	26	55	74	178	0.41
Finland	2	10	19	56	79	166	0.62
Spain		4	13	58	68	143	0.41
Brazil	11	10	14	36	66	137	0.74
Belgium	3	6	18	38	70	135	0.49
Mexico	1	5	12	28	73	119	0.97
India	7	13	21	28	44	113	0.89
South Africa		12	25	13	40	90	0.77
Total (N)	**783**	**1,261**	**2,205**	**4,123**	**5,572**	**13,944**	**1.00**

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

2.5 World-leading institutions in environmental research

Not surprisingly, given the dominance of the US in number of papers in environmental research, US institutions essentially dominate the list of leading institutions in the field, with 31 institutions among the world's top 50 institutions in the last 10 years (Table X). US institutions are generally those with the highest impact. The most productive institution is the US National Oceanic & Atmospheric Administration, which produced 28% more papers than the next leading institution, the US Environmental Protection Agency. The next four positions are occupied by US institutions.

Canada is the second most present country in the top 50, with four institutions: Environment Canada (EC), ranked 7th; the Department of Fisheries and Oceans (DFO), ranked 25th; the University of British Columbia (UBC), ranked 28th, and the University of Toronto (UT), 47th. These Canadian institutions have very high ARIFs, particularly when compared to institutions from countries other than the US. In terms of national and international collaboration rates, the US stands out once again, with the highest percentage of national collaboration and the lowest percentage of international collaboration. The likely explanation for this phenomenon is that, as the US accounts for nearly half of the worldwide production of papers, a US researcher choosing at random would have roughly one chance out of two of picking a US colleague to collaborate with. Canada's four most present institutions account for the highest percentage among all Canadian institutions of international collaborations. The French CNRS has the highest international collaboration rate, with more than 50% of papers co-authored with a foreign collaborator, while NASA is the leading institution that collaborates the least internationally (only 21%).

The dominance of US institutions and their propensity to collaborate with each other is depicted in Figure 6. The figure shows the network of collaboration among the top 50 institutions in environmental research worldwide. Each institution is represented by a circle; the size of the circle is determined by the number of inter-institutional collaborations between 1995 and 2004. Links between circles identify pairs of institutions with 25 collaborations or more.

The network is completely dominated by US institutions, which are clustered together and attached to smaller clusters, such as the French-Italian network (three French institutions and one Italian); the Scandinavian network (Lund University, University of Helsinki, and the University of Stockholm), which is very disconnected from the main network; and the Asian network (the Chinese Academy of Science, the University of Tokyo, and Kyoto University). The American cluster is also linked to the Australian CSIRO, the Russian Academy of Science, and other American universities that are outside of the main cluster. Finally, there is a group in the network that does not appear to have links between its institutions that are strong enough to be called a cluster and that comprises only Canadian institutions that have stronger links with each other than with the other institutions.

2.5.1 International collaboration network in environmental research

Figure 6 represents the collaboration network of the world's most collaborative institutions in environmental research. The most active Canadian institution, EC, cannot be differentiated from the US cluster using the usual faction analysis; it also has stronger links with US institutions, even though this institution collaborates more with other Canadian institutions than with foreign institutions. The DFO is probably the only member of a "Canadian cluster" within the international network because it is strongly linked with other Canadian institutions that have relatively weak links with foreign institutions. McGill University and UBC collaborate equally with national and international institutions and have relatively weak links with both DFO and EC. ■

Table X Number of papers, ARIF, national and international collaboration rates of leading institutions in environmental research, 1995–2004

Rk	Institution	Country	Papers	ARIF	Nat't collabo.	Int'l collabo.	Rk 25 Yrs*
1	NOAA - National Oceanic & Atmospheric Admin.	US	4,476	1.14	69.5%	22.2%	*(1)*
2	USEPA- US Environmental Protection Agency	US	3,505	1.17	69.2%	13.4%	*(2)*
3	USDA ARS- Agricultural Research Service	US	3,472	1.10	50.0%	14.6%	*(3)*
4	NASA	US	3,279	1.21	79.0%	32.3%	*(4)*
5	USGS - US Geological Survey	US	3,275	1.18	61.2%	12.5%	*(9)*
6	University of Washington	US	3,142	1.18	52.0%	22.4%	*(5)*
7	**Environment Canada**	**Canada**	**3,033**	**1.14**	**54.7%**	**33.9%**	***(7)***
8	CSIC - Consejo Superior de Investig. Cient.	Spain	2,688	1.11	35.5%	37.7%	*(25)*
9	University of Wisconsin	US	2,662	1.18	51.2%	17.5%	*(6)*
10	University of California, Davis	US	2,640	1.21	43.8%	22.4%	*(8)*
11	University of Colorado	US	2,530	1.17	66.0%	21.9%	*(19)*
12	University of Maryland	US	2,482	1.22	60.0%	21.7%	*(13)*
13	Colorado State University	US	2,269	1.07	55.1%	19.0%	*(14)*
14	University of California, Berkeley	US	2,200	1.23	50.5%	23.0%	*(17)*
15	NCAR - National Center for Atmospheric Res.	US	2,167	1.18	62.7%	33.8%	*(23)*
16	Chinese Academy of Sciences	China	2,150	0.85	32.4%	41.2%	*(43)*
17	Texas A&M University System	US	2,123	1.00	48.8%	17.3%	*(15)*
18	Oregon State University	US	2,119	1.12	56.7%	19.6%	*(16)*
19	Russian Academy of Sciences	Russia	2,044	0.70	17.4%	44.0%	*(12)*
20	USDA FS - Forest Service	US	1,996	0.92	72.1%	13.7%	*(20)*
21	Cornell University	US	1,939	1.18	42.0%	20.4%	*(18)*
22	University of Florida	US	1,850	1.06	45.0%	19.1%	*(21)*
23	University of Arizona	US	1,841	1.16	44.5%	21.2%	*(26)*
24	CSIRO	Australia	1,832	1.06	42.1%	32.4%	*(11)*
25	**Fisheries and Oceans Canada**	**Canada**	**1,826**	**1.16**	**53.4%**	**28.7%**	***(10)***
26	University of Minnesota	US	1,792	1.18	53.0%	16.4%	*(24)*
27	CNRS - Centre national de la recherche scient.	France	1,770	1.12	49.3%	50.2%	*(37)*
28	**UBC - University of British Columbia**	**Canada**	**1,761**	**1.11**	**34.0%**	**34.9%**	***(30)***
29	CNR - Consiglio Nazionale delle Ricerche	Italy	1,718	0.93	54.9%	37.5%	*(40)*
30	University of Illinois	US	1,716	1.12	55.1%	20.0%	*(22)*
31	University of Georgia	US	1,711	1.12	49.5%	15.1%	*(27)*
32	Harvard University	US	1,640	1.13	57.6%	27.6%	*(31)*
33	Centre for Ecology and Hydrology (NERC)	UK	1,621	1.01	54.8%	27.1%	*(38)*
34	INRA - Institut National de la Rech. Agronom.	France	1,605	1.11	39.6%	35.1%	*(42)*
35	Pennsylvania State University	US	1,595	1.11	46.3%	18.2%	*(32)*
36	Lund University	Sweden	1,554	1.06	29.3%	41.7%	*(33)*
37	University of Texas	US	1,546	1.07	49.0%	20.6%	*(28)*
38	ETH - Swiss Federal Institute of Technology	Switzerland	1,530	1.23	34.9%	40.6%	*(57)*
39	North Carolina State University	US	1,453	1.07	52.1%	13.8%	*(34)*
40	University of Michigan	US	1,440	1.15	52.8%	19.7%	*(29)*
41	Michigan State University	US	1,430	1.18	47.6%	21.4%	*(36)*
42	University of Tokyo	Japan	1,426	0.96	55.2%	28.9%	*(62)*
43	University of Helsinki	Finland	1,409	1.10	43.2%	35.8%	*(54)*
44	University of North Carolina	US	1,405	1.16	55.2%	14.9%	*(39)*
45	SLU - Swedish University of Agricultural Sci.	Sweden	1,362	0.98	33.6%	32.7%	*(60)*
46	Imperial College London	UK	1,334	1.11	35.5%	33.6%	*(52)*
47	**University of Toronto**	**Canada**	**1,327**	**1.18**	**35.9%**	**32.7%**	***(41)***
48	UCSD - University of California, San Diego	US	1,280	1.32	52.3%	29.8%	*(49)*
49	Rutgers State University	US	1,277	1.17	56.1%	18.6%	*(48)*
50	Stockholm University	Sweden	1,269	1.04	33.8%	44.9%	*(64)*

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

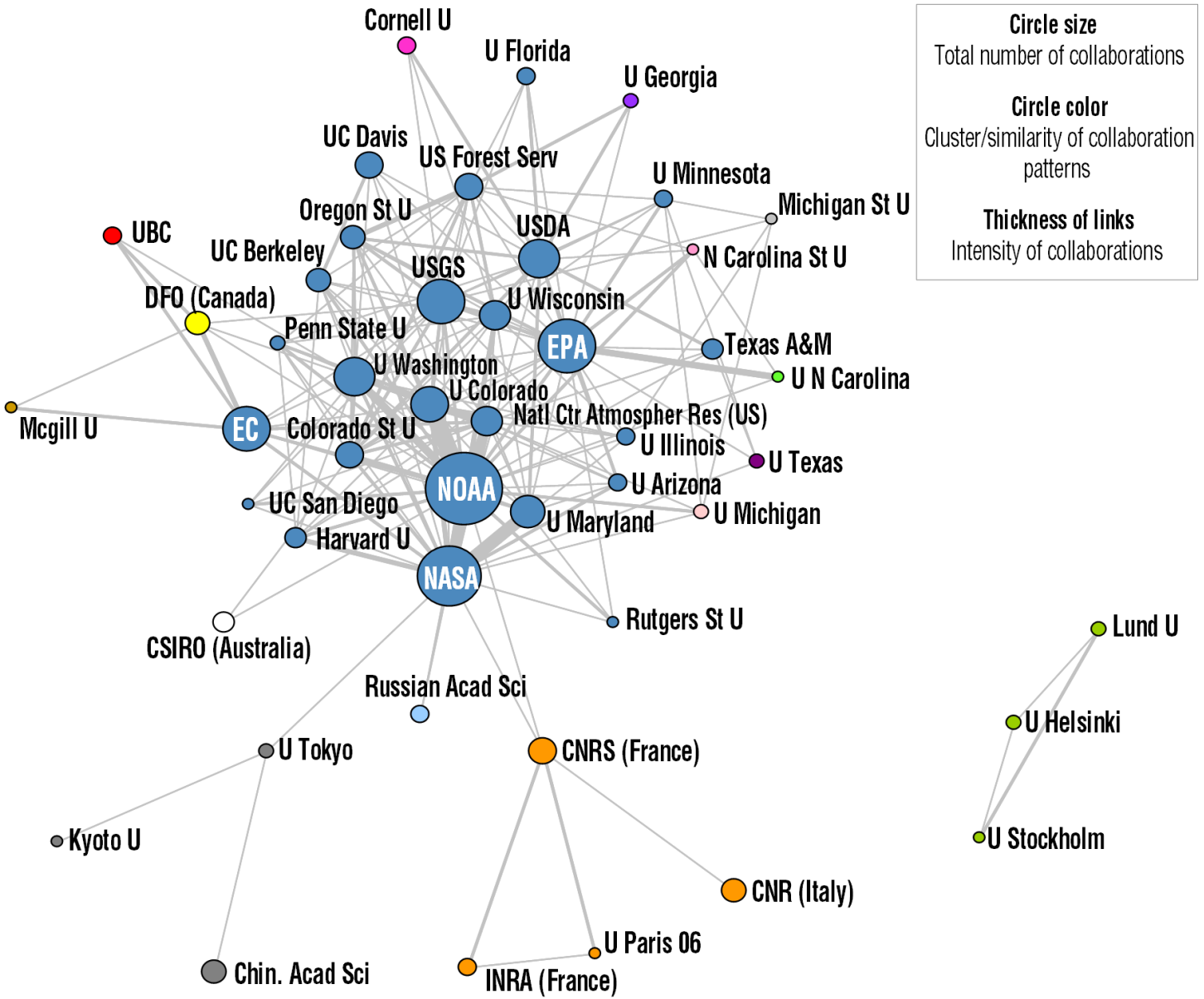

Figure 6 Collaboration networks of the most collaborative world institutions in environmental research, 1995–2004

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

3 Environmental Research at the Canadian Level

This section presents a detailed examination of Canadian output in environmental research. It analyzes output by province, institutional sector, and institution. The last section focuses on EC's R&D spending, scientific production, collaboration patterns, and principal collaborators.

3.1 Provinces

Ontario accounted for most of the scientific output in environmental research and represented 44.4% of Canadian production over the last 25 years (Table XI). Over that period, Quebec and British Columbia experienced steady growth in research output and increased their combined share of Canadian papers to about half that of Ontario's. More particularly, over the last 10 years (1995–2005), Quebec's output in environmental research reached about 22% of the country's publications in the field, from 13% at the beginning of the 1980s.

Table XI Distribution of Canadian scientific papers* in environmental research by province per 5-year period, 1980–2004

Province	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	1980-2004
ON	48.3%	45.4%	44.0%	43.0%	43.5%	44.4%
QC	12.6%	15.4%	18.6%	22.1%	21.5%	18.8%
BC	14.1%	14.1%	15.3%	17.5%	19.0%	16.4%
AB	9.9%	9.1%	9.0%	9.5%	10.5%	9.6%
NS	7.1%	6.8%	5.6%	5.4%	5.6%	6.0%
MB	5.5%	5.5%	5.3%	5.0%	4.0%	5.0%
SK	3.2%	3.5%	4.7%	5.1%	5.7%	4.6%
NF	2.1%	3.3%	3.6%	3.0%	2.7%	3.0%
NB	2.7%	3.0%	2.5%	2.4%	2.8%	2.7%
NT/YT/NU	0.4%	0.5%	0.5%	0.6%	0.7%	0.6%
PEI	0.3%	0.1%	0.5%	0.3%	0.2%	0.3%
Canada	**5,803**	**7,547**	**8,609**	**10,531**	**11,147**	**43,637**

* Note: The sum of percentage of each province may be higher than the Canadian total because some papers are subject to inter-provincial collaborations.

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

3.1.1 Provincial specialization

The distribution of output in environmental research by specialty and province provides information about areas of specialization and concentrations of expertise. Table XII presents number of papers by province and specialization by environmental research area, compared to that for the whole of Canada in the field, during the last decade.

British Columbia is highly specialized in *Environmental Planning, Management & Conservation* (1.37, or 37% higher than the Canadian level); Alberta in *Environmental Engineering, Chemistry & Biotechnology*

(1.51) and in *Environmental Planning, Management & Conservation* (1.64); Manitoba in *Environmental Sciences - General* (1.60) and in *Pollution, Environmental Toxicology & Health* (1.23); Quebec in *Environmental Engineering, Chemistry & Biotechnology* (1.29); New Brunswick in *Ecology & Biological Resources* (1.54); Nova Scotia in *Climate, Meteorology & Atmospheric Sciences* (1.30) and in *Ecology & Biological Resources* (1.52); and finally, Newfoundland and Labrador in *Ecology & Biological Resources* (2.03). Ontario has several poles of relatively high effort, such as *Climate, Meteorology & Atmospheric Sciences* (1.20), *Environmental Sciences – General* (1.16), *Pollution, Environmental Toxicology & Health* (1.22), and *Water Resources* (1.17).

Table XII Canadian scientific papers* in environmental research by province and by specialty, 1995–2004

Specialty		ON	PQ	BC	AB	NS	SK	MB	NF	NB	NT/YT/NU	PE	Canada
Climate, Meteorology & Atmospheric Sciences	**Papers**	**1,445**	**617**	**531**	**237**	**199**	**142**	**52**	**28**	**22**	**3**	**0**	**2,789**
	SI	1.20	1.01	1.04	0.85	1.30	0.94	0.41	0.35	0.30	0.16	0.00	1.00
Ecology & Biological Resources	**Papers**	**2,041**	**1,439**	**1,413**	**584**	**542**	**387**	**290**	**376**	**260**	**42**	**36**	**6,486**
	SI	0.73	1.02	1.19	0.90	1.52	1.11	0.99	2.03	1.54	0.94	2.01	1.00
Env. Engineering, Chemistry & Biotechnology	**Papers**	**666**	**468**	**188**	**252**	**48**	**86**	**56**	**38**	**23**	**2**	**1**	**1,667**
	SI	0.92	1.29	0.62	1.51	0.52	0.96	0.74	0.80	0.53	0.17	0.22	1.00
Env. Planning, Management & Conservation	**Papers**	**781**	**347**	**523**	**342**	**58**	**124**	**87**	**37**	**50**	**15**	**5**	**2,083**
	SI	0.87	0.76	1.37	1.64	0.51	1.10	0.93	0.62	0.92	1.04	0.87	1.00
Environmental Sciences - General	**Papers**	**1,379**	**565**	**418**	**313**	**92**	**123**	**198**	**40**	**63**	**73**	**6**	**2,743**
	SI	1.16	0.94	0.83	1.14	0.61	0.83	1.60	0.51	0.88	3.85	0.79	1.00
Pollution, Env. Toxicology & Health	**Papers**	**1,894**	**869**	**516**	**269**	**127**	**194**	**199**	**54**	**87**	**11**	**11**	**3,600**
	SI	1.22	1.11	0.78	0.75	0.64	1.00	1.23	0.53	0.93	0.44	1.10	1.00
Water Resources	**Papers**	**1,172**	**421**	**377**	**171**	**127**	**112**	**96**	**46**	**60**	**4**	**1**	**2,310**
	SI	1.17	0.84	0.89	0.74	1.00	0.90	0.92	0.70	1.00	0.25	0.16	1.00
Environment Total	**Papers**	**9,378**	**4,726**	**3,966**	**2,168**	**1,193**	**1,168**	**978**	**619**	**565**	**150**	**60**	**21,678**
	SI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* Note: The sum of papers of each province can be higher than the total number of papers by specialty because some papers are subject to inter-provincial collaborations

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

3.2 Institutional sectors

As in other fields of science, the university sector dominates environmental research publications, accounting for 76.5% of Canadian output between 2000 and 2004 (Table XIII). The university sector also significantly increased its share of Canadian papers by 16.5% (from 60.5% to 76.5% between the 1980–1984 and 2000–2004 periods). The output of the federal government (including EC) remained fairly steady at around 33% of all Canadian publications during that period, as did industry, which, ranking third in importance, represented 7.0% of all production between 1980 and 2004. Provincial governments did not keep pace with development in other sectors. Their contribution to overall Canadian output fell from 6.1% in 1995–1998 to 4.9% in 2000–2004.

Table XIII Canadian scientific environmental research papers* by institutional sector and by five-year period, 1980–2004

	1980-1984		1985-1989		1990-1994		1995-1999		2000-2004		1980-2004	
Sector	**Papers**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
University	3,513	(60.5%)	4,826	(63.9%)	5,834	(67.8%)	7,586	(72.0%)	8,528	(76.5%)	30,287	(69.4%)
Federal Gov.	2,025	(34.9%)	2,557	(33.9%)	2,902	(33.7%)	3,482	(33.1%)	3,537	(31.7%)	14,503	(33.2%)
Industry	375	(6.5%)	441	(5.8%)	586	(6.8%)	883	(8.4%)	786	(7.1%)	3,071	(7.0%)
Provincial Gov.	423	(7.3%)	508	(6.7%)	513	(6.0%)	641	(6.1%)	545	(4.9%)	2,630	(6.0%)
Hospital	44	(0.8%)	78	(1.0%)	102	(1.2%)	107	(1.0%)	93	(0.8%)	424	(1.0%)
Other	130	(2.2%)	168	(2.2%)	232	(2.7%)	300	(2.8%)	341	(3.1%)	1,171	(2.7%)
Unknown	20	(0.3%)	28	(0.4%)	25	(0.3%)	44	(0.4%)	208	(1.9%)	325	(0.7%)
Canada (N)	**5,803**	**100%**	**7,547**	**100%**	**8,609**	**100%**	**10,531**	**100%**	**11,147**	**100%**	**43,637**	**100%**

* Note: The sum and percentage of papers of each sector can be higher than the total number of papers because some papers are subject to inter-sectoral collaborations

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

Figure 7 presents the evolution of the impact of each sector in environmental research over the last 25 years. On average, universities and the federal government showed a slightly higher impact than Canada taken as a whole. Universities had an 8% (ARIF: 1.08) higher impact than the world and a 9% (ARIF: 1.09) higher impact than federal government. Industries scored 4% higher than the world level for the whole period, while provincial departments and hospitals were 5% less than the world level. As ARIF is a relative indicator, it is interesting to position the leading Canadian institution (in total output) against individual sectors. EC scored 12% (ARIF: 1.12) higher than the world level and 3.9% higher than Canadian universities and the federal government.

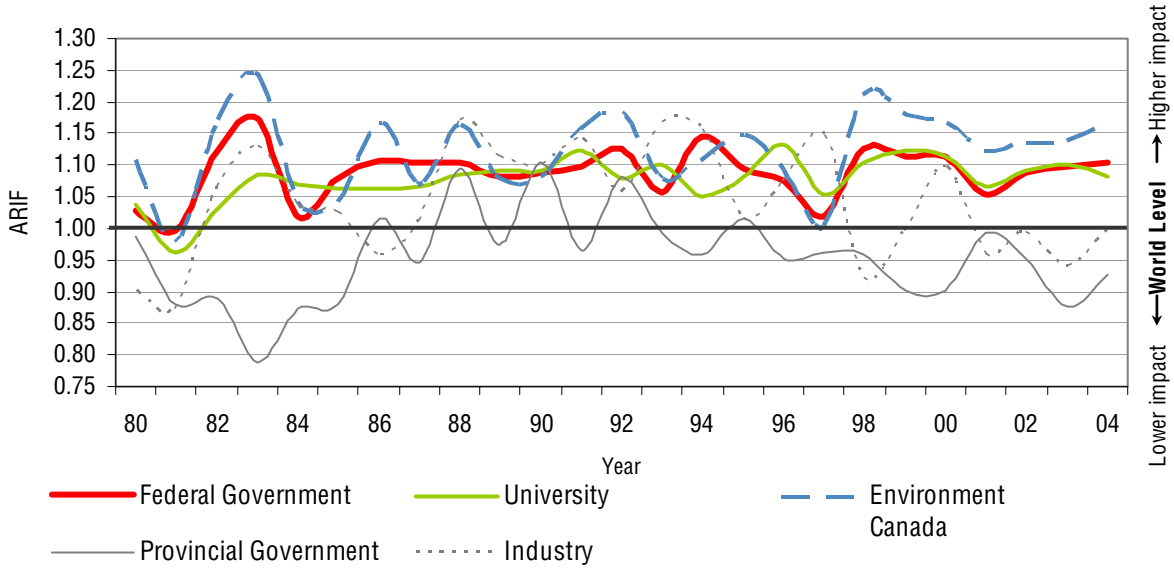

Figure 7 Average relative impact factor (ARIF) of environmental research papers by sector and Environment Canada, 1980–2004

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

Active Canadian researchers in environmental research have gradually increased their collaborative efforts with national partners (Figure 8). Between 1980 and 2004, the proportion of publications co-authored with partners from other Canadian institutions rose from 14.4% to 32.0%. While the international and national collaboration rate were about level, collaborations with international researchers surpassed national collaborations from 2001, reaching 41% in 2004.

Provincial and industry sector collaborations took place primarily at the national level, which represented more than 65% of these sectors' papers in environmental research. The federal sector's rate of collaboration with other Canadian institutions accelerated starting in the early 1990s, and the national collaboration rate of this sector reached 55% in 2004, a level which is about 18 percentage points higher than the national collaboration rate of universities.

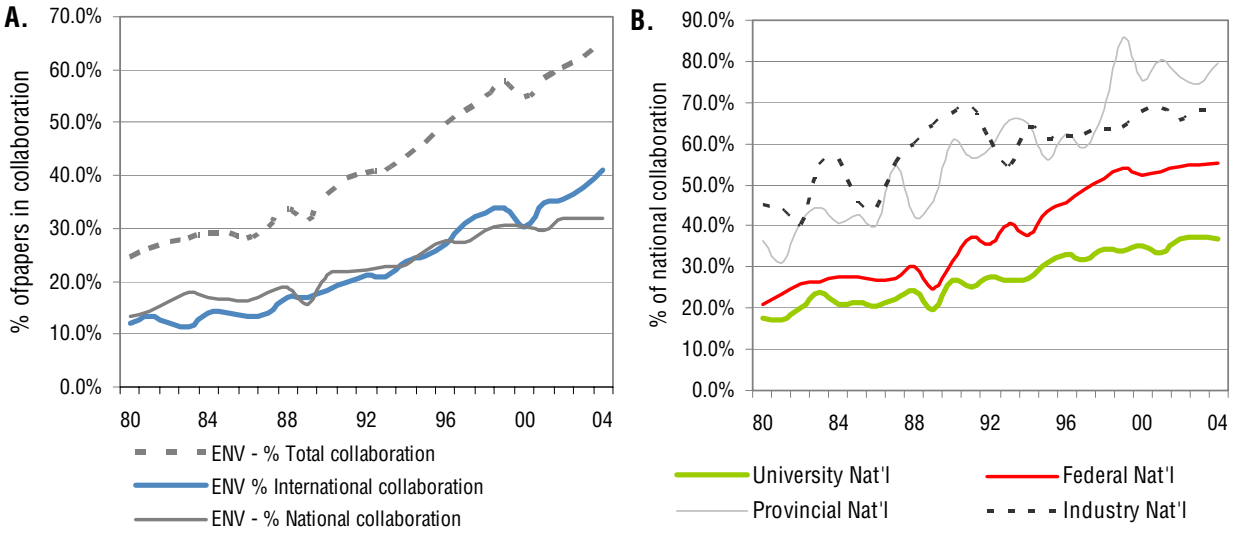

Figure 8 Share of papers in environmental research published in collaboration **(A)** by Canada and **(B)** by Canadian institutional sector

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

Table XIV presents an inter-sectoral collaboration matrix, which shows that the university sector represents the largest source of national partners for researchers in all other sectors. Between 1995 and 1999, researchers in other sectors co-authored about 46% (35% to 61%) of their environmental research publications with universities. The level of collaboration with universities increased by 8 percentage points on average for the 2000–2004 period.

EC and other federal departments represent the second largest source of partners for industry and provincial governments. Between 2000 and 2004, 8.4% of university environmental research publications were co-authored with EC, and 18.4% were co-authored with all federal government departments (including EC). Note that federal organizations, including EC, increased their collaboration activities with universities by about 18% over the last 10 years. The Provincial and Industry sectors also increased their collaboration with academics by more than 25% over the same period.

Universities also modestly intensified their partnership efforts with other sectors. Between 1995–1999 and 2000–2004, there was an increase of more than one percentage point in the collaboration rate between universities and the federal government (including EC), bringing the rate to 18.4%.

Table XIV Distribution of inter-sectoral collaborations in environmental research in Canada for two 5-year periods, 1995–1999 and 2000–2004

Sector \ Collaborator		Environment Canada		University		Federal Government		Industry		Provincial Government		Hospital		Other	
	Period	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Environment Canada	95-99			38.7%	(561)	10.2%	(148)	7.6%	(110)	3.6%	(52)	0.2%	(3)	2.7%	(39)
	00-04			45.4%	(719)	10.5%	(166)	6.1%	(96)	3.2%	(51)	0.4%	(6)	3.3%	(53)
University	95-99	7.4%	(561)			17.2%	(1,301)	4.3%	(326)	4.0%	(306)	1.0%	(77)	1.7%	(127)
	00-04	8.4%	(719)			18.4%	(1,567)	4.3%	(367)	3.9%	(330)	0.8%	(69)	2.1%	(176)
Federal Gov.	95-99	4.3%	(148)	37.4%	(1,301)			7.0%	(242)	3.8%	(134)	0.3%	(9)	2.2%	(78)
	00-04	4.7%	(166)	44.3%	(1,567)			5.7%	(200)	3.5%	(123)	0.3%	(12)	2.6%	(91)
Industry	95-99	12.5%	(110)	36.9%	(326)	27.4%	(242)			5.9%	(52)	0.6%	(5)	3.4%	(30)
	00-04	12.2%	(96)	46.7%	(367)	25.4%	(200)			4.7%	(37)	0.8%	(6)	3.1%	(24)
Provincial Gov.	95-99	8.1%	(52)	47.7%	(306)	20.9%	(134)	8.1%	(52)			2.8%	(18)	3.4%	(22)
	00-04	9.4%	(51)	60.6%	(330)	22.6%	(123)	6.8%	(37)			2.9%	(16)	2.6%	(14)
Hospital	95-99	2.8%	(3)	72.0%	(77)	8.4%	(9)	4.7%	(5)	16.8%	(18)			0.9%	(1)
	00-04	6.5%	(6)	74.2%	(69)	12.9%	(12)	6.5%	(6)	17.2%	(16)			2.2%	(2)
Other	95-99	13.0%	(39)	42.3%	(127)	26.0%	(78)	10.0%	(30)	7.3%	(22)	0.3%	(1)		
	00-04	15.5%	(53)	51.6%	(176)	26.7%	(91)	7.0%	(24)	4.1%	(14)	0.6%	(2)		

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

3.3 Canadian Institutions

This section compares the output of leading Canadian institutions in environmental research. Over the 25-year period, in the journals dataset used in this study, around 725 Canadian institutions authored a total of 43,637 papers. The 25 most active institutions in the field are highlighted along with the 10 leading institutions for each environmental research specialty. The national collaboration network of the most collaborative Canadian institutions in environmental research is analysed.

3.3.1 Top 25 environmental research producers

Table XV lists the 25 most productive institutions in environmental research, in terms of number of papers, between 1995 and 2004. The top ranking institution during the period was EC with 3,000 papers, representing approximately 14% of Canadian research papers in this field. The second largest player in the field was also a federal science-based department, DFO, with 1,760 papers. This output performance is comparable to that of the most prolific academic institution, UBC, the third leading institution in Canada. Two other federal departments ranked among the top 10: Natural Resources Canada (10th, with 870 papers) and Agriculture and Agri-Food Canada (9th, with 751 papers).

This ranking also features some 20 universities, including 6 in the top 10 performers: UT (4th); McGill University (5th); the University of Alberta (6th); the University of Guelph (7th); the University of Waterloo (8th); and Laval University (10th).

Between the 1995–1999 and 2000–2004 periods, the institutions that increased their output in environmental research the most (by more than 25%) were the University of Ottawa (41%), the University of Toronto (33%), the University of Saskatchewan (31%), the University of Victoria (29%), Queens University (27%), and Trent University (25%).

The ARIF (or expected impact) for these 25 key players provides a proxy indicator of the scientific quality of their output in environmental research (Table XV). Six institutions have an ARIF higher than 1.15, meaning that their papers can be expected to get 15% more citations than the world average in the field. These high impact institutions are: McMaster University (1.20); UT (1.18); the University of Waterloo (1.18); the University of Victoria (1.17); DFO (1.16); and Dalhousie University (1.16). EC also has quite a high scientific impact compared to other leading Canadian institutions, ranking 7th for ARIF (1.14). In spite of its high overall rank (11th) based on number of papers, Agriculture and Agri-Food Canada (AAFC) has the lowest ARIF score (0.97). However, this score of AAFC in environmental research is higher than that observed in agriculture research (ARIF: 0.85)[13].

Table XV shows the proportion of papers produced by leading institutions and written with international and national collaborators. Collaboration with foreign researchers is not a strong trend for leading Canadian institutions in environmental research, at least compared to levels of national collaboration. Only four institutions have rates of international collaboration in environmental research higher than the average (37%) for NSE in Canada between 1995 and 2004: the University of Calgary (41%); Dalhousie University (40%); the University of Western Ontario (39%); and York University (37%). Leading federal organizations in environmental research have an average international collaboration rate of 27.5%. Among those, EC has the highest international collaboration rate, at 34%.

Institutions that collaborate most with other Canadian institutions are the Université du Québec à Montréal (55%), EC (55%), Agriculture and Agri-Food Canada (54%), DFO (53%), Natural Resources Canada (53%), the University of Manitoba (51%), the University of Ottawa (49%), and the University of Saskatchewan (48%).

Among the 25 most active Canadian players, 16 institutions rank among the world's top 200 research institutions in environmental research, and the 10 leading Canadian institutions rank among the world's top 100 research institutions in the field. This reveals that these institutions, located in main metropolitan areas, are not just well positioned at the national level but are also well established as international contributors to environmental research.

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[13] Côté G. 2006. *Profile of Canadian Scientific Collaboration in Agriculture Research (1993-2004)*, Prepared by Science-Metrix for Agriculture and Agri-Food Canada (AAFC), 29 pages.

Table XV Number of papers, ARIF, national and international collaboration rates of leading Canadian institutions in environmental research, 1995–2004

Papers				Other indicators			
Canadian rank	World rank	Institution	Papers 1995-2004	ARIF 1995-2004	Int'l collabo	Nat't collabo	*Rank (25 years)*
1	**7**	**Environment Canada**	**3,033**	**1.14**	**33.9%**	**54.7%**	***(1)***
2	25	Fisheries and Oceans Canada	**1,826**	1.16	28.7%	53.4%	*(2)*
3	28	University of British Columbia	**1,761**	1.11	34.9%	34.0%	*(3)*
4	47	University of Toronto	**1,327**	1.18	32.7%	35.9%	*(4)*
5	51	McGill University	**1,262**	1.09	32.6%	43.3%	*(5)*
6	53	University of Alberta	**1,149**	1.05	26.0%	40.7%	*(7)*
7	79	University of Guelph	**968**	1.08	29.3%	43.8%	*(6)*
8	82	University of Waterloo	**917**	1.18	29.0%	43.4%	*(9)*
9	91	Natural Resources Canada	**870**	1.03	26.6%	53.0%	*(11)*
10	96	Université Laval	**832**	1.05	26.9%	41.6%	*(10)*
11	110	Agriculture and Agri-Food Canada	**751**	0.97	21.0%	54.2%	*(8)*
12	140	Dalhousie University	**655**	1.16	39.7%	37.4%	*(12)*
13	159	Université de Montréal	**614**	1.06	28.2%	47.4%	*(14)*
14	161	University of Saskatchewan	**608**	1.01	33.4%	48.4%	*(15)*
15	164	Simon Fraser University	**601**	1.12	22.6%	38.4%	*(13)*
16	184	McMaster University	**540**	1.20	33.0%	48.0%	*(16)*
17	>200	University of Manitoba	**492**	1.02	19.1%	50.8%	*(17)*
18	>200	University of Victoria	**472**	1.17	34.5%	33.9%	*(26)*
19	>200	Queen's University	**467**	1.09	24.8%	45.6%	*(19)*
20	>200	York University	**452**	1.10	36.9%	44.2%	*(24)*
21	>200	University of Ottawa	**447**	1.11	25.7%	48.8%	*(23)*
22	>200	University of Calgary	**432**	1.10	41.0%	39.8%	*(18)*
23	>200	Memorial University of Newfoundland	**427**	1.03	30.4%	41.0%	*(22)*
24	>200	Université du Québec à Montréal	**426**	1.11	26.5%	54.9%	*(28)*
25	>200	University of Western Ontario	**409**	0.96	39.1%	36.4%	*(21)*

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

3.3.2 Top 10 science producers by specialty

Table XVI presents the top ten Canadian institutions by environmental research specialty between 1995 and 2004. EC largely dominated Canadian publications in four specialties: *Climate, Meteorology & Atmospheric Science* (935 papers); *Pollution, Environmental Toxicology & Health* (587 papers); *Environmental Sciences - General* (431 papers); and *Water Resources* (379 papers). This department contributed more then 33% of Canadian scientific output in *Climate, Meteorology & Atmospheric Science* and more than 15% of Canadian papers in *Environmental Toxicology & Health, Environmental Sciences – General*, and *Water Resources*.

EC also performed well in *Ecology & Biological Resources* (469 papers), ranking third behind DFO and UBC. This output corresponds to 7% of the Canadian papers in this specialty.

In addition to its first place ranking in *Ecology & Biological Resources* (956 papers; 15% of Canadian output), DFO performed well in other specialties: it came in third in *Environmental Sciences – General*, third in *Water Resources*, and fourth in *Pollution, Environmental Toxicology & Health*.

Regarding academic institutions, UBC ranks high in several fields: third in *Climate, Meteorology & Atmospheric Science*; second in *Ecology & Biological Resources*; second in *Environmental Engineering, Chemistry & Biotechnology*; first in *Environmental Planning, Management & Conservation*; second in *Pollution, Environmental Toxicology & Health*; and fourth in *Water Resources*.

Other notably high rankings for academic institutions include: McGill University, second in *Climate, Meteorology & Atmospheric Science*; UT, second in *Environmental Science – General*; the University of Alberta, first in *Environmental Engineering, Chemistry & Biotechnology*; and the University of Waterloo, second in *Water Resources*.

In addition, a number of specialist institutions have a relatively high impact compared to the world average (Table XVI)—for example, the University of Victoria (1.28) in *Climate, Meteorology & Atmospheric Science* and the University of Toronto (1.31), Dalhousie University (1.27), and the University of British Columbia (1.26) in *Ecology & Biological Resources*. The University of Alberta, the most productive institution in *Environmental Engineering, Chemistry & Biotechnology*, also has the highest ARIF score (1.16). Other institutions with high scientific impact include:

- Agriculture and Agri-Food Canada (1.34) in *Environmental Planning, Management & Conservation;*
- the University of Waterloo (1.39), Natural Resources Canada (1.33), McGill University (1.27), and EC (1.22) in E*nvironmental Science – General;*
- DFO (1.43), McMaster University (1.35), the University of Guelph (1.34), and EC (1.24) in *Pollution, Environmental Toxicology & Health*;
- the University of Waterloo (1.24) and UBC (1.20) in *Water Resources*.

Table XVI Number of scientific papers and average relative impact factor of the most productive Canadian institutions by specialty, 1995–2004

Climate, Meteorology & Atmospheric Sciences

Rk	Institution	Papers	ARIF
1	**Environment Canada**	**935**	**1.07**
2	McGill University	268	1.00
3	University of British Columbia	202	1.07
4	University of Toronto	196	1.12
5	York University	196	0.97
6	University of Victoria	188	1.28
7	Natural Resources Canada	175	0.95
8	Dalhousie University	132	1.05
9	Fisheries and Oceans Canada	114	0.79
10	University of Alberta	111	0.93

Ecology & Biological Resources

Rk	Institution	Papers	ARIF
1	Fisheries and Oceans Canada	956	1.17
2	University of British Columbia	605	1.26
3	**Environment Canada**	**469**	**1.15**
4	Université Laval	420	1.08
5	Simon Fraser University	377	1.14
6	University of Toronto	353	1.31
7	University of Alberta	345	1.10
8	University of Guelph	344	0.98
9	McGill University	325	1.14
10	Dalhousie University	320	1.27

Environmental Engineering, Chemistry & Biotechnology

Rk	Institution	Papers	ARIF
1	University of Alberta	164	1.16
2	University of British Columbia	143	1.02
3	Université Laval	112	1.16
4	McGill University	105	0.87
5	**Environment Canada**	**102**	**0.92**
6	Natural Resources Canada	99	1.00
7	University of Toronto	84	1.03
8	Agriculture and Agri-Food Canada	81	1.04
9	University of Waterloo	77	0.98
10	Université de Montréal	66	1.01

Environmental Planning, Management & Conservation

Rk	Institution	Papers	ARIF
1	University of British Columbia	218	0.97
2	Agriculture and Agri-Food Canada	167	1.34
3	University of Alberta	156	0.97
4	Natural Resources Canada	149	0.83
5	University of Guelph	134	1.03
6	**Environment Canada**	**130**	**1.11**
7	McGill University	94	1.29
8	University of Toronto	82	1.24
9	BC Ministry of Forests	71	0.67
10	University of Sask.	68	0.85

Environmental Sciences - General

Rk	Institution	Papers	ARIF
1	**Environment Canada**	**431**	**1.22**
2	University of Toronto	247	1.20
3	Fisheries and Oceans Canada	244	1.09
4	Natural Resources Canada	197	1.33
5	University of Alberta	180	0.97
6	McGill University	153	1.27
7	University of British Columbia	151	0.90
8	University of Waterloo	119	1.39
9	University of Guelph	108	0.97
10	Trent University	96	1.28

Pollution, Environmental Toxicology & Health

Rk	Institution	Papers	ARIF
1	**Environment Canada**	**587**	**1.24**
2	University of British Columbia	244	1.02
3	University of Toronto	235	1.04
4	Fisheries and Oceans Canada	224	1.43
5	Health Canada	217	1.04
6	McGill University	214	1.00
7	University of Waterloo	206	1.16
8	University of Guelph	196	1.34
9	McMaster University	178	1.35
10	Université de Montréal	177	1.00

Water Resources

Rk	Institution	Papers	ARIF
1	**Environment Canada**	**379**	**1.07**
2	University of Waterloo	262	1.24
3	Fisheries and Oceans Canada	236	1.06
4	University of British Columbia	198	1.20
5	University of Toronto	130	1.18
6	McGill University	103	1.07
7	University of Alberta	91	1.16
8	University of Guelph	87	1.07
9	INRS	85	1.18
10	McMaster University	75	1.13

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

3.3.3 Canadian collaboration network in environmental research

The above analyses strongly suggest that there is an important network of national collaborators around the leading Canadian federal departments in environmental research. Two important clusters of collaboration between Canadian institutions are built around EC and DFO. Apart from these, collaborative links between academic institutions are relatively weak. This situation emphasizes the central role played by science-based federal government departments in the pattern of national scientific collaborations.

Figure 9 illustrates the network of collaboration among the most collaborative Canadian institutions in environmental research between 1995 and 2004. Figure 6 shows each institution represented by a circle with a size that is determined by the number of collaborations for the 10-year period. Links between circles identify pairs of institutions with more than 20 collaborations (2 collaborations per year)[14] in the period. The width of the links is proportional to the number of collaborations. Circles have been positioned in Euclidean space using a spring embedded algorithm. The algorithm positions circles on a plane according to the strength of the relationship between pairs of institutions (number of collaborations)[15]. Table XX in Appendix B presents the matrix of inter-institutional collaboration among the top 10 Canadian institutions and their 20 most important collaborators by importance (rank) and by proportion of total collaboration (1995–2004).

EC is the most important collaborator for 10 of the 14 other most active institutions. This makes it the central hub of the Canadian network in environmental research. EC's principal collaborators are DFO (154 collaborations), the University of Saskatchewan (147 collaborations), the University of Guelph (121 collaborations), UT (113 collaborations), McGill University (108), UBC (101), and the University of Waterloo (98). The next section provides greater detail about EC's collaborators by specialty.

The second most important hub starts from DFO and is related to *Ecology & Biological Resource*s. This cluster includes institutions located in close proximity to both the Atlantic (Memorial University, the University of New Brunswick, Dalhousie University) and the Pacific (UBC, the University of Victoria) coasts and near the Bas-Saint-Laurent region (Université du Québec à Rimouski, Université Laval, Institut national de la recherche scientifique). The University of Manitoba also collaborated with EC in *Ecology & Biological Resource*s as well as in *Pollution, Environmental Toxicology & Health*.

Another cluster can be identified in the Montreal metropolitan region. McGill University mainly collaborated with EC in *Climate, Meteorology & Atmospheric Science* and in *Pollution, Environmental Toxicology & Health.* This university also has important links with Agriculture and Agri-food Canada in several specialties and with the University of Montréal in *Pollution, Environmental Toxicology & Health.*

Despite the limited intensity of collaborations, the positions of the University of Guelph, the University of Waterloo, and the University of Alberta in the network are quite central in terms of the number and geographical diversity of links. UBC represents the Western hub of the network.

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[14] This number is arbitrary but yielded maximum readability for the representation of the network.

[15] For more details, see the paragraph on the visualization of collaboration networks in the methods section.

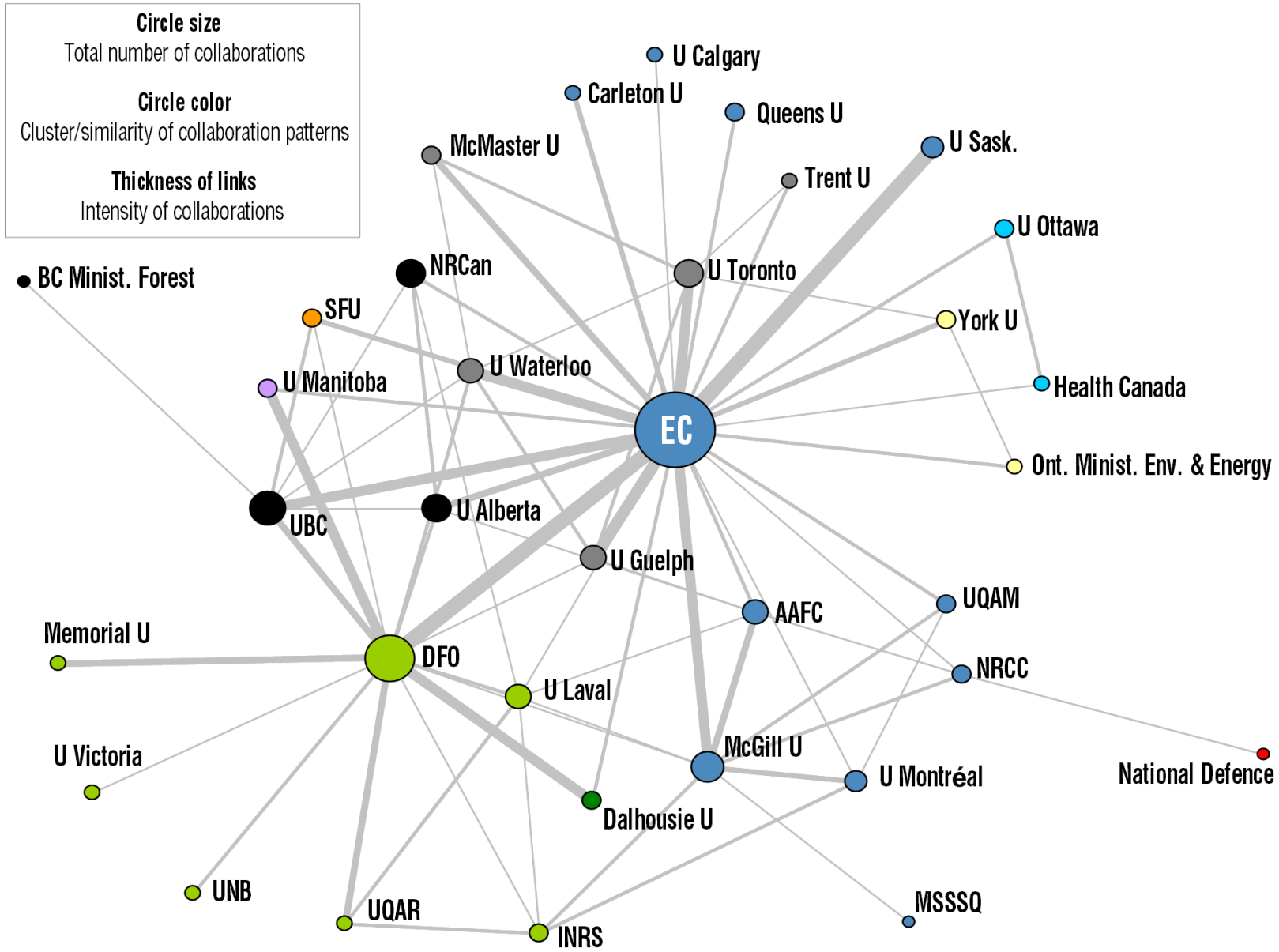

Figure 9 National collaboration network of the most collaborative Canadian institutions in environmental research, 1995–2004

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

UT appears to be central in Ontario. Its main collaborators are McMaster University and the University of Guelph in *Pollution, Environmental Toxicology & Health* and EC and Trent University in *Environmental Sciences – General*.

Figure 9 clearly supports the concept of regional clusters. These clusters would be even more pronounced if federal departments were divided into regional branches or research centers. Overall, it is clear that the dominant cluster is that around EC and DFO, as Canadian institutions have somewhat strong or very strong links with these two departments and relatively weak links with each other.

3.3.4 Focus on Environment Canada

Given that EC is one of the top 10 world-leading institutions and is the largest producer of scientific papers in environmental research in the country, this final section presents a detailed analysis of the Department's output, specialization, scientific impact, and collaborators.

EC's global efforts in R&D represent 4% of the total federal government expenditures on R&D (Figure 10). The intramural portion of the R&D performed by the Department makes up more than 9% of federal intramural R&D expenditures. Preliminary data on R&D for fiscal year 2005/2006 indicates that total expenditures equal $226 million, 86% of which will be allotted to intramural research.

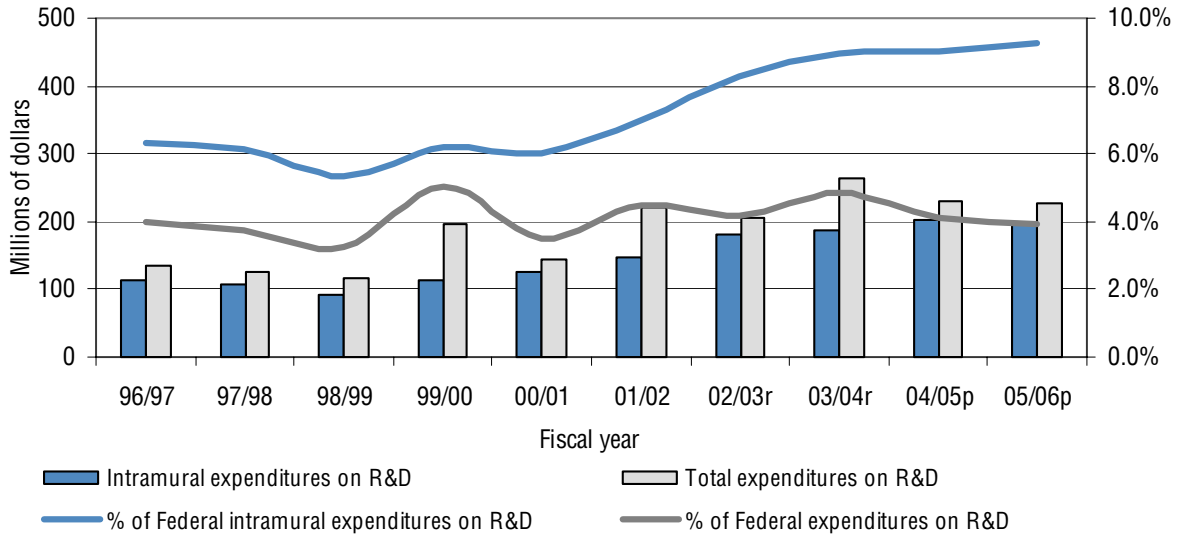

Figure 10 Environment Canada's intramural and total expenditures on R&D and share of federal expenditures on R&D, 1996/1997-2005/2006

Note: p: preliminary; r: revised
Source: Statistics Canada, Federal government spending on science and technology, Service Bulletin Science Statistics Vol. 29, No. 7, December 2005

The Department accounted for 16% of Canadian output in environmental research papers in 2003 and 13% in 2004 (Figure 11). These percentages could be explained by the focus of government researchers on policy-driven science and on a variety of mandates that are in line with Department

responsibilities and business lines. In fact, a portion of the work undertaken by government researchers is not published in peer-reviewed publications. Consequently, one can assume that the Department's output in environmental research is likely to be commensurate with the Department's expenditures in this scientific area.

The annual scientific production of EC increased three-fold over the last 25 years, from 100 to 300 papers. With the exception of a peak in 2003 at 361 papers, the level of output has remained fairly constant after 1997. Also after 1997, EC was responsible for 45% of the federal scientific output in environmental research. The annual output of EC is the highest of all Canadian environmental research institutions. Other institutions with more than 150 papers per year in 2004 are DFO (196 papers), UBC (186 papers), UT (163 papers), and the University of Alberta (152 papers).

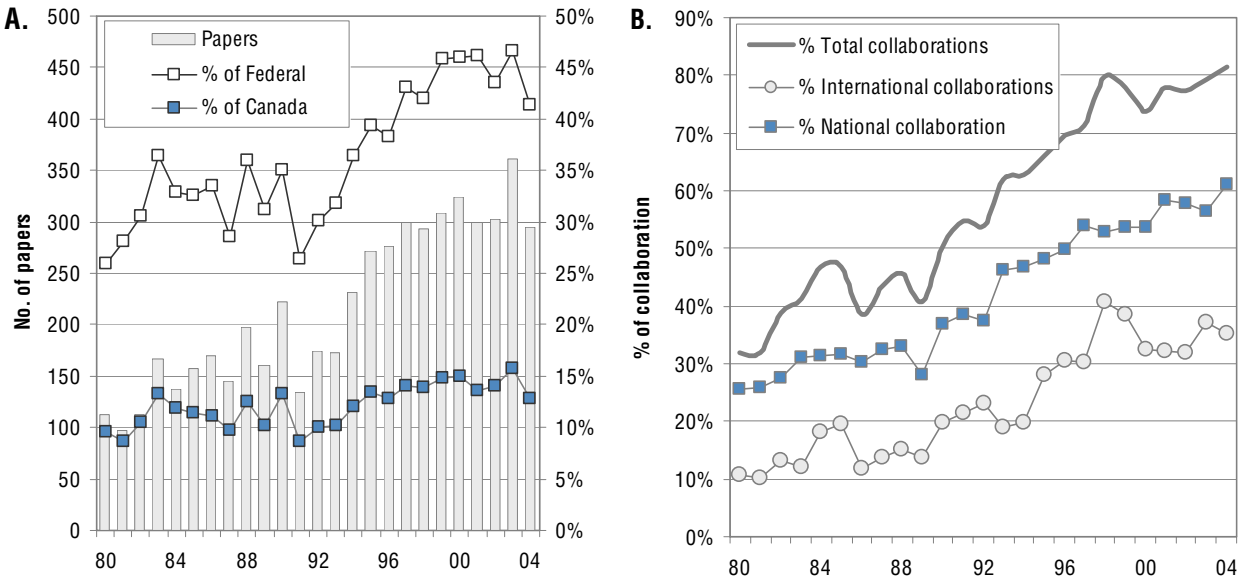

Figure 11 Environment Canada's scientific papers **(A)** and collaboration rates **(B)** in environmental research per year, 1980–2004

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

EC's large contribution to Canadian environmental research is due, at least in part, to the Department's high rate of collaboration with the national and international scientific communities. In fact, the total collaboration rate of the Department was about 32% in 1980 and by 2004 had increased to 81%. Most of EC's collaborators are from Canadian institutions. In 2004, 60% of the Department's scientific output was co-authored with Canadian researchers, and 35% was co-authored with international researchers. Also noteworthy, the international collaboration rate stagnated at around 34% over the last 10 years while the national collaboration rate increased over the same period.

This is also true for collaboration patterns in each environmental specialty, with the exception of research published in *Climate, Meteorology & Atmospheric* journals, in which 46% of papers were coauthored with international counterparts and 37% with Canadian counterparts (2000-2004) (Table XVII). Another area of high international collaboration was *Environmental Sciences – General*

(39%), in which several journals are dedicated to global environmental issues. Over the last 5 years, the highest levels of national collaboration are in *Environmental Planning, Management & Conservation* (74%), *Ecology & Biological Resources* (73%), and *Pollution, Environmental Toxicology & Health* (72%). Conversely, the lowest level of national collaboration activity is in *Climate, Meteorology & Atmospheric* Science (37%) and in *Environmental Engineering, Chemistry & Biotechnology* (44%).High overall collaboration rates (over 80%) can be observed in four of the seven environmental areas. The highest collaboration rate was 89% in *Ecology & Biological Resources* and the lowest was 62% in *Environmental Engineering, Chemistry & Biotechnology*.

Table XVII Environment Canada's scientific papers in collaboration by 5-year period and by specialty, 1980–2004

Specialty	Level of collaboration	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	1980-2004
Climate, Meteorology & Atmospheric Sciences	International	21.7%	22.6%	29.2%	46.1%	45.7%	38.7%
	National	28.3%	15.7%	28.8%	38.3%	37.2%	33.1%
	Total*	**45.3%**	**34.0%**	**54.0%**	**69.8%**	**72.1%**	**62.1%**
Ecology & Biological Resources	International	10.2%	16.2%	21.6%	30.0%	28.4%	22.5%
	National	32.5%	42.8%	60.3%	64.8%	72.9%	56.6%
	Total*	**40.8%**	**56.6%**	**73.3%**	**81.5%**	**89.4%**	**70.8%**
Environmental Engineering, Chemistry & Biotechnology	International	0.0%	6.3%	21.6%	22.8%	31.1%	18.9%
	National	36.0%	37.5%	51.4%	45.6%	44.4%	43.9%
	Total*	**36.0%**	**43.8%**	**64.9%**	**59.6%**	**62.2%**	**55.6%**
Environmental Planning, Management & Conservation	International	31.3%	0.0%	5.7%	25.5%	26.5%	20.0%
	National	31.3%	45.8%	51.4%	66.0%	73.5%	61.5%
	Total*	**56.3%**	**45.8%**	**54.3%**	**76.6%**	**85.5%**	**71.2%**
Environmental Sciences - General	International	13.1%	15.2%	19.6%	31.9%	38.6%	20.0%
	National	21.4%	29.5%	38.5%	53.3%	61.8%	61.5%
	Total*	**56.3%**	**45.8%**	**54.3%**	**76.6%**	**85.5%**	**71.2%**
Pollution, Environmental Toxicology & Health	International	11.7%	8.3%	11.4%	26.0%	30.0%	27.3%
	National	29.9%	34.6%	44.3%	59.0%	72.1%	46.5%
	Total*	**35.1%**	**40.4%**	**51.9%**	**74.0%**	**82.2%**	**63.8%**
Water Resources	International	11.1%	15.6%	19.4%	25.9%	18.6%	20.9%
	National	27.2%	28.3%	42.4%	55.7%	55.2%	54.3%
	Total*	**36.4%**	**41.1%**	**57.1%**	**72.2%**	**67.0%**	**64.4%**
Environment (Total)	International	13.1%	14.8%	20.5%	33.8%	33.9%	26.3%
	National	28.7%	31.1%	41.4%	51.8%	57.4%	45.8%
	Total*	**38.9%**	**43.1%**	**56.9%**	**73.2%**	**77.9%**	**63.2%**

* Note: The totals are less than the sum of international and national percentage figures because some papers are subject to both international and national collaborations.
Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

The Department's primary partners in environmental research as a whole have already been identified (Section 3.3.3). Table XIX presents, for each specialty over the last decade, the 10 most important Canadian and international partners in terms of number and proportion of EC articles written in collaboration.

Between 1995 and 2004, EC's main collaborators in *Climate, Meteorology & Atmospheric Science* were US federal organizations such as the NOAA (79 papers; 12% of collaborations), NASA (61 papers; 9.2% of collaborations), and the NCAR (60 papers; 9% of collaborations). The Department has also

participated in collaborative activities with the leading academic institution in the area, McGill University (62 papers; 9% of collaborations). In *Ecology & Biological Resources*, EC had already been working closely with the University of Saskatchewan, the University of Alberta, and Simon Fraser University.

In *Environmental Sciences – General*, the Department has primarily collaborated with DFO and UT. Another area of collaboration was with the University of Guelph and DFO in *Pollution, Environmental Toxicology & Health*. Finally, the Department's primary collaborator in *Water Resources* was the University of Waterloo.

Over the last 25 years, EC published more papers related to *Climate, Meteorological & Atmospheric Sciences* than any other environmental area (Table XVIII). The Department increased its output level by about 90% during the 1990s. Between the 1995–1999 and 2000–2004 periods, the output in this field decreased by about 2% and stabilized, maintaining the Department's rate of production at around 100 papers per year. The scientific impact in this area is 9% higher than at the world level and has remained quite steady following the 1985–1989 period. Other specialty areas, with the exception of *Environmental Engineering, Chemistry & Biotechnology* and *Environmental Planning, Management & Conservation*, have experienced about the same level of output (between 220 and 250 papers) over the last 5-year period. The Department also significantly increased its scientific impact in *Ecology & Biological Resources* and in *Environmental Sciences - General* over the last ten years. In these two areas together, with research published in *Pollution, Toxicology & Health* journals, the Department has had a scientific impact 20% higher than that at the world level. However, the impact of the Department's papers in *Water Resources* decreased by about 10% over the last 10 years. ■

Table XVIII Environment Canada's scientific papers in collaboration by 5-year period and by specialty, 1980–2004

	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	1980-2004
Specialty	**No. (ARIF)**	**No. (ARIF)**	**No. (ARIF)**	**No. (ARIF)**	**No. (ARIF)**	**No. (ARIF)**
Climate, Meteorology & Atmospheric Sciences	**106** (1.40)	**159** (1.06)	**250** (1.09)	**473** (1.05)	**462** (1.08)	**1,450** (1.09)
Ecology & Biological Resources	**157** (0.95)	**173** (1.01)	**116** (1.04)	**233** (1.09)	**236** (1.20)	**915** (1.08)
Environmental Engineering, Chemistry & Biotechnology	**25** (1.34)	**32** (0.99)	**37** (0.95)	**57** (0.92)	**45** (0.91)	**196** (0.98)
Environmental Planning, Management & Conservation	**16** (1.27)	**24** (1.13)	**35** (1.29)	**47** (1.15)	**83** (1.08)	**205** (1.15)
Environmental Sciences - General	**84** (1.11)	**105** (1.17)	**148** (1.08)	**182** (1.25)	**249** (1.20)	**768** (1.17)
Pollution, Environmental Toxicology & Health	**77** (1.16)	**156** (1.22)	**158** (1.30)	**300** (1.20)	**287** (1.28)	**978** (1.24)
Water Resources	**162** (1.10)	**180** (1.13)	**191** (1.07)	**158** (1.12)	**221** (1.03)	**912** (1.09)
Environment (Total)	**627** (1.12)	**829** (1.11)	**935** (1.12)	**1,450** (1.13)	**1,583** (1.15)	**5,424** (1.13)

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

Table XIX Environment Canada's 10 most important collaborators by number of scientific papers, by proportion of collaborations, and by specialty, 1995–2004

Climate, Meteorology & Atmospheric Sciences

Rk	Institution	Collabo	% Collabo
1	US NOAA	79	11.9%
2	McGill University	62	9.4%
3	US NASA	61	9.2%
4	US NCAR	60	9.0%
5	York University	50	7.5%
6	University of British Columbia	38	5.7%
7	University of Colorado	33	5.0%
8	University of Toronto	31	4.7%
9	UK Meteorological Office	26	3.9%
10	Dalhousie University	25	3.8%

Environmental Sciences - General

Rk	Institution	Collabo	% Collabo
1	Fisheries and Oceans Canada	49	14.4%
2	University of Toronto	42	12.3%
3	Carleton University	19	5.6%
4	University of Waterloo	18	5.3%
5	Lancaster University (UK)	17	5.0%
6	University of Guelph	16	4.7%
7	University of Saskatchewan	15	4.4%
8	McMaster University	13	3.8%
9	University of Alberta	10	2.9%
10	Trent University	8	2.3%
10	University of Manitoba	8	2.3%
10	DK National Environ. Res. Institute	8	2.3%

Ecology & Biological Resources

Rk	Institution	Collabo	% Collabo
1	University of Saskatchewan	62	15.5%
2	University of Alberta	47	11.7%
3	Simon Fraser University	37	9.2%
4	Fisheries and Oceans Canada	23	5.7%
5	University of British Columbia	20	5.0%
6	Memorial Univ. of Newfoundland	14	3.5%
6	University of Ottawa	14	3.5%
7	Université de Montréal	13	3.2%
8	University of Guelph	12	3.0%
8	University of Waterloo	12	3.0%
8	Université Laval	12	3.0%
8	University of Guelph	12	3.0%
8	University of Waterloo	12	3.0%

Pollution, Environmental Toxicology & Health

Rk	Institution	Collabo	% Collabo
1	University of Guelph	61	13.3%
2	Fisheries and Oceans Canada	43	9.4%
3	University of Saskatchewan	39	8.5%
4	University of Waterloo	28	6.1%
5	McGill University	23	5.0%
6	University of Toronto	22	4.8%
7	University of British Columbia	19	4.1%
8	Carleton University	18	3.9%
9	Trent University	17	3.7%
9	Health Canada	17	3.7%
10	University of Manitoba	12	2.6%
10	Agriculture and Agri-Food Canada	12	2.6%
10	Okayama University	12	2.6%

Environmental Engineering, Chemistry & Biotechnology

Rk	Institution	Collabo	% Collabo
1	National Research Council Canada	7	11.3%
2	McMaster University	5	8.1%
3	University of British Columbia	4	6.5%
3	University of Guelph	4	6.5%
3	Health Canada	4	6.5%
4	Natural Resources Canada	3	4.8%
5	University of Alberta	2	3.2%
5	Carleton University	2	3.2%
5	University of California, Davis	2	3.2%
5	York University	2	3.2%
5	McGill University	2	3.2%

Water Resources

Rk	Institution	Collabo	% Collabo
1	University of Waterloo	27	10.3%
2	McMaster University	23	8.8%
3	Fisheries and Oceans Canada	20	7.6%
4	Queen's University	16	6.1%
5	University of Saskatchewan	15	5.7%
6	University of Guelph	13	5.0%
7	University of Toronto	11	4.2%
8	University of Calgary	10	3.8%
9	McGill University	8	3.1%
9	University of Ottawa	8	3.1%
9	Ryerson Polytechnic University	8	3.1%

Environmental Planning, Management & Conservation

Rk	Institution	Collabo	% Collabo
1	Agriculture and Agri-Food Canada	10	9.3%
2	University of Saskatchewan	8	7.5%
2	University of Regina	8	7.5%
3	University of British Columbia	7	6.5%
4	Fisheries and Oceans Canada	6	5.6%
4	Trent University	6	5.6%
5	University of Guelph	4	3.7%
5	University of Waterloo	4	3.7%
5	USGS - US Geological Survey	4	3.7%
5	Ont. Ministry of Environ. & Energy	4	3.7%

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

4 Conclusion

This scientometric analysis reveals that significant growth has taken place in international environmental scientific research. At the beginning of the 1980s, there were slightly more than 15,100 research papers published annually in the field, and that number more than doubled (to 34,900 papers) by 2004. This growth is higher than the one observed for all papers indexed in the SCI databases (SCI and SSCI). Over the last 25 years, the number of environmental research papers has increased 2.3 times, while the number of papers in all scientific fields has grown 1.6 times. Environmental research now represents 5.1% of papers in the ISI databases, compared to 3.6% in 1980.

The research output of Canada in environmental research is remarkable. Canada is internationally acknowledged to be a prolific producer of high quality environmental science. Although the position of Canada (third internationally) in terms of number of papers has not changed in the last 5 years, it is likely to change in the coming years due to the improving output performance of countries such as China, Germany, Spain, and Japan. Also, the UK reached the same level of impact held by Canada in the last 5 years. Nevertheless, Canada invests considerably in environmental research compared to other countries and maintains the quality of its scientific research in the field. Finally, the multicriteria ranking according to four indicators of the 13 leading countries places Canada at number one in environmental research over the last 25 years.

The present analysis also found that, compared to other leading countries, Canada expends a relatively large amount of its scientific effort in the area of *Ecology & Biological Resources*. In addition, Canada has a relatively high scientific impact in this area. While it maintains a fairly high level of impact in most other areas, Canada, in comparison to other countries, does not strongly emphasize any one particular area of research. Canada has also demonstrated a lower level of impact and under-specialization in the area of *Environmental Engineering, Chemistry & Biotechnology* (as noted in the previous bibliometric study by OST in 2002). However, papers in this area tend to be published in journals that are not particularly dedicated to environmental engineering but are oriented towards more broad-based engineering research—journals not used for this study. In addition, engineering and chemical research articles are disseminated through means, such as conference proceedings, that are not covered by the databases used for this study. Therefore, contrary to other specialties, research in *Environmental Engineering, Chemistry & Biotechnology* may not be well represented based on the methodology used. The inclusion of bibliographic references from engineering-specific journals and proceedings compiled in other databases would benefit the quantitative evaluation of Canada's output in this area.

Despite this limitation, this scientometric study constitutes the most comprehensive quantitative analysis of peer-reviewed environmental research published around the world and provides insight into the state of environmental research in Canada. This report should ideally be followed by other studies that would help to contextualize Canada and other leading countries' research output and take into account these nations' scientific policies, political situations, and capacities for the improvement of their environmental performance. ■

Appendix A Environmental research journals classified by specialty

Climate, Meteorology & Atmospheric Sciences

- Agricultural and Forest Meteorology
- Agricultural Meteorology
- Annales Geophysicae-Atmospheres Hydrospheres and Space Sciences
- Archiv Fur Meteorologie Geophysik Und Bioklimatologie Serie A-Meteorologie Und Geophysik
- Archiv Fur Meteorologie Geophysik Und Bioklimatologie Serie B-Klimatologie Umweltmeteorologie Strahlungsforschung
- Archives For Meteorology Geophysics and Bioclimatology Series A-Meteorology and Atmospheric Physics
- Archives For Meteorology Geophysics and Bioclimatology Series B-Theoretical and Applied Climatology
- Atmosphere-Ocean
- Atmospheric Environment
- Atmospheric Environment Part A-General Topics
- Atmospheric Environment Part B-Urban Atmosphere
- Atmospheric Research
- Australian Meteorological Magazine
- Boundary-Layer Meteorology
- Bulletin of The American Meteorological Society
- Climate Dynamics
- Climate Research
- Climatic Change
- Dynamics of Atmospheres and Oceans
- International Journal of Biometeorology
- International Journal of Climatology
- International Journal of Remote Sensing
- Izvestiya Akademii Nauk Fizika Atmosfery I Okeana
- Izvestiya Akademii Nauk Sssr Fizika Atmosfery I Okeana
- Izvestiya Atmospheric and Oceanic Physics
- Journal of Applied Meteorology
- Journal of Atmospheric and Oceanic Technology
- Journal of Atmospheric and Solar-Terrestrial Physics
- Journal of Atmospheric and Terrestrial Physics
- Journal of Atmospheric Chemistry
- Journal of Climate
- Journal of Climate and Applied Meteorology
- Journal of Climatology
- Journal of Geophysical Research-Atmospheres
- Journal of Geophysical Research-Oceans and Atmospheres
- Journal of The Atmospheric Sciences
- Journal of The Meteorological Society of Japan
- Meteorological Applications
- Meteorological Magazine
- Meteorologische Rundschau
- Meteorology and Atmospheric Physics
- Monthly Weather Review
- Papers In Meteorology and Geophysics
- Quarterly Journal of The Royal Meteorological Society
- Radio Science
- Rivista Di Meteorologia Aeronautica
- Tellus
- Tellus Series A-Dynamic Meteorology and Oceanography
- Tellus Series B-Chemical and Physical Meteorology
- Theoretical and Applied Climatology
- Weather and Forecasting
- Zeitschrift Fur Meteorologie

Ecology & Biological Resources

- Acta Oecologica-International Journal of Ecology
- Acta Oecologica-Oecologia Applicata
- Acta Oecologica-Oecologia Generalis
- Acta Oecologica-Oecologia Plantarum
- Advances In Ecological Research
- Advances In Microbial Ecology
- African Journal of Ecology
- American Midland Naturalist
- American Naturalist
- Annual Review of Ecology and Systematics
- Applied Soil Ecology
- Aquatic Microbial Ecology
- Archive of Fishery and Marine Research
- Auk
- Austral Ecology
- Australian Journal of Ecology
- Australian Journal of Marine and Freshwater Research
- Australian Wildlife Research
- Biochemical Systematics and Ecology
- Biotropica
- Bird Study
- California Fish and Game
- Canadian Field-Naturalist
- Canadian Journal of Fisheries and Aquatic Sciences
- Condor
- Ecography
- Ecological Bulletins
- Ecological Entomology
- Ecological Monographs
- Ecological Research
- Ecological Studies
- Ecology
- Ecology Letters

- Ecology of Freshwater Fish
- Ecoscience
- Ecosystems
- Environmental and Experimental Botany
- Environmental Biology of Fishes
- Environmental Entomology
- Evolutionary Ecology
- Fems Microbiology Ecology
- Fisheries Research
- Freshwater Biology
- Functional Ecology
- Global Ecology and Biogeography
- Global Ecology and Biogeography Letters
- Helgoland Marine Research
- Holarctic Ecology
- Ibis
- Investigacion Pesquera
- Journal of Animal Ecology
- Journal of Applied Ichthyology
- Journal of Applied Ichthyology-Zeitschrift Fur Angewandte Ichthyologie
- Journal of Avian Biology
- Journal of Biogeography
- Journal of Chemical Ecology
- Journal of Ecology
- Journal of Economic Entomology
- Journal of Experimental Marine Biology and Ecology
- Journal of Fish Biology
- Journal of Freshwater Ecology
- Journal of Marine Systems
- Journal of Natural History
- Journal of Sea Research
- Journal of Vector Ecology
- Journal of Wildlife Management
- Limnology and Oceanography
- Marine and Freshwater Research
- Marine Ecology-Progress Series
- Marine Ecology-Pubblicazioni Della Stazione Zoologica Di Napolil
- Marine Mammal Science
- Microbial Ecology
- Molecular Ecology
- Natural History
- New Zealand Journal of Ecology
- New Zealand Journal of Marine and Freshwater Research
- Northwest Science
- Oecologia
- Oikos
- Ornis Scandinavica
- Oryx
- Pedobiologia
- Phytocoenologia
- Phytoprotection
- Plant Cell and Environment
- Plant Ecology
- Polar Biology
- Population Ecology
- Proceedings of the Academy of Natural Sciences of Philadelphia
- Researches on Population Ecology
- Reviews in Fish Biology and Fisheries
- Revue D'Ecologie Et De Biologie Du Sol
- Revue D'Ecologie-La Terre Et La Vie
- Sarsia
- South African Journal of Wildlife Research
- South African Journal of Wildlife Research-Suid- Afrikaanse Tydskrif Vir Natuurnavorsing
- Studies On Neotropical Fauna and Environment
- Terre Et La Vie-Revue D Ecologie Appliquee
- Theoretical Population Biology
- Transactions of the American Fisheries Society
- Transactions of the North American Wildlife and Natural Resources Conference
- Trends In Ecology & Evolution
- Vegetatio
- Vie et Milieu-Life and Environment
- Wilson Bulletin

Environmental Engineering, Chemistry & Biotechnology

- Acta Biotechnologica
- Aerosol Science and Technology
- Annali Di Chimica
- Applied and Environmental Microbiology
- Applied Catalysis A-General
- Applied Catalysis B-Environmental
- Biocatalysis and Biotransformation
- Biodegradation
- Bioprocess and Biosystems Engineering
- Bioprocess Engineering
- Bioresource Technology
- Building and Environment
- Civil Engineering For Practicing and Design Engineers
- Cold Regions Science and Technology
- Desalination
- Effluent & Water Treatment Journal
- Environmental Engineering Science
- Environmental Progress
- Environmental Technology
- Environmental Technology Letters

- Green Chemistry
- International Biodeterioration Bulletin
- International Journal of Environmental Analytical Chemistry
- Journal American Water Works Association
- Journal of Environmental Engineering-Asce
- Journal of Geotechnical and Geoenvironmental Engineering
- Journal of Hazardous Materials
- Journal of Hydraulic Engineering-Asce
- Journal of Industrial Microbiology & Biotechnology
- Journal of Irrigation and Drainage Engineering-Asce
- Journal of The Air & Waste Management Association
- Journal of The Environmental Engineering Division-Asce
- Journal of Waterway Port Coastal and Ocean Engineering-Asce
- Ozone-Science & Engineering
- Proceedings of the Institution of Civil Engineers-Water Maritime and Energy
- Process Biochemistry
- Renewable & Sustainable Energy Reviews
- Stochastic Hydrology and Hydraulics
- Water & Wastes Engineering

Environmental Planning, Management & Conservation

- Alternatives-Perspectives On Society Technology and Environment
- Annual Review of Energy and The Environment
- Biocycle
- Biodiversity and Conservation
- Biological Conservation
- Biological Control
- Climate Policy
- Coastal Management
- Coastal Zone Management Journal
- Conservation & Recycling
- Conservation Biology
- Crc Critical Reviews In Environmental Control
- Critical Reviews In Environmental Control
- Earth Island Journal
- Ecological Economics
- Ecology Law Quarterly
- Ecosystem Health
- Energy Journal
- Energy Policy
- Environment and Behavior
- Environment and Planning A
- Environment and Planning B-Planning and Design
- Environment and Planning C-Government and Policy
- Environment and Urbanization
- Environmental & Resource Economics
- Environmental Claims Journal
- Environmental Conservation
- Environmental Ethics
- Environmental Impact Assessment Review
- Environmental Management
- Environmental Policy and Law
- Forest Ecology and Management
- Harvard Environmental Law Review
- Human and Ecological Risk Assessment
- International Journal of Sustainable Development and World Ecology
- Irrigation Science
- Japca-The Journal of The Air & Waste Management Association
- Journal of Applied Ecology
- Journal of Aquatic Plant Management
- Journal of Architectural and Planning Research
- Journal of Environmental Economics and Management
- Journal of Environmental Management
- Journal of Environmental Monitoring
- Journal of Environmental Quality
- Journal of Range Management
- Journal of Soil and Water Conservation
- Journal of The Chartered Institution of Water and Environmental Management
- Journal of The Institution of Water and Environmental Management
- Journal of Water Resources Planning and Management-Asce
- Land Use Policy
- Landscape and Urban Planning
- Marine Policy
- Natural Resources Forum
- Natural Resources Journal
- Natural Resources Lawyer
- New Forests
- Ocean Management
- Pest Management Science
- Population and Environment
- Regulated Rivers-Research & Management
- Resource and Energy Economics
- Resource Recovery and Conservation
- Resources and Conservation
- Resources and Energy
- Resources Policy
- River Research and Applications
- Society & Natural Resources
- Soil Use and Management
- Stochastic Environmental Research and Risk Assessment
- Transportation Research Part D-Transport and Environment
- Urban Ecology
- Water Supply & Management

- Wildlife Monographs
- Wildlife Research
- Wildlife Society Bulletin

Environmental Sciences - General

- Agricultural Wastes
- Agriculture and Environment
- Agriculture Ecosystems & Environment
- Agro-Ecosystems
- Ambio
- Annual Review of Environment and Resources
- Antarctic Science
- Arctic
- Arctic and Alpine Research
- Arctic Antarctic and Alpine Research
- Biogeochemistry
- Biological Wastes
- Biology and Environment-Proceedings of The Royal Irish Academy
- Catena
- Chemosphere
- Critical Reviews In Environmental Science and Technology
- Current Contents/Agriculture Biology & Environmental Sciences
- Ecological Applications
- Ecological Engineering
- Ecological Modelling
- Environment
- Environmental Geology
- Environmental History
- Environmental Politics
- Environmental Research
- Environmental Science & Technology
- Environmental Values
- Environmetrics
- Estuaries
- Futures
- Geomicrobiology Journal
- Global and Planetary Change
- Global Biogeochemical Cycles
- Global Change Biology
- Global Environmental Change-Human and Policy Dimensions
- Human Ecology
- Journal of Aerosol Science
- Journal of Agricultural & Environmental Ethics
- Journal of Agricultural Biological and Environmental Statistics
- Journal of Arid Environments
- Journal of Coastal Research
- Journal of Energy and Development
- Journal of Environmental Psychology
- Journal of Environmental Sciences
- Journal of Environmental Systems
- Journal of Forestry
- Mountain Research and Development
- Polar Research
- Remote Sensing of Environment
- Sar and Qsar In Environmental Research
- Science of The Total Environment
- World Watch

Pollution, Environmental Toxicology & Health

- American Industrial Hygiene Association Journal
- American Journal of Industrial Medicine
- Annals of Occupational Hygiene
- Applied Geochemistry
- Aquatic Toxicology
- Archives of Environmental Contamination and Toxicology
- Archives of Environmental Health
- Aviation Space and Environmental Medicine
- British Journal of Industrial Medicine
- Bulletin of Environmental Contamination and Toxicology
- Ecotoxicology
- Ecotoxicology and Environmental Safety
- Environmental and Molecular Mutagenesis
- Environmental Carcinogenesis & Ecotoxicology Reviews- Part C of Journal of Environmental Science and Health
- Environmental Carcinogenesis Reviews-Part C of Journal of Environmental Science and Health
- Environmental Health Perspectives
- Environmental Mutagenesis
- Environmental Pollution
- Environmental Pollution Series A-Ecological and Biological
- Environmental Pollution Series B-Chemical and Physical
- Environmental Science and Pollution Research
- Environmental Toxicology
- Environmental Toxicology and Chemistry
- Environmental Toxicology and Pharmacology
- Environmental Toxicology and Water Quality
- European Journal of Pharmacology-Environmental Toxicology and Pharmacology Section
- Fluoride
- Fundamental and Applied Toxicology
- Indoor Air
- Indoor Air-International Journal of Indoor Air Quality and Climate
- Industrial Health
- International Archives of Occupational and Environmental Health
- International Journal of Hygiene and Environmental Health
- International Journal of Occupational and Environmental Health
- Japca-The International Journal of Air Pollution Control and Hazardous Waste Management

- Journal of Analytical Toxicology
- Journal of Contaminant Hydrology
- Journal of Environmental Health
- Journal of Environmental Pathology and Toxicology
- Journal of Environmental Pathology Toxicology and Oncology
- Journal of Environmental Science and Health Part A-Environmental Science and Engineering
- Journal of Environmental Science and Health Part A-Environmental Science and Engineering & Toxic and Hazardous Substance Control
- Journal of Environmental Science and Health Part A-Toxic/Hazardous Substances & Environmental Engineering
- Journal of Environmental Science and Health Part B- Pesticides Food Contaminants and Agricultural Wastes
- Journal of Environmental Science and Health Part C-Environmental Carcinogenesis & Ecotoxicology Reviews
- Journal of Environmental Science and Health Part C-Environmental Carcinogenesis Reviews
- Journal of Environmental Science and Health Part C-Environmental Health Sciences
- Journal of Occupational and Environmental Hygiene
- Journal of Occupational and Environmental Medicine
- Journal of Occupational Medicine
- Journal of The Air Pollution Control Association
- Journal of Toxicology and Environmental Health
- Journal of Toxicology and Environmental Health-Part A
- Journal of Toxicology and Environmental Health-Part A- Current Issues
- Journal of Toxicology and Environmental Health-Part B- Critical Reviews
- Marine Pollution Bulletin
- Microbial Ecology In Health and Disease
- Mutation Research-Environmental Mutagenesis and Related Subjects
- Mutation Research-Genetic Toxicology and Environmental Mutagenesis
- Occupational and Environmental Medicine
- Pesticide Science
- Pesticides Monitoring Journal
- Radiation and Environmental Biophysics
- Residue Reviews
- Reviews of Environmental Contamination and Toxicology
- Scandinavian Journal of Work Environment & Health
- Toxicological and Environmental Chemistry
- Toxicology
- Toxicology and Applied Pharmacology
- Toxicology and Industrial Health
- Toxicology Letters
- Water Air and Soil Pollution
- Zentralblatt Fur Hygiene Und Umweltmedizin

Water Resources

- Acta Hydrochimica Et Hydrobiologica
- Advances In Water Resources
- Agricultural Water Management
- Aquatic Conservation-Marine and Freshwater Ecosystems
- Aquatic Sciences
- Archiv Fur Hydrobiologie
- Environmental Geology and Water Sciences
- Ground Water
- Ground Water Monitoring and Remediation
- Hydrobiologia
- Hydrological Sciences Journal-Journal Des Sciences Hydrologiques
- International Hydrographic Review
- International Review of Hydrobiology
- Internationale Revue Der Gesamten Hydrobiologie
- Journal of Geophysical Research-Oceans
- Journal of Great Lakes Research
- Journal of Hydrology
- Journal of the American Water Resources Association
- Journal Water Pollution Control Federation
- Marine Environmental Research
- Nordic Hydrology
- Progress In Water Technology
- Research Journal of The Water Pollution Control Federation
- Schweizerische Zeitschrift Fur Hydrologie-Swiss Journal of Hydrology
- Water and Environment Journal
- Water Environment Research
- Water Pollution Control
- Water Quality Research Journal of Canada
- Water Research
- Water Resources Bulletin
- Water Resources Research
- Water Sa
- Water Science and Technology
- Water-Engineering & Management
- Wem-Water Engineering & Management
- Zeitschrift Fur Wasser Und Abwasser Forschung-Journal For Water and Wastewater Research

Appendix B Inter-institutional collaboration among top 10 Canadian institutions and their 20 most important collaborators

Table XX Inter-institutional collaboration among top 10 Canadian institutions and their 20 most important collaborators in environmental research by importance (rank) and by proportion of total collaboration, 1995–2004

	Institution / Collaborator	Environment Canada		Fisheries and Oceans Canada		University of British Columbia		University of Toronto		McGill University		University of Alberta		University of Guelph		University of Waterloo		Natural Resources Canada		Université Laval	
		Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)
TOP 10 Institions	**Environment Canada**			1	(11.8%)	1	(9.5%)	1	(14.3%)	1	(13.2%)	1	(11.2%)	1	(20.1%)	1	(16.6%)	1	(6.8%)	3	(6.0%)
	Fisheries and Oceans Canada	1	(6.7%)			2	(7.3%)	7	(3.0%)	7	(3.9%)	2	(6.8%)	4	(5.3%)	3	(7.5%)	17	(2.5%)	1	(9.7%)
	University of British Columbia	6	(4.4%)	5	(6.0%)			14	(2.4%)	27	(1.1%)	4	(4.2%)	8	(3.3%)	5	(4.6%)	3	(5.1%)	29	(0.8%)
	University of Toronto	4	(4.9%)	20	(1.8%)	13	(1.8%)			15	(1.8%)	15	(1.6%)	3	(7.0%)	6	(4.2%)	12	(3.0%)	21	(1.4%)
	McGill University	5	(4.7%)	14	(2.5%)	29	(0.8%)	16	(1.9%)			10	(2.2%)	15	(1.7%)	24	(1.0%)	14	(2.8%)	6	(5.2%)
	University of Alberta	9	(3.4%)	8	(3.6%)	7	(2.7%)	21	(1.4%)	14	(1.8%)			9	(3.0%)	10	(2.5%)	2	(6.8%)	13	(1.8%)
	University of Guelph	3	(5.3%)	13	(2.5%)	11	(1.9%)	3	(5.3%)	26	(1.2%)	6	(2.6%)			2	(8.0%)	5	(4.0%)	25	(1.0%)
	University of Waterloo	7	(4.3%)	9	(3.4%)	8	(2.5%)	6	(3.2%)	40	(0.7%)	9	(2.2%)	2	(7.8%)			21	(2.3%)	15	(1.8%)
	Natural Resources Canada	18	(1.8%)	27	(1.1%)	6	(2.9%)	15	(2.3%)	12	(2.1%)	3	(5.9%)	6	(4.0%)	11	(2.4%)			5	(5.6%)
	Université Laval	32	(1.3%)	7	(3.8%)	75	(0.4%)	32	(0.9%)	8	(3.2%)	17	(1.3%)	29	(0.8%)	17	(1.5%)	4	(4.6%)		
Canadian universities	Carleton University	15	(2.4%)											19	(1.3%)			19	(2.5%)		
	Dalhousie University			2	8.0%					19	(1.6%)									17	(1.8%)
	INRS			12	2.5%					5	(5.0%)									4	(5.6%)
	McMaster University	10	(3.1%)					2	(6.0%)	11	(2.1%)			16	(1.7%)	4	(4.7%)				
	Memorial University of Newfoundland			4	6.0%																
	Queens University	20	(1.7%)			16	(1.4%)	8	(2.7%)							7	(3.4%)				
	Ryerson Polytechnic University							11	(2.5%)												
	Simon Fraser University	13	(2.7%)	16	2.1%	4	(3.3%)														
	Trent University	17	(2.0%)					5	(3.4%)	16	(1.7%)					18	(1.4%)				
	Université de Montréal									3	(7.2%)	11	(1.9%)							10	(3.4%)
	Université du Québec à Montréal									4	(5.7%)							15	(2.8%)	9	(4.0%)
	Université sherbrooke									20	(1.6%)									16	(1.8%)
	University of Calgary					15	(1.5%)					7	(2.4%)					16	(2.6%)		
	University of Manitoba			3	7.9%	10	(1.9%)					8	(2.3%)	18	(1.3%)	9	(2.7%)				
	University of New Brunswick			11	2.6%											16	(1.5%)	9	(3.5%)		
	University of Northern British Columbia											18	(1.3%)								
	University of Ottawa	19	(1.8%)					18	(1.5%)	18	(1.6%)							7	(3.6%)	14	(1.8%)
	University of Saskatchewan	2	(6.4%)									13	(1.7%)	12	(2.2%)	14	(1.9%)				
	University of Victoria			17	2.1%	9	(2.0%)											13	(3.0%)		
	University of Western Ontario													10	(2.8%)						
	UQAR			6	5.1%															2	(7.5%)
	UQTR																			20	(1.6%)
	Wilfrid Laurier University															8	(2.9%)				
	York University	12	(2.7%)					4	(3.4%)												

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST

Table XX (Cont'd) Inter-institutional collaboration among top 10 Canadian institutions and their 20 most important collaborators in environmental science by importance (rank) and by proportion of total collaboration, 1995–2004

	Collaborator \ Institution	Environment Canada		Fisheries and Oceans Canada		University of British Columbia		University of Toronto		McGill University		University of Alberta		University of Guelph		University of Waterloo		Natural Resources Canada		Université Laval	
		Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)	Rk	(%)
Provincial	Alberta Environment											16	(1.4%)								
	Alberta Research Council											20	(1.3%)								
	BC Ministry of Health					12	(1.9%)														
	British Columbia Ministry of Forests					5	(3.0%)														
	MAPAQ (Quebec Ministry of Agriculture)																			12	(2.4%)
	MRNF (Quebec Ministry of Natural Resources)																			8	(4.8%)
	Ontario Ministry of Environment and Energy							19	(1.5%)							13	(2.0%)				
	Ontario Ministry of Natural Resources							17	(1.8%)					7	(3.6%)			6	(3.8%)		
	Ontario Workers' Compensation Board							10	(2.5%)												
	Royal Ontario Museum							20	(1.5%)												
	Santé et Services sociaux Québec									9	(3.0%)									11	(3.4%)
International	CNRS																			19	(1.6%)
	Indiana University					17	(1.4%)														
	INRA																			18	(1.6%)
	Michigan State University													14	(1.8%)						
	NASA	11	(2.8%)															11	(3.1%)		
	Nat'l Center for Atmosph Res (NCAR)	14	(2.6%)					13	(2.4%)	13	(1.8%)										
	NOAA	8	(4.2%)	10	2.7%	18	(1.3%)														
	Norwegian Institute for Nature Research															20	(1.4%)				
	The University of Texas													20	(1.3%)						
	University of California, Davis							12	(2.4%)												
	University of Maryland									10	(2.4%)							8	(3.6%)		
	University of Minnesota					20	(1.2%)														
	University of Washington			15	2.4%	3	(3.7%)														
	University of Wisconsin					14	(1.8%)					14	(1.7%)	11	(2.3%)	15	(1.5%)				
	US-EPA													17	(1.5%)						
	US-Forest Service																	10	(3.5%)		
	US-FWS			19	1.9%																
	US-GS			18	1.9%							12	(2.0%)			12	(2.0%)	18	(2.5%)		

Source: Data compiled by Science-Metrix from Thomson-Scientific data prepared by OST