The Influence of Scientists and Scientific Knowledge on International Environmental Policy: Canada, Persistent Organic Pollutants, and the Stockholm Convention

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Abstract

This thesis seeks to enhance our understanding of the role of science in international environmental policymaking through a case study of the influence of scientists and scientific knowledge on Canada's foreign policy with respect to persistent organic pollutants (POPs) from shortly before the discovery of the global nature of the problem (around 1980) to the signing of the United Nations Convention on Persistent Organic Pollutants (in 2001). The influence of different types of scientific knowledge and actions by scientists in the formation and development of Canada's POPs foreign policy is analyzed. A typology of knowledge types and knowledge actions was developed. Three main conclusions were drawn: (1) different types of scientific knowledge influence policy differently; (2) cross-disciplinary transmission of knowledge is a critical action; and (3) there is a dynamic interaction between differing knowledge types and actions that affects policy differently during the various stages of policy development.
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<tr>
<td>AMAP</td>
<td>Arctic Monitoring and Assessment Programme</td>
</tr>
<tr>
<td>CACAR</td>
<td>Canadian Arctic Contaminants Assessment Report</td>
</tr>
<tr>
<td>DDT</td>
<td>Dichlorodiphenyl trichloroethane</td>
</tr>
<tr>
<td>DEW</td>
<td>Distant early warning</td>
</tr>
<tr>
<td>DFO</td>
<td>Department of Fisheries and Oceans</td>
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<tr>
<td>DIAND</td>
<td>Department of Indian Affairs and Northern Development</td>
</tr>
<tr>
<td>EC</td>
<td>Environment Canada</td>
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<td>FAO</td>
<td>Food and Agriculture Organization</td>
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<tr>
<td>HC</td>
<td>Health Canada</td>
</tr>
<tr>
<td>HCB</td>
<td>Hexachlorobenzene</td>
</tr>
<tr>
<td>HCH</td>
<td>Hexachlorocyclohexane</td>
</tr>
<tr>
<td>IFCS</td>
<td>Intergovernmental Forum on Chemical Safety</td>
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<tr>
<td>IOMC</td>
<td>Inter-organizational Programme for the Sound Management of Chemicals</td>
</tr>
<tr>
<td>IPCS</td>
<td>International Programme on Chemical Safety</td>
</tr>
<tr>
<td>INAC</td>
<td>Indian and Northern Affairs Canada</td>
</tr>
<tr>
<td>IR</td>
<td>International Relations</td>
</tr>
<tr>
<td>LRTAP</td>
<td>Convention on Long-range Transboundary Air Pollution</td>
</tr>
<tr>
<td>NCP</td>
<td>Northern Contaminants Program</td>
</tr>
<tr>
<td>OC</td>
<td>Organochlorine</td>
</tr>
<tr>
<td>OECD</td>
<td>Organization for Economic Cooperation and Development</td>
</tr>
<tr>
<td>PBT</td>
<td>Persistent, bioaccumulative, and toxic substance</td>
</tr>
<tr>
<td>PCB</td>
<td>Polychlorinated biphenyl</td>
</tr>
<tr>
<td>POP</td>
<td>Persistent organic pollutant</td>
</tr>
<tr>
<td>SOAER</td>
<td>State of the Arctic Environment Report</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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Chapter 1. Introduction

Many problems that become the object of international environmental policy are recognized and understood only through scientific research, including problems such as stratospheric ozone depletion, climate change, and persistent organic pollutants. Science is therefore an important element in the policymaking process, and as such, social scientists have sought a deeper understanding of the relationship between science and policy. Studies in the social sciences have identified and investigated numerous factors related to scientists and scientific knowledge that influence international environmental policy formation and development. Since around 2000, the number of these studies has increased phenomenally; however, most treat science in a superficial manner in the sense that they do not dig deep into the inner workings of science and track both its obvious and subtle relationships to policymaking. In addition, few specifically examine the influence of such factors in Canada. To understand fully how international environmental policy is initiated and developed both in Canada and elsewhere, mapping the influence of scientists and scientific knowledge from the discovery of an environmental problem to an advanced endpoint (e.g., the signing of an international environmental agreement) is necessary.

This thesis seeks to increase our knowledge of the link between science and policy in general, and between science and Canada’s environmental foreign policy in particular, through a case study of the influence of scientists and scientific knowledge on Canada’s foreign policymaking with respect to persistent organic pollutants (POPs) from the discovery of the problem up to the signing in 2001 of the United Nations Stockholm Convention on Persistent Organic Pollutants (hereafter referred to as the Stockholm Convention).
POPs became an object of international environmental policymaking because of their persistence, toxicity, and ability to be transported throughout the globe and accumulate in cold environments. Canada played a leadership role in developing the Stockholm Convention and helped convince the international community that global regulation of POPs was necessary. Thus, there is a large literature describing the scientific work of Canadian scientists and describing Canada’s foreign policymaking efforts; however, there has been little work investigating the relationship between the two. My thesis aims to fill this gap. The central question investigated in this thesis is:

What types of scientific knowledge and what actions by scientists were most influential in the formation and development of Canada’s foreign policy on POPs between 1980 and 2001?

The case of POPs provides an excellent setting for investigating the role of science in international environmental policymaking in general, and the influence of Canadian scientists and scientific knowledge in the formation of Canada’s foreign policymaking in particular, for the following reasons. First, as mentioned above, POPs are a major environmental problem. They are an international problem, with global environmental and human health implications.

Second, POPs is a recent example of an international environmental problem for which a multilateral environmental agreement has been formed (i.e., the Stockholm Convention). The Stockholm Convention provides a logical endpoint for studying the influence of scientists and scientific knowledge on policymaking. Furthermore, the fact that the entire development of the POPs issue, from the discovery of the problem to the signing of
the Stockholm Convention, occurred within the last twenty years means that many of the scientists involved in influencing policy formation are still available to be interviewed.

Third, as already mentioned, the Canadian government played a leadership role on POPs. After the discovery of POPs contamination in the Arctic, Canada began a major research program, the Northern Contaminants Program (NCP), to gain a better understanding of what pollutants were present in the Arctic, the pathways through which they arrived in the Arctic, and their implications for human health and the environment. Thus, support for scientific research was a major part of Canada’s leadership role in the formation of the Stockholm POPs Convention.

Fourth, POPs is an issue of particular importance to Canadians due to contamination of the Canadian Arctic. POPs tend to accumulate in cooler regions of the world and, consequently, much of northern Canada is contaminated. Since Canada’s northern indigenous peoples rely heavily on the northern environment as a source of foods, they have also become highly contaminated. Thus, Canadians are experiencing some of the worst effects of POPs in the world. This makes the issue of particular interest to Canada.

Finally, there is a large volume of scientific research on the problem. For the social scientist, this means detailed data are available for investigating the inner workings of science and its relationship to policy. The community of Canadian scientists involved in POPs research between 1980 and 2001 was relatively large and many of these scientists were involved in efforts to promote the formation of a multilateral environmental agreement. They were also heavily involved in educating and working with the indigenous peoples of the Arctic with respect to the POPs issue, which in turn influenced policy.
As mentioned earlier, few studies have analyzed the relationship between Canadian scientists, scientific knowledge, and Canada’s environmental foreign policymaking process on POPs. The work that has been done to present lacks depth. To the best of my knowledge, this study is the first in-depth historical analysis of the influence of Canadian science on Canada’s foreign policymaking on POPs, and as such contributes to understanding not only to the science-policy interface in Canada, but also the interface in general. The knowledge gained through this study may be used to better focus scientists’ efforts on the generation of knowledge that is useful and influential with respect to foreign policy and on activities that enhance the likelihood of formulating effective policy decisions. Furthermore, the results of this study may be used to enhance our understanding of the influence of science and scientists on international regime-formation processes.

Based on the social science literature related to the science-policy interface, I selected two concepts related to scientists and scientific knowledge as the basis for my analysis. First, related to scientific knowledge, I selected the concept of “knowledge types” (Hunt and Shackley 1999; Dimitrov 2002, 2003a, 2003b; Selin and Eckley 2003; Wilkening 2004). The concept of knowledge types revolves around the idea that different types of scientific knowledge may influence policymaking differently. Each of the authors cited above categorizes knowledge differently. As will be explained in Chapter 2, I use a categorization of knowledge types loosely based on the work of Wilkening and Dimitrov. Throughout my period of analysis, I determined which knowledge types were most prominent in stimulating policy at each stage of development of the issue, and how these knowledge types influenced policy. Second, related to scientists, I selected the concept of “knowledge actions”. Three main categories of knowledge actions are knowledge creation, knowledge translation, and
knowledge transmission (Wilkening 2004). The first step of my analysis was to survey the academic literature on the science-policy interface, and, based on this, develop a general categorization of knowledge types and actions.

The period of analysis for this case study is the time-span beginning shortly before the discovery of the global nature of the POPs problem (around 1980) up to the signing of the Stockholm POPs Convention (in 2001). To evaluate how the influence of scientists’ actions and scientific knowledge types on Canadian foreign policy evolved over time, I divided this period of analysis (1980-2001) into four time-periods. This was the second step of my analysis. The knowledge types and knowledge actions influential on Canadian foreign policy were identified and analyzed in each of these periods (the third step of my analysis), and, by comparing the results from the four time-periods, the evolution of the influence of scientists and scientific knowledge with respect to the policymaking process in Canada was determined (the fourth step of my analysis).

Finally, based on my results from the case study, I created a more detailed and refined categorization of knowledge types and actions which I believe will be a useful addition to the general literature on the science-policy interface of international environmental problems (Chapter 5). By examining the influence of both scientists and scientific knowledge my analysis provides a more detailed, multi-dimensional model of the influence of science on policy than is generally found in the literature. It contributes not only to our understanding of the influence of scientists and scientific knowledge on the Canadian environmental foreign policymaking process, but also to our understanding of the science-policy interface in general.
The remainder of this thesis is divided into five parts. Chapter 2 summarizes the academic literature on the science-policy interface and describes the theoretical framework that will be used to answer the thesis question. Chapter 3 provides background on the science of POPs and an explanation of the scientific terms needed to understand the developments in POPs science discussed in Chapter 4, and thus, the impacts they had on policy. Chapter 4 presents the case study. Each of the four time-periods is analyzed and compared in terms of the influence of scientists’ actions and scientific knowledge types on Canada’s environmental foreign policy process. In Chapter 5, I present my refined categorization of knowledge types and actions as an improved model of the influence of scientists and scientific knowledge on policy development. In Chapter 6, I summarize my conclusions and provide suggestions for future research.
Chapter 2. The science-policy interface: Theory and method

In the social sciences, the role of scientists and scientific knowledge are recognized as key factors in foreign policymaking and regime formation\(^1\). Numerous studies (discussed below) examine these roles, yet most are limited in that they tend to focus either on scientific knowledge or scientists; few focus on both. In this thesis I focus on both scientists and scientific knowledge. Specifically, I focus on the influence of scientists and scientific knowledge on Canada’s environmental foreign policymaking process on POPs (and indirectly I also address regime formation).

Canadian policymaking with respect to POPs began in the mid-to-late 1980s and an international regime formation process was formally begun in the late 1990s. However, the social science literature dealing with these historical events is somewhat limited. The studies that exist tend to analyze the influence of science in terms of the effectiveness of scientific assessments on the policymaking process, and almost all focus on international regime formation.

Noelle Eckley, for instance, analyzes the effectiveness of scientific assessments on the incorporation of scientific knowledge into international policymaking (1999), examines the impact of regional assessments of the POPs issue on later global assessments (2000), and discusses the impacts of the Arctic Monitoring and Assessment Programme’s assessments on international policymaking (Eckley and Selin 2003). Rodan et al. (1999) and Selin and Hjelm (1999) look at the role of science and policy in the process of developing screening procedures for identifying POPs.

\(^1\) Regimes are "social institution[s] composed of agreed upon principles, norms, rules, and decision-making procedures that govern the interactions of actors in specific issue areas" (Osherenko and Young 1993, 1).
Several works published in *Northern Lights Against POPs: Combating Toxic Threats in the Arctic* (Downie and Fenge 2003) look at the role of organizations on POPs policymaking at both the national and international levels. Reiersen et al. (2003) examine the role of the Arctic Monitoring and Assessment Programme in the international regime-formation processes. Shearer and Han (2003) discuss the role of Canada and the Northern Contaminants Program on the international policymaking processes. Selin (2003) and Downie (2003) discuss the events leading up to the formation of the LRTAP POPs Protocol and the Stockholm Convention respectively.

None of these works deal specifically with the influence of scientific knowledge types or the actions of scientists. Rather, they tend to examine the general incorporation of scientific knowledge into policy through scientific assessments and the general impact of scientists through scientific institutions such as the Arctic Monitoring and Assessment Programme. As stated above, this thesis is designed to fill this gap in the literature by means of a detailed study of the influence of both scientific knowledge types and actions by scientists on Canada’s environmental foreign policymaking process on POPs.

In this chapter I review the international relations (IR) literature on the influence of scientists and scientific knowledge on foreign policymaking and regime formation. Based on this literature I chose two concepts as the basis for my investigation of the influence of scientists and scientific knowledge on Canadian foreign policymaking on POPs. The first concept relates to the actions of scientists that influence policy. I term this *knowledge actions*. As discussed below, my starting point in examining knowledge actions is scientists’ roles in generating, interpreting, and communicating scientific knowledge. My second concept, related to scientific knowledge, is *knowledge types*. Scientific knowledge in itself
(i.e., independent of the actions of scientists) may influence policy and several recent publications suggest that various types of knowledge may affect policy differently (Dimitrov 2002, 2003a, 2003b; Wilkening 2004). Using these two concepts and based on a survey of the literature, I devised a categorization scheme of knowledge actions and types with which to begin my analysis. This categorization scheme is discussed below.

A sub-discipline of IR theory that might be called “the science and politics of international environmental problems” first took shape in the early 1990s. Peter Haas (1989), through his concept of epistemic communities, was one of the first to offer a detailed approach to studying the influence of science on international environmental policymaking. Epistemic community theory (Haas 1989, 1990a, 1990b, 1992a, 1992b, 1993a, 1993b, 1997) emphasizes, and examines more deeply than previous work, the roles of scientists in the international policymaking process. Epistemic communities are “[networks] of professionals with recognized expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain” (Haas 1992, 3). According to Haas, epistemic communities (or members of epistemic communities) may, in addition to producing scientific knowledge, eventually become part of an international policymaking bureaucracy, thus enhancing their influence in defining problems and shaping their solutions. If members of an epistemic community have political influence in several states, they can help create a convergence of understanding with respect to the problem, which can then be used to gain consensus around a solution. Peter Haas developed his epistemic community concept through a case study of Mediterranean pollution (Haas 1989). He then applied it to the case of stratospheric ozone depletion (Haas 1992b). Haas’ epistemic community theory has since been adopted and re-molded for application to variety of cases, including nuclear
Epistemic community theory focuses almost exclusively on the role of scientists. It does not adequately address the influence of scientific knowledge. In addition, the theory focuses mostly on activities related to the direct political power of groups of scientists, rather than the full range of scientists’ activities (power and non-power related) that influence the policymaking process. There are also other problems with epistemic community theory. For instance, there may be multiple interpretations of a given issue within an epistemic community, and consequently, there may be multiple solutions advocated within the same community. In other words, there may be sub-communities within single community of experts. Because of these and other problems, I chose to focus on the activities (actions) of scientists rather than on communities of scientists. I focus on scientists’ actions because I believe this to be a more fundamental level of analysis. Scientists’ actions may or may not relate to their ‘community’ involvement.

Influenced by Haas’ work, much of the literature before 2000 focused on the role of scientists in international environmental policymaking. Starting in the mid-to-late 1990s, however, the role of scientific knowledge began to attract analytic attention. Osherenko and Young (1993), for instance, looked at “knowledge-based factors” that influence regime formation. Knowledge-based factors “affect power and operate as determinants of interest,” in addition to playing “a more direct role in regime formation” (Osherenko and Young 1993, 19). According to Osherenko and Young, the degree to which policymakers share a common understanding of an environmental problem, its causes, and solutions may influence the
likelihood of regime formation. Osherenko and Young’s treatment of knowledge-based factors does not, however, analyze the influence of scientists and scientific knowledge in detail. They merely highlight the influence of both scientists and scientific knowledge. To better understand the complex influences of scientists and scientific knowledge in the policymaking process, a more nuanced approach is needed. As already mentioned, I examine both scientists (via knowledge actions) and scientific knowledge (via knowledge types) to gain a fuller understanding of the role of science in policy.

More recently, the impact of scientific assessments (where assessments are one form of action by scientists) has become a hot topic in the IR literature on the science-policy interface (Selin and Eckley 2003; Parson 2002; Selin and Hjelm 1999; Rodan et al. 1999). While such studies codify the “large-scale” activities of scientists, they do not codify “everyday activities” of scientists that might influence policy. To understand the influence of scientists on policymaking, it is necessary to understand both the large-scale and everyday actions of scientists.

Wilkening (2004) uses three categories of knowledge actions (creation, translation, and transmission) to capture both the large- and small-scale aspects of scientists’ influence. Knowledge creation is the creation of new knowledge through any of a wide variety of activities (e.g., scientific experiments). Knowledge translation is the conversion of knowledge into another form, usually for a different audience (e.g., translating scientific knowledge into layman terms for policymakers or for journalists). This often involves a change in the way the knowledge is expressed (e.g., converting technical language to lay or everyday language). Knowledge transmission is the spread of knowledge (e.g., the dissemination of knowledge within an academic discipline via scientific journals).
I employed Wilkening’s three categories of knowledge actions as my starting point for analyzing the influence of scientists’ actions on Canada’s foreign POPs policymaking process. However, as will become apparent in the discussion of the case study in Chapter 4, I refined them considerably, arriving at a set of distinct actions within each of these three categories.

In recent years, a number of concepts based on knowledge types have also emerged in the literature. Hunt and Shackley (1999), for instance, identify three types of knowledge that are relevant to the policymaking process: academic knowledge, bureaucratic knowledge, and fiducial knowledge. Academic knowledge is the type of knowledge that is created in academia, bureaucratic knowledge the type of knowledge used by policymakers in making policy decisions, and fiducial knowledge the form of knowledge created when academic knowledge is translated into a policy-relevant form for policymakers. This codification, however, divides scientific knowledge into only two types – “pure” academic knowledge and “policy-oriented” knowledge.

Radoslav Dimitrov (2002, 2003a, 2003b) codifies knowledge differently. Analyzing the cases of deforestation and coral reef protection to find out why international regimes failed to form relative to these issues, he identified three types of research-derived shared knowledge: “(a) knowledge about the extent of the problem, (b) knowledge about the causes of the problem, and (c) knowledge about its consequences for human societies” (Dimitrov 2002, 55). Of these three types, he concludes that knowledge about the transnational consequences of an international environmental problem is the most significant. The main reason international regime formation has so far been unsuccessful in the deforestation and
coral reef cases, he concludes, is the lack of scientific evidence detailing their transboundary consequences.

Ken Wilkening (2004) codifies knowledge in a similar fashion to Dimitrov. Through an analysis of Japan’s acid rain history between 1868 and 1990 he identifies six types of “policy-influencing” knowledge: (1) existence knowledge (“concepts expressing the existence of a problem”), (2) character knowledge (“concepts expressing the character of some aspect of a problem”), (3) extent-intensity knowledge (“concepts describing the extent and/or intensity of the problem or an aspect of it, including trends and distributions”), (4) cause and effect knowledge (“concepts codifying chains of cause and effect”), (5) impact knowledge (“concepts delineating impacts of the problem on society and/or ecosystems”), and (6) solution knowledge (“concepts expressing all or part of the solution [to the problem in question]”). According to Wilkening, over the course of Japan’s acid rain history, these different knowledge types influenced Japan’s acid rain policy in different ways.

Framework and Methodology

Using Wilkening’s concepts of knowledge actions and Dimitrov’s and Wilkening’s concepts of knowledge types as starting points, I devised a general typology of knowledge actions and types for my analysis of the influence of scientists and scientific knowledge on Canadian foreign policymaking on POPs between 1980 and 2001, as shown in Figure 2.1. Using this scheme, I began my analysis of each of the four time-periods. The determination of these time-periods is discussed in the following section.
**Figure 2.1** A typology of scientific knowledge types and actions

<table>
<thead>
<tr>
<th>Knowledge Types</th>
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<tr>
<td>existence</td>
</tr>
<tr>
<td>extent</td>
</tr>
<tr>
<td>cause(^2)</td>
</tr>
<tr>
<td>consequences</td>
</tr>
<tr>
<td>character</td>
</tr>
</tbody>
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<tr>
<th>Knowledge Actions</th>
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<tr>
<td>creation</td>
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<tr>
<td>translation</td>
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<td>transmission</td>
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</tbody>
</table>

**Period of analysis**

The time-span covered in this case study extends from shortly before the discovery of the global nature of the POPs problem (around 1980) up to the signing of the Stockholm Convention (in 2001). To evaluate how knowledge types and knowledge actions evolved over time, I divided this time-span into four periods. I defined these four time-periods using the concept of a "problem-framework" (Wilkening 2004). A problem-framework is a framework for representing/interpreting an environmental problem. It is an understanding of a specific problem (e.g., POPs), including accepted knowledge about the problem, methodologies and approaches to research, and potential solutions.\(^3\)

\(^2\) In this case I am using Wilkening's concept. Cause knowledge codifies chains of cause and effect, and is an amalgam of other knowledge types that describe the cause and effect chain from sources to receptor to impacts.

\(^3\) Wilkening (2004, 16) defines a problem-framework as "a more or less coherent, codified, and integrated set of methodologies, knowledge derived from the methodologies, and orientations and approaches to the generation and application of the knowledge, that relate to a specific environmental problem area, and that serve as a template for researching and understanding the problem and for action to address the problem area during a given time-period and at a given geographic location".
Between 1980 and 2001, there were four time-periods associated with three distinct problem-frameworks that characterize the changing nature of the POPs problem. The transition between each problem-framework is marked by a sort of "paradigm shift" (or as Wilkening terms it, an "epistemic shift") which significantly alters the perceived nature of the problem. The four time-periods are Pre-1985, 1985-1989, 1989-1996, and 1996-2001, where the three problem-frameworks are associated with the second, third, and fourth periods; the first lacks a distinct problem-framework (see Figure 2.2). Each is discussed below. By comparing the changing influence of different knowledge types and actions between each of the four time-periods, their evolution through time with respect to the policymaking process and their relationship to the POPs problem-framework can be determined.

The first period extends from the late 1800s to the mid-1980s, and is characterized by the slow buildup of scientific knowledge related to POPs. During this period, POPs was not recognized as a distinct environmental problem. Various local and regional problems related to chemical substances (such as DDT) that later came to be defined under the label "POPs" were recognized as environmental problems; however, the extent of the cross-boundary and international/global consequences of these contaminants (especially with respect to the Arctic, and other cold climates) were not known. Around the mid-1980s, though, high concentrations of many POPs were discovered throughout the Arctic environment. Since most of these chemicals had never been used in the Arctic, scientists hypothesized that the sources must lie outside the Arctic. This realization marks the creation of the first POPs problem-framework and the shift between the 1st and 2nd periods. As will be explained in Chapter 4, the first POPs problem-framework was formulated by a technical committee.
convened by the Department of Indian Affairs and Northern Development (DIAND) in 1985. Hence, 1985 marks the transition between the first and second periods.

The second period extends from 1985 to 1989, and is characterized by the growing recognition of the regional/global nature of the problem. After the discovery of widespread contamination of the Arctic environment, the problem was seen mostly as an ecological contamination problem. However, it seemed likely that the indigenous people of the Arctic would also be highly contaminated since they rely heavily on traditional but now contaminated food sources. Studies throughout the Arctic were conducted during this period on a variety of species, primarily to determine the extent of the issue. In 1988 and 1989, two studies were published that identified POPs as a potential human health risk for Arctic indigenous peoples. Eric Dewailly et al. (1989) found extremely high concentrations of POPs in the breast milk of indigenous women in Nunavik. Around the same time, Kinloch and Kuhnlein (1988) found high levels of polychlorinated biphenyls (PCBs) in the blood and breast milk of the residents of Broughton Island, Northwest Territories (now part of Nunavut). The publication of the work of Dewailly et al. (1989) marks a shift in the POPs problem-framework from an ecological problem to a potential human health issue, and the transition from the 2nd to the 3rd period.

The third period extends from 1989 to 1996, and is characterized by the growing acknowledgement of potentially severe risks to human health by exposure to POPs. Thus, there was a shift in emphasis between the second and third periods. POPs were still viewed as a problem of environmental contamination but was now overlaid with concern about their human health risks.
Meanwhile, during the third period evidence was building for the third and final shift in the POPs problem-framework. From the late 1970s, evidence accumulated suggesting that many chemicals (including many POPs) could interfere with the endocrine system. This so-called environmental endocrine hypothesis suggested that many environmental toxins (including many POPs) acted as endocrine disruptors (to be explained in Chapter 3), and could therefore have major environmental and health impacts even at very low concentrations. In 1996, the environmental endocrine hypothesis was popularized in the book *Our Stolen Future* (Colborn et al. 1996), marking the final shift in the POPs problem-framework, from a problem of high-exposure effects to a problem of low-dose effects due to interference with the endocrine system. This also marks the transition from the 3rd to the 4th period.

The publication date of *Our Stolen Future* is a somewhat arbitrary end-point, since much of the evidence for the hypothesis had been collected by the early 1990s and the hypothesis had already made its way into many scientific disciplines, government circles, and to the general public. Nonetheless, it represents the mass-dissemination of the environmental endocrine hypothesis to the general public, and marks the acceptance of endocrine disruptors as a new threat to the environment by the general public (Krimsky 2000). The end of the fourth period, and the endpoint for my study, is marked not by a shift in the POPs problem-framework but by the signing of the Stockholm POPs Convention in 2001.
Figure 2.2 Time-periods of analysis and evolution of problem-frameworks

<table>
<thead>
<tr>
<th>Period I</th>
<th>Period II</th>
<th>Period III</th>
<th>Period IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>(no framework)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local problem, local solution</td>
<td>Regional/global problem, global solution</td>
<td>Regional/global problem, global solution</td>
<td>Regional/global problem, global solution</td>
</tr>
<tr>
<td>A problem of environmental contamination</td>
<td>A problem of environmental contamination</td>
<td>Also a human health problem</td>
<td>Also a human health problem</td>
</tr>
<tr>
<td>Toxic effects at high concentrations</td>
<td>Toxic effects at high concentrations</td>
<td>Toxic effects at high concentrations</td>
<td>Endocrine disruption even at low concentrations</td>
</tr>
</tbody>
</table>

During each of these time-periods, I determined which knowledge types and which knowledge actions were most prominent, and how they influenced policy. Then I compared the results from each time-period to identify general trends. Finally, I returned to my template of knowledge types and actions (Figure 2.1), and, based on my findings from the case study, I refined my categorization of knowledge types and actions.

A combination of document analysis and semi-structured interviews were used to gather information on the different knowledge types and actions that were influential during each of the four time-periods. Documents used include scientific journal articles, scientific reports, government documents, newspaper articles, and social science literature. Scientific journal articles were used primarily to trace the development of the science, and identify potential interviewees. Scientific reports were used to identify the major developments in policy and the science of POPs, priorities and policy positions (of whomever was responsible for the report), the state of knowledge at the time of publication, and potential interviewees.
Major scientific reports include the 1992 special issue of the journal *Science of the Total Environment*, the *Canadian Arctic Contaminant Assessment Reports*, and the Arctic Monitoring and Assessment Program's *State of the Arctic Environment Reports*.

Government documents were used primarily to identify government priorities and policy positions. They were also useful in identifying policy developments and which knowledge types were influential in shaping these developments. Newspaper articles were used to determine what knowledge was in the public sphere. They were also analyzed to determine how issues were presented, and how scientific knowledge was being connected in the public domain (e.g., endocrine effects and Arctic contamination).

The social science literature related to POPs is diverse and includes analyses of the effect of scientific assessments on the international POPs policymaking process and analyses of other environmental problems. This literature aided in identifying major scientific developments (from a policy perspective), major policy developments, and the influence of specific knowledge types and actions on environmental problems.

Eleven scientists who conducted POPs research in Canada during the time-span of my analysis were interviewed: Terry Bidleman (Meteorological Service of Canada), Sue Bonnyman (Northwest Territories Environmental Contaminants Committee), Birgit Braune (Canadian Wildlife Service), Aaron Fisk (National Water Research Institute – Canadian Center for Inland Waters), Mehran Alaee (National Water Research Institute), Neil Burgess (Canadian Wildlife Service), Don Mackay (Trent University), Frank Wania (University of Toronto), Tom Harner (Meteorological Service of Canada), Marlene Evans (National Hydrology Research Institute), and Ih Chu (Health Canada - Environmental and Occupational Toxicology Division, Healthy Environments and Consumer Safety Branch).
Interviewees were selected based on a review of the scientific literature and through personal contacts. Over fifty scientists were contacted, but only those who responded, and were available, were interviewed. Interviews were conducted via email and telephone.

Interviewees were asked about:

- The general chronology of their involvement in POPs research,
- how they disseminated their research results to other scientists, both within their academic discipline and to scientists from other disciplines who also studied POPs,
- how they communicated their research results to policymakers,
- their relationship with policymakers,
- how they communicated their research results to the general public,
- their relationship with the general public,
- their involvement in policymaking (both direct and indirect), and
- their most important research results (in their opinion), whether these results were influential in policy, and how they were influential.

The interviews were semi-structured. Thus, the interviewee was asked a question and then allowed to elaborate on certain points, provide anecdotes, illustrate their experiences, etc.

Before going into the case study, an outline of the science of POPs is provided as background in the following chapter, Chapter 3. This chapter details the characteristics of POPs, and some of the research that has led to our current understanding of them.
Chapter 3. The science of POPs

Introduction

Canada’s POPs policy cannot be fully understood without some understanding of the science that guided this policy. This chapter provides a basic background of POPs science.

POPs are a group of hundreds of chemical compounds with diverse characteristics, many of which are not fully understood. Some are pesticides, others are byproducts of industry. Most have been regulated domestically in industrialized nations for almost 20 years, yet others have been identified only recently (and some undoubtedly remain to be discovered).

The term “persistent organic pollutants” or POPs is relatively new. A variety of terms have been used to refer to all or a portion of the chemical compounds included under the POPs category. For instance, chlorinated POPs have been historically referred to simply as “organochlorines” (OCs) or organochlorine pollutants. Many of the chemicals identified by the Convention on Long-range Transboundary Air Pollution (LRTAP) and the Stockholm Convention as POPs were previously studied and regulated under the similar label of persistent, bioaccumulative and toxic chemicals (PBTs). In general, the schemes used to classify the types of pollutants discussed in this thesis are complex and are often political. Since the term “persistent organic pollutant” did not come into common use until the mid-1990s, when referring to scientific works I will usually employ the terms used by the authors themselves.

This chapter outlines the basic scientific understanding of POPs in the following sequence. First, the POPs classification scheme used in this thesis is explained; namely, the so-called “dirty dozen” POPs compounds that form the basis for regulation in the Stockholm
Convention. The remaining five sections explain the basic properties that define POPs: molecular structure, persistence, volatility and its relationship to long-range transport, bioaccumulation, and effects on wildlife and human health. To facilitate understanding of technical terminology, scientific terms are defined in footnotes.

**Classification and the "Dirty Dozen"**

POPs first began to be produced in large quantities in the first half of the 20\(^{th}\) century. Dozens of new substances, or mixtures of substances, were produced throughout the industrialized world. Some, when they first appeared, were touted as technological wonders. These new substances included pesticides which promised “a revolution in the efficacy of pest control” (van Emden 1989). Others were industrial chemicals, such as PCBs, which became prominent in electronics. Many shared the valued property of persistence (discussed below), which resulted in long-lasting action in their respective application. Many of these chemicals did not cause immediate, visible harm to humans upon contact, so they were assumed to be quite safe (which they were relative to some of the alternative pesticides and industrial chemicals available). Although negative aspects of persistent, organic chemicals had been identified by the mid-1940s, the full extent of their environmental consequences was not truly recognized until the early 1960s with the publication of Rachel Carson’s *Silent Spring* (van Emden 1989).

As mentioned earlier, there are hundreds of POPs; however, the scope of this thesis is limited to those designated in the Stockholm Convention. Consequently, subsequent discussion of POPs is restricted to the Stockholm Convention’s chosen “dirty dozen” compounds.
The dirty dozen are twelve compounds that are notorious for their ability to be transported over long distances, their persistence in the environment, as well as their bioaccumulative and toxic properties. They were originally selected in 1995 from a tentative list of compounds to be regulated under LRTAP (which was undergoing its screening process at the time). The LRTAP selection process is discussed further in the following chapter.

The Stockholm Convention categorizes the dirty dozen into three main groups: pesticides (aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, and toxaphene), industrial chemicals (hexachlorobenzenes (HCBs) and polychlorinated biphenyls (PCBs)), and combustion and industrial process byproducts (dioxins and furans). Each of these 12 is briefly discussed below.  

**Pesticides**

**Aldrin**

Aldrin is an insecticide used to protect crops and wooden structures. Its primary use was to “control soil insects such as termites, corn rootworm, wireworms, rice water weevil, and grasshoppers” (Eckley 2001, 33) and it was used in Canada for over 25 years. Most uses of aldrin were banned by the mid-1970s (in the industrialized world), though it continued to be used as a termiticide in many poorer regions of the world (e.g., Venezuela, Malaysia, many parts of Africa), (Environment Canada. 2005b). No sales of aldrin have been registered in Canada since 1984.

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4 In-text citations are references for specific substances. General references for the dirty dozen include: Eckley (2001), UNEP (2001), and Environment Canada (2005a).
Chlordane

Chlordane is a mixture of chlordane isomers, other organochlorines, and byproducts. Each specific chemical in the mixture has its own physical and chemical properties (e.g., volatility, persistence), and this influences their fate in the environment (e.g., how far they travel, where they are most likely to be found). Even structurally similar molecules can behave differently in biota. Cis-chlordane (one isomer of chlordane), for instance, is a better insecticide than trans-chlordane (Vetter 2001).

Figure 3.1 Isomers of chlordane (cis-chlordane and trans-chlordane)

Note: the only structural difference between the two molecules presented below is the position of the chlorine on the far right of the molecule. In cis-chlordane (the molecule on the left), the thick line indicates that the chlorine is ‘up’ (it is coming out of the page). In trans-chlordane (the molecule on the right), the dashed line indicates that the chlorine is going ‘down’ (into the page).

Chlordane was used to control insect pests in forestry, agriculture, and in the home. It was used on lawns and in gardens as an insecticide, and was applied to the foundations of
homes and other wooden structures to protect against termites. Chlordane was registered for use in Canada for over forty-five years, though most use was phased out in the 1970s. All uses of chlordane in Canada, other than for the control of termites, were banned in 1985, and since 1995 all sales and uses of chlordane have been banned. Use of chlordane continued in many less developed countries into the 1990s.

*Dichlorodiphenyltrichloroethane (DDT)*

DDT’s insecticidal properties were discovered in 1939 by Paul Muller. DDT was credited with stopping a major typhus epidemic near the end of the Second World War and, consequently, Muller won the Nobel Prize for Physiology and Medicine in 1948. DDT was used for the control of agricultural pests and insect vectors of disease, and is still in use in many countries for the control of malaria-carrying mosquitoes. Most uses of DDT in Canada were banned in 1974, though “the consumption of existing stocks of DDT was permitted until 1990” (Environment Canada. 2005b).

*Dieldrin*

Similar to aldrin (dieldrin is actually a breakdown product of aldrin), dieldrin was used to control soil insects, agricultural pests, and textile pests. It was also used to control mosquitoes. Dieldrin was used in Canada for over 25 years. Most uses of dieldrin were banned by the mid-1970s (in the industrialized world), though it continued to be introduced to the environment through the use of aldrin in many poorer regions of the world (see Aldrin, above). No sales of dieldrin have been registered in Canada since 1984.

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5 Isomers are molecules that have the same number of each type of atom but which differ in their structure. Congeners are molecules that are variants of the same molecular structure. See Figure 3.1
**Endrin**

Endrin is both a rodenticide (for the control of mice and voles in orchards) and an insecticide (for the protection of crops against leaf-eating insects) (U.S. EPA 2005a). As an insecticide, endrin was used worldwide on a variety of crops, including tobacco, rice, and cotton. Endrin was used as an insecticide in Canada, was banned in 1994, and was targeted for “virtual elimination” under the Toxic Substances Management Policy in 1995.

**Heptachlor**

Heptachlor is an insecticide that was used in the home against termites, and in agriculture to control insect pests. In some areas it has been used extensively for the control of fire ants. Heptachlor was widely used in Canada as a pesticide, though most uses were phased out in the 1970s. All uses of heptachlor were banned in 1985, and all sales were banned in 1990.

**Mirex**

Mirex was never registered for use as an agricultural pesticide in Canada, though it was used as a flame retardant (e.g., in plastics and electrical goods). It was used extensively for the control of fire ants in the United States, termites in South Africa, and leaf cutters in South America. Mirex was also used in electrical goods, paints, and plastics as a flame retardant. Canada banned all uses of Mirex in 1978.
Toxaphene

Toxaphene is a mixture of over 177 chemicals. Like chlordane (see above) each of these chemicals has different physical, chemical, and biological properties. Toxaphene was used as a major agricultural insecticide in the 1940s. In the United States its primary use was in cotton production, although it was used extensively to control ticks and mites in livestock. Until it was banned in 1982, toxaphene was one of the most heavily used insecticides in the US. In the 1970s, toxaphene was also one of the worlds most widely used pesticides (Environment Canada. 2005b). All uses of toxaphene were banned in Canada in 1982. All sales were banned in 1985.

Industrial Chemicals

Polychlorinated biphenyls (PCBs)

PCBs are a group of structurally similar industrial chemicals. There are 209 different PCB congeners, and each has its own chemical and physical characteristics. The degree of chlorination of PCBs greatly affects their behavior in the environment (e.g., highly chlorinated PCBs have greater persistence).

Their fire-resistance, low volatility, and stability made them ideal dielectrics, coolants, and lubricants in electrical transformers (U.S. EPA 2005b). PCBs were used for hundreds of applications (e.g., as plasticizers for paints, and in pigments in carbonless copy-paper). In 1977 Canada banned the “manufacture, process, use, [sale] or import” of PCBs (Chlorobiphenyls Regulations, SOR 91/152, s. 3.). PCBs have been used in almost every country, and huge quantities are contained in electrical equipment still in use.
**Hexachlorobenzene (HCB)**

HCB was originally produced as a fungicide for grains, and was commonly used to protect wheat seeds. These uses, however, were restricted by most industrialized nations in the 1970s, though use of HCB as a pesticide continued in many less developed countries. Canada banned all sales and use of HCBs in 1982. More recently, HCB has been used as a reagent in chemical manufacturing. HCB is also a byproduct of some industrial processes.

**Combustion and industrial process byproducts**

**Dioxins (Polychlorinated dibenzo-para-dioxins)**

Dioxins are a group of chemicals that share similar molecular structures. They are unintentionally produced through combustion (e.g., burning hospital or household wastes) and industrial processes (e.g., bleaching of paper products). Many dioxins are extremely toxic, even at very low concentrations, though characteristics vary widely from one dioxin to another.

**Furans (Polychlorinated dibenzofurans)**

Furans are a group of chemicals that share similar molecular structures. Like dioxins, they are created unintentionally through combustion and industrial processes. Many furans are also extremely toxic (though characteristics vary widely from one dioxin to another).

The widespread distribution of these contaminants in the environment and their adverse effects first came to light in the early-to-mid 1960s (Carson 1962, Jensen 1966). Rachel Carson’s famous *Silent Spring* associated pesticide use with harmful effects on
wildlife, and brought the issue to public attention. In the sciences, such contaminants soon became a major object of study. For example, Shifrin and Toole (1998) state that almost 2000 scientific articles discussing the toxicology of PCBs and the effects of PCBs on health were published between 1966 and 1976.

The flurry of research following Carson’s publication of *Silent Spring* demonstrated the presence of organochlorine contaminants in multiple locations around the globe—from PCBs in the Arctic, Baltic, and North seas to DDT in the Antarctic (Jensen 1966; Tatton and Ruzicka 1967; Holden 1970). Concerns over the health effects of organochlorine contaminants were heightened after the *yusho* (Japanese for “oil illness”) poisoning in 1968 in Japan. In the developed world, the use of many POPs was banned starting in the early 1970s. For instance, DDT and PCBs were banned by the United States in 1972 and 1979, respectively. All uses of mirex in Canada were banned in 1978 and toxaphene use was restricted in 1982 (see Table 3.1). Many less developed countries, however, continued to use

### Table 3.1 Regulation of the ‘Dirty Dozen’ in Canada (excluding dioxins and furans)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Date of Regulation (ban or restricted use) in Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldrin</td>
<td>1995</td>
</tr>
<tr>
<td>Chlordane</td>
<td>1995</td>
</tr>
<tr>
<td>DDT</td>
<td>1990</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>1995</td>
</tr>
<tr>
<td>Endrin</td>
<td>1994</td>
</tr>
<tr>
<td>Heptachlor</td>
<td>1990</td>
</tr>
<tr>
<td>Hexachlorobenzene</td>
<td>1982</td>
</tr>
<tr>
<td>Mirex</td>
<td>1978</td>
</tr>
<tr>
<td>PCBs</td>
<td>1977</td>
</tr>
<tr>
<td>Toxaphene</td>
<td>1985</td>
</tr>
</tbody>
</table>
these chemicals because they could not afford alternatives or did not have the technical capacity to develop alternatives (Downie 2003).

**Molecular Structure**

POPs are organic, meaning the structures of their molecules are carbon-based. The frame of the molecule is made primarily of carbon atoms, while the branches off the main frame consist of hydrogen atoms or any of a variety of other atoms or groups of atoms. These branches are called “substituents.”

All POPs discussed in this thesis are organochlorines (OCs), meaning that they are organic and that at least one substituent in the molecule is a chlorine atom (see Figure 3.2). Chlorine provides POPs “with properties of both persistence and biological activity” (Lipnick and Muir 2000).

Many POPs designations refer not to a single chemical compound but to a mixture or group of similar compounds. For instance, toxaphene is a mixture of over 300 different compounds (isomers and congeners of polychloroboranes and camphenes), each of which has different chemical and physical properties (Lipnick and Muir 2000).

**Figure 3.2 A Polychlorinated biphenyl**

![A Polychlorinated biphenyl](image)
Persistence

POPs are persistent in the environment, meaning they remain in the environment for relatively long periods of time. In general, they do not easily degrade chemically or biologically in the environment. In many cases, breakdown products are also persistent. Generally, persistence increases with the number of chlorine atoms (Mackay et al. 1992).

Paul Muller, the discoverer of DDT's insecticidal properties, emphasized persistence in his Nobel Lecture in 1948 as one of seven characteristics of a good insecticide. Referring to DDT, he stated:

"My fly cage was so toxic after a short period that even after very thorough cleaning of the cage, untreated flies, on touching the walls, fell to the floor. I could carry on my trials only after dismantling the cage, having it thoroughly cleaned and after that leaving it for about one month in the open air." (Paul Muller 1948)

Persistence is measured by the half-life of a compound (or the rate of degradation) in a particular environment. The half-life is the time it takes for half of a given substance to decay. Persistence is dependent not only on the physical properties of the substance in question, but also on environmental conditions such as temperature, light, and the medium in which the substance is found (e.g., water, air, soil, sediments). Measurements of persistence are therefore only applicable in similar environments. For example, the atmospheric half-life of chlordane is the time it takes for half of an initial quantity of chlordane to degrade in the

---

6 The characteristics of a good insecticide, according to Paul Muller, were: "(1) great insect toxicity, (2) rapid onset of toxic action, (3) little or no mammalian or plant toxicity, (4) no irritant effect and no or only a faint odour, (5) wide range of action, (6) long and persistent action, i.e. good chemical stability, and (7) low price" (from http://nobelprize.org/medicine/laureates/1948/muller-lecture.pdf).
atmosphere. The atmospheric half-life of chlordane (6.2 hours), however, is not the same as its half-life in water (14.4 – 20.6 days, see Table 3.2). Similarly, the half-life measured in the Arctic is not equivalent to the half-life measured in the tropics or temperate locations. For instance, the half-life of trans-chlordane (one isomer of chlordane) at Sleeping Bear Dunes (Michigan, U.S.) is 5.2 years, whereas the half-life of trans-chlordane in Alert (Nunavut, Canada) is 8.3 years (NCP 2003). In some cases, half-lives may vary by almost an order of magnitude, depending on the environment (Northern Contaminants Program 2003).

### Table 3.2 Half-lives of POPs (Ritter et al. 1995)

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Half-life in soil</th>
<th>Half-life in water</th>
<th>Half-life in air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldrin</td>
<td>Rapidly degrades into Dieldrin</td>
<td>--</td>
<td>0.6 hours</td>
</tr>
<tr>
<td>Chlordane</td>
<td>1 year</td>
<td>14.4 – 20.6 days</td>
<td>6.2 hours</td>
</tr>
<tr>
<td>DDT</td>
<td>Up to 10 – 15 years</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>Up to 5 years</td>
<td>&gt; 4 years</td>
<td>--</td>
</tr>
<tr>
<td>Endrin</td>
<td>Up to 12 years</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Heptachlor</td>
<td>Up to 2 years</td>
<td>Approx. 3.5 days</td>
<td>--</td>
</tr>
<tr>
<td>Hexachlorobenzene</td>
<td>2.7 – 22.9 years</td>
<td>Approx. 6 years</td>
<td>Approx. 2 years</td>
</tr>
<tr>
<td>Mirex</td>
<td>Up to 10 years</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>PCBs</td>
<td>10 days – 1.5 years</td>
<td>2 – 6 years</td>
<td>3 weeks – 17 years</td>
</tr>
<tr>
<td>Toxaphene</td>
<td>100 days – 12 years</td>
<td>6 hours</td>
<td>4 – 5 days</td>
</tr>
</tbody>
</table>

---

*a* Ritter et al. 1995;  
Sometimes measurements of overall persistence are used. These are calculated using a weighted mean of atmospheric, water, and soil persistence. The Stockholm Convention used the following criteria for persistence (Eckley 2001).

### Table 3.3 Stockholm Convention criteria for persistence

<table>
<thead>
<tr>
<th>Medium</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>2 days</td>
</tr>
<tr>
<td>Water</td>
<td>2 months</td>
</tr>
<tr>
<td>Soil</td>
<td>6 months</td>
</tr>
<tr>
<td>Sediment</td>
<td>6 months</td>
</tr>
</tbody>
</table>

**Volutility and Long-range Transport**

POPs are semi-volatile, meaning they are found in significant fractions in the gaseous phase, as well in their liquid or solid phases. Semi-volatile compounds have vapour pressures\(^8\) between 100.1 and \(10^6\) Pa at standard temperature and pressure.\(^9\) Substances with lower vapour pressures are not found in significant quantities in the gaseous phase, whereas substances with higher vapour pressures are found mostly in the gaseous phase.

The long-range transport of POPs is associated with their persistence and their volatility. POPs can be transported over long distances in their gaseous phase, as well as adsorbed onto aerosols before re-condensation or deposition. Atmospheric transport is the primary mode of long-range transport for POPs. As we shall see in later chapters, the long-range atmospheric transport of POPs was the principle characteristic that motivated Canada,

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\(^7\) Note: Persistence is related to the degree of chlorination of PCBs.

\(^8\) Vapour pressure is a measurement of the pressure exerted by the molecules of a given vapour (Hill et al. 2005). It expresses the tendency of a substance to vaporize. The boiling point of any given substance is at the point where its vapour pressure is equal to the pressure exerted by the atmosphere.

\(^9\) Standard temperature and pressure (or STP) is defined as 25°C, and 1 atm.
and the international community, to cooperate in forming a global convention to regulate their use.

Although POPs’ primary mode of transport is atmospheric, they also spend considerable time in non-gaseous forms adsorbed onto a variety of surfaces, including algae, snow, and ice, and can be transported over long distances on ocean and river currents (Li 2002; Northern Contaminants Program 2003).

During their lifetimes, POPs may evaporate and condense numerous times as they are transported in the atmosphere. Since condensation occurs most readily at cold temperatures, POPs are most likely to condense in cold environments; for instance, in the polar regions and in glacial or mountainous regions (Blais et al. 1998). Conversely, evaporation is less likely in these same cold environments. Hence, POPs in cold environments will have a lower rate of evaporation, and will therefore be slower in re-joining the global atmospheric currents. In other words, semi-volatile compounds will spend a smaller proportion of their time in their gas phase in cooler climates, and are therefore more likely to remain in cold environments. It follows that cooler regions become “sinks” where POPs accumulate (Wania and Mackay 1993). This effect is known as global fractionation, or the “grasshopper effect”. Due to the grasshopper effect, northern countries with extensive cold environments (e.g., Canada) are most strongly affected by POPs, and, consequently, most are active in pushing for global POPs regulation.

As mentioned earlier, long-range transport occurs through the atmosphere, ocean currents, and rivers. In the remainder of this thesis the term ‘long-range transport’ will be used to refer to the larger phenomenon including all of these transport mechanisms, unless otherwise specified.
Bioaccumulation and biomagnification

POPs bioaccumulate and biomagnify. Bioaccumulation is the accumulation of a substance in an organism. This results from two properties of POPs. First, they are lipophilic, meaning they have an affinity for lipids, or fatty tissues. This inhibits an organism’s ability to excrete POPs in urine. Second, POPs cannot be easily broken down. Thus, POPs remain in the fatty tissue of animals and humans for long periods of time.

POPs do break down, both biologically and chemically, but organisms usually consume these substances faster than they can break them down. Thus, over time, POPs accumulate (i.e., bioaccumulate), sometimes up to toxic levels. Though organisms can absorb POPs through their skin and respiratory surfaces (e.g., gills), the primary mode of contamination is generally through diet (except at the lowest trophic levels\textsuperscript{10}).

A good illustration of bioaccumulation and biomagnification is the case of beluga whales in the St. Lawrence. A team of scientists, led by Pierre Beland of the St. Lawrence National Institute of Ecotoxicology found high levels of contaminants in St. Lawrence beluga whales. The team determined that contaminants in St. Lawrence fish could not account for all the contaminants in belugas, and that only by feeding on migratory animals could the whales accumulate POPs up to concentrations found. Eels, they determined, were responsible for “half of the total organohalogen concentration seen in the whales” (Beland 1996, 79). In this case, POPs were biologically transported by eels from the industrial areas of the Great Lakes to the Atlantic where belugas bioaccumulated them to such levels that most belugas exhibited a wide variety of health problems including immune deficiencies, tumors, lesions, and

\textsuperscript{10} Trophic level: A level in the food web. At the lowest levels are species like zooplankton that feed on plankton, whereas species at the highest levels, such as polar bears, have few or no predators.
stomach ulcers, and which, “according to Canadian regulations, made [them] toxic waste” (Beland 1996, 77).

Bioaccumulation is measured using a bioaccumulation factor. This is “the ratio of the concentration of a substance in an organism to the concentration in water, based on uptake from the surrounding medium and food” (Environment Canada 1999). Generally, if the bioaccumulation factor for a substance is greater than 5000, it is considered bioaccumulative. Since the bioaccumulation factor cannot always be determined from wildlife data, a measurement of the octanol-water partition coefficient $^{11}$ is often used. The Stockholm Convention included bioaccumulation in its criteria for selecting POPs (they set their bioaccumulation factor at 5000 and/or the logarithm of the octanol-water partition coefficient (log $K_{ow}$) at >5).

Besides bioaccumulation, POPs also biomagnify, meaning organisms at higher trophic levels end up being the most highly contaminated. Since species at higher trophic levels consume many organisms that have bioaccumulated POPs throughout their lifetimes, these higher-level species ingest significantly larger quantities of POPs, and are therefore more highly contaminated by POPs (i.e., POPs biomagnify as one moves up the food chain). Species at the highest trophic level, such as polar bears and whales, are the most highly contaminated, and are therefore at greatest risk of adverse effects.

An early example of biomagnification was documented by Eldridge Hunt and Arthur Bischoff (1960) at Clear Lake, California. Toxaphene had been applied to the lake at 0.2 parts per million (ppm) to kill nuisance fish. “Four months later, plankton contained 73 ppm toxaphene, goldfish fat 200 ppm, and fat from a pelican which died at the lake, 1700 ppm.”
(West 1964, 628). Though toxaphene may not have been toxic at the levels applied to the lake, biomagnification resulted in effects at higher trophic levels that were devastating.

It should be noted that concentrations of POPs in the Arctic are nowhere near these levels; however, the bioaccumulation potential in the Arctic is very high due to the fat content of Arctic animals.

**Effects on Wildlife and Humans**

*Effects of high-level exposure*

The effects of POPs at high concentrations were first observed at the end of the 19th century. Chloracne, an acne-like rash, was first associated with organochlorines in 1899 by Karl Herxheimer (1899) in workers exposed to synthetic chemicals. Since then, there have been numerous industrial accidents involving organochlorines where chloracne and other symptoms of exposure have been observed.

As mentioned earlier, the *yusho* poisoning in Japan in 1968 increased concerns over the health effects of POPs after more than 1500 people were poisoned by rice oil contaminated by PCBs. A similar incident in 1979 occurred in Taiwan (it was called *yucheng*, which also translates as “oil illness”). The effects on human health as a result of these exposures in Japan and Taiwan (including children born to women who were exposed) were tracked by scientists. In both cases, children born to exposed mothers had low birth weights, pigment disorders, and reduced intellectual function (Rogan et al. 1986). In the yucheng incident, reduced immune function was noticed (Chang et al. 1981).

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11 The octanol-water partition coefficient ($K_{ow}$) is a measurement of how much of a substance will dissolve in octanol as compared to how much of the substance will dissolve in water. Solubility of a substance in octanol is assumed to be relatively close to its solubility in fatty tissues.
In 1976 in Seveso, Italy a broken valve resulted in a massive plume of POPs (mostly dioxins) which drifted through the town. Medium-term effects observed after the incident included a variety of skin conditions (including chloracne) and a significant change in the sex ratio of children born to exposed parents (Jongbloet et al. 2002). Documented long-term effects from this POPs exposure include increased mortality from certain heart diseases, respiratory diseases, and cancers (Bertazzi et al. 1998; Signorini et al. 2000). Diabetes deaths were also “significantly above expectations” in females (Signorini et al. 2000). The overall mortality rate, however, did not differ significantly from the general population (Signorini et al. 2000).

In general, effects of high-level exposure to POPs vary and include liver damage (Drinker 1937, Bertazzi et al. 1998), chloracne (Rogan 1988), reduced immune function (Chang et al. 1981), and in cases of severe exposure, death. Even at very low concentrations, POPs exposure has been associated with weakened immune function (Northern Contaminants Program 2003), behavioral, neurological, developmental, and hormonal abnormalities (Harada 1976; Rogan et al. 1986; Rogan et al. 1988; Jacobson and Jacobson 1990). Many of these effects result from endocrine disruption (discussed below).

**Endocrine disruption**

The endocrine system is the body’s chemical communications system. It directs many bodily functions including, for example, growth and development (from conception to adulthood) and insulin concentration in the blood through a complex system of hormonal messengers which are produced and released in minute quantities by special glands and which can only be received by specific receptors. The binding of a hormone to a receptor
starts a chain of events that eventually results in the desired response. Some synthetic chemicals, however, interfere with the transmission of these hormonal messages. This phenomenon is known as “endocrine disruption” and the chemicals that cause this reaction are known as “endocrine disruptors”. Endocrine disrupters can: (a) alter hormone synthesis by inhibiting or altering the rate of the production of hormones, upsetting the natural balance of that hormone in the organism, (b) alter hormone storage and/or release, (c) alter hormone transport by altering the concentration of globulins, which act as a sort of transport mechanism for some hormones, (d) mimic hormones, fooling the organism into a response, (e) prevent hormones from binding to the hormone receptor, (f) increase the breakdown of hormones by stimulating the production of enzymes for breaking down POPs, but which also break down hormones (enzyme induction), and (g) affect post-receptor activation (the binding of a hormone to a receptor site is the start of a chain reaction that ends with the organisms desired response; some endocrine disrupters can interfere with that chain, preventing or altering the response).

POPs can be passed through the placenta, and it is during the fetal stage of development that endocrine disruptors have their greatest impacts. During this stage, development is regulated by minute changes in hormone concentrations.

Although many endocrine disrupters are weak and require significantly higher concentrations than natural hormones to elicit similar reactions, in some cases only 0.5% to 5% of receptor sites need to be occupied to get a full response (Kelce and Gray 1999). In other words, there are instances where it doesn’t take much to get a significant reaction. A change in hormone concentration on the order parts per billion can measurably alter development (Dieringer et al. 1979; Colborn et al. 1996). For example, Jacobson and
Jacobson (1990), looking at the effects of prenatal and postnatal exposure to PCBs on visual recognition memory, found a significant correlation between prenatal exposure to PCBs and performance on tests of visual recognition memory at 4 years of age. PCB concentrations were on average 2.5 nanograms per milliliter of umbilical cord serum. In comparison, a grain of salt (weighing approximately 10 milligrams) would need to be dissolved in 4 million liters of water to achieve this concentration. However, it should be noted that relative to some other endocrine disruptors, most POPs exhibit only very weak effects (as endocrine disruptors).

Many effects have been observed in wildlife, including reproductive and behavioral abnormalities, and immune suppression. The reproductive system is particularly vulnerable to OCs (Nelson 1972). Reproductive failure has been associated with POPs in ranch mink (Aulerich et al. 1973), herring gulls (Keith 1966; Gilbertson 1974), beluga whales (Beland et al. 1993) and terns (Ludwig and Tomoff 1966), feminization of gull embryos (Fry and Toone 1981), and eggshell thinning in brown pelicans (Andersen, et al. 1975) and double-crested cormorants (Gress, et al. 1973).

Behavioral abnormalities affecting reproductive success have also been noted in wildlife exposed to POPs. McArthur et al. (1983) associated POPs contamination (a mixture of DDE, PCBs, mirex, and photomirex) in ring doves with disinterest and delays in breeding. Additional examples of behavioral effects associated with contamination include abnormal incubation behavior, loss of expression of territoriality, poor parenting, and female-female pairing (Fox et al. 1978; Fry and Toone 1981; McArthur et al. 1983). Immune suppression has been observed in mallards (Friend and Trainer 1970), polar bears (Lie et al. 2004), and belugas (Beland et al. 1993).
Both accumulation of and sensitivities to POPs differ from species to species, and vary between the sexes (Addison and Smith 1974). Even within a group of related compounds (e.g., dioxins) the variability in toxicity can be significant (Shifrin and Toole 1998). Under these circumstances, assessing the effects of a single chemical is difficult.

Studies have revealed POPs effects in human populations that are similar to those in wildlife. POPs-related endocrine disrupting effects in human populations include reduced immunological function (Chang et al. 1981; Bilrha et al. 2003), developmental problems, decreased IQ, and behavioral abnormalities (Rogan 1988; Jacobson and Jacobson 1990). However, it should be noted that prior to 2005, actual human health effects in the Arctic had not been associated with POPs.

Since most human POPs exposure comes from our diets (Liem et al. 2001), some people are more highly exposed than others. For instance, Inuit suffer greater exposure to POPs than Dene, Caucasian, or Metis living in the same area because the traditional Inuit diet includes more marine mammals, which are quite fatty and which contain more contaminants than terrestrial mammals in the same region. Consequently, they have the highest blood contaminant levels, and are most likely to suffer from adverse effects.

Traditional toxicology is based on a tolerable daily intake (TDI) of a given substance. Individuals exposed to levels higher than the TDI are at risk of adverse effects. Hormonal effects are not a linear function of their concentration in the body, however. Each hormone has maximum effects at a specific, and quite often very low, concentration. After this point, increasing the concentration of hormones may no longer result in greater effects—in fact, increasing the concentration may result in decreased effects (vom Saal et al. 1995). To make matters more complicated, mixtures of chemicals can have compound effects—minute
quantities of multiple endocrine disruptors can result in significant effects (vom Saal et al. 1995).

Conclusion

Since the publication of Rachel Carson’s *Silent Spring* in 1962, scientific knowledge about POPs has increased phenomenally. However, despite years of research, significant uncertainties remain. The number of chemicals is enormous. Identifying specific compounds, how they are transported in the atmosphere and oceans, and associating them with specific effects in humans and wildlife is a major task.

The effects of low-level contamination are subtle and complex, yet the implications are significant. Walter Rogan and Beth Gladen (1991, 411), discussing the implications of their research on reduced intellectual function in children exposed to PCBs and dioxins, warned that, similar to low level lead poisoning, “the public health consequences are potentially large, since about 5% of all US children may be affected… A small shift in the mean performance may result in a large reduction in the number of children with high levels of achievement”.

The multitude of POPs compounds and their persistence, volatility, long-range transport, global fractionation, bioaccumulation, and biomagnification combined with their effects in wildlife and humans, constitutes a vast and complex puzzle. The next chapter, Chapter 4, looks at how the pieces of this monumental puzzle were historically put together, which types of pieces and which types of scientific knowledge were most significant in terms of generating policy development in Canada, and what scientific activities relative to this knowledge were most important at each stage of Canada’s policy development.
Chapter 4. Case study: POPs science and policy

The time-span of this study begins shortly before the discovery of POPs in the Canadian Arctic and, hence, discovery of the transboundary and global nature of the POPs problem, and ends with the signing of the Stockholm Convention in 2001. This time-span can be divided into four distinct time-periods associated with the creation of three problem-frameworks.

In this chapter, each of the four periods is discussed in four sections. The first section (summary of scientific developments) is a general introduction to the major scientific developments of the period. Important research projects and critical events related to POPs science are explained. Based on the information in the first section, the second section (knowledge types) analyzes the major types of scientific knowledge that influenced policy during the period. The third section (knowledge actions) analyzes the critical knowledge-related actions of scientists that influenced policy. Finally, the fourth section (influence on policy decisions) discusses Canada’s major foreign policy decisions during the period and maps the influence of scientific knowledge (in terms of knowledge types) and scientists (in terms of knowledge actions) with respect to these decisions. When discussing “Canada’s POPs foreign policy”, I include domestic policy decisions related to POPs that set the stage for foreign policy decisions (e.g., the domestic decision to investigate sources and pathways of POPs to the Canadian Arctic—a decision that would provide Canada “with knowledge to be seen as a well-informed and credible [international] leader in the area of northern contaminants” (Shearer 1991)).
Before the analysis, two points should be noted: First, since the term “persistent organic pollutant” did not come into use until the mid-1990s, I will generally follow the terms used by those involved when discussing scientific and political developments prior to this time. Second, the key events and studies related to POPs tend to revolve around some compounds (most notably PCBs and DDT) more than others (e.g., aldrin, dieldrin, and furans). I suggest two reasons for this imbalance. First, PCBs and DDT are high-profile pollutants (they were the focus of several major events, including the publication of Silent Spring and the yusho poisoning). They have received much more attention than the other pollutants (in terms of research, media attention, etc.) and, consequently, they have had more influence on policy.

**Period I: Pre-1985**

**Summary of scientific developments**

The main developments related to the science of POPs during Period I were:

- the general and ‘random’ accumulation of scientific knowledge related to the group of chemicals that would later be defined as POPs and their behavior in the environment from the late 1800s to the mid-1980s,
- the documentation of POPs contamination in the Arctic, and, most importantly,
- the “discovery” of the transboundary POPs problem (at the end of the period).

Each of these developments is discussed below.

As discussed in the previous chapter, scientific knowledge related to POPs had been ‘randomly’ accumulating since the late 1800s. This disparate knowledge, however, was never tied together as pertaining to a single, identifiable international environmental problem.
Selected POPs were known to cause environmental problems—for instance, Rachel Carson, identified DDT and other pesticides as a *local* environmental problem. Carson’s book sparked an explosion of research from the 1960s on. POPs contamination was studied extensively in the Great Lakes (Keith 1966; Aulerich et al. 1973; Gilbertson 1974; Fox et al. 1978), the Baltic Sea (Jensen 1966; Widmark 1967; Jensen et al. 1969) and the North Sea (Holden and Marsden 1967; Freudenthal and Geve 1973). Yet, despite the plethora of studies about contamination in these heavily populated areas, no one singled out POPs as an international or global problem. Environmental contamination by substances that would later be categorized as POPs was merely one part of a larger, general problem of wildlife contamination found in numerous locations around the world, a problem primarily centered on heavily industrialized regions like the Baltic Sea and the Great Lakes.

This began to change around 1970. Organochlorine (OC) contamination in the Canadian Arctic was first noted by a British scientist, Alan Holden, who was analyzing PCB and DDT concentrations found in seals in the United Kingdom, St. Lawrence River, and Canadian Arctic in 1970. He concluded that PCB concentrations were highest “in areas where high human population densities, with their associated industrial activities, discharge to the sea” (Holden 1970, 270). His findings were noted but since the concentrations were low, they received little attention.

The first major Arctic-wide study of OCs was conducted by Bowes and Jonkel (1974). By taking samples from polar bears, whose populations can be divided into discrete sub-populations representative of geographical areas, general geographical trends of contamination were analyzed. Although contamination varied by location, PCB and DDT contamination was found in all samples. The sources of this contamination, however,
remained unknown. Bowes and Jonkel suspected that sources might include “ocean, river, and air currents, as well as migratory animals”, and that “man’s activity in the higher latitudes” may add to the total (Bowes and Jonkel 1975, 2121-2122).

Studies in the Arctic continued to document OC contamination (Addison and Smith 1974; Wagemann and Muir 1984; McNeely and Grummer 1984); yet despite this research, the Arctic was generally assumed to be a pristine environment free from the contamination that was associated with industrial development in more southern latitudes. The relatively small quantities of OCs found in the Arctic were viewed as relatively harmless. In the 1960s and 1970s “oil gushed from rigs, rivers caught fire, skies were blackened by soot and smog, songbirds dropped dead, and many species were on the verge of extinction” (Cone 2005, 27); hence, the problems of the Canadian Arctic drew little notice.

Even though there was little attention to contamination in the Canadian Arctic and even though POPs had not been identified as a distinct problem, much was known about these chemicals:

(a) POPs were persistent in the environment. For instance, persistence was one of the major ‘advantages’ cited for OCs over traditional pesticides (Muller 1948).

(b) POPs could be transported over long distances. Starting in the early 1960s, a series of studies revealed contamination in various locations around the world, including the Antarctic (Tatton and Ruzicka 1967), the Arctic (Holden 1970; Bowes and Jonkel 1974; Addison and Smith 1974), the Great Lakes (Keith 1966; Aulerich et al. 1973; Gilbertson 1974; Fox et al. 1978), the North Sea (Holden and Marsden 1967; Freudenthal and Geve 1973), and the
Baltic Sea (Jensen 1966; Widmark 1967; Jensen et al. 1969). Before the mid-1980s, almost all work on long-range atmospheric transport of pollutants to the Arctic revolved around the issue of Arctic haze (Ottar 1981; Khalil and Rasmussen 1983; Oehme and Ottar 1984; Hov et al. 1984). Long-range transport of POPs was noted, but it was not identified as a major issue.

(c) POPs could be found throughout the Arctic. As mentioned, Holden (1970) was the first to identify OC contamination in the Arctic. The sources of the contamination were unknown, though Rappe (1974) suggested that cold temperatures increased pesticide deposition and that this may explain the OC concentrations found in the Arctic.

(d) POPs bioaccumulate and biomagnify in the environment. Rachel Carson discussed biomagnification in *Silent Spring* (1962). Robinson et al. (1967) and Jensen et al. (1969) reported the bioaccumulation and biomagnification of aldrin, endrin, DDT, and PCBs in the environment.

(e) POPs could be found in many of the traditional foods consumed by Arctic indigenous peoples. By the mid-1970s, traditional indigenous foods such as marine mammals (Addison and Smith 1974) and fish (Bowes and Jonkel 1975) were known to be contaminated.

(f) Several POPs interfered with the endocrine system in wildlife. Fry and Toone (1981) associated DDT contamination with abnormal sexual development (feminization) in gull embryos. Glen Fox of the Canadian Wildlife Service suggested in 1978 that the likely source
of behavioral abnormalities in Lake Ontario herring gulls was “endocrine dysfunction” caused by OC pollutants (Fox et al. 1978).

It was not until 1985 that the key components of the POPs puzzle were put together and a ‘new’ problem was ‘discovered’. The discovery came about indirectly through concerns about contamination associated with the cleanup of Canada’s Distant Early Warning (DEW) line sites. The DEW line was a series of radar sites set up in the Arctic during the 1950s to detect air attacks by the U.S.S.R. over the Arctic. However, technological advances made the sites unnecessary, and they were abandoned, leaving contaminated sites throughout the Arctic. The contaminants of concern were primarily OCs (specifically, PCBs). Questions about DEW line contamination were taken up by the Department of Indian Affairs and Northern Development Canada (DIAND), and included concerns about contaminants in native diets. DIAND organized a committee in 1985, the Technical Committee on Contaminants in Northern Ecosystems and Native Diets (hereafter called the Technical Committee on Contaminants), consisting of members from four federal departments – Indian and Northern Affairs Canada (INAC, part of DIAND), Environment Canada (EC), Health Canada (HC), and the Department of Fisheries and Oceans (DFO), as well as the Government of the Northwest Territories (GNWT). The committee conducted a baseline literature review of the available scientific knowledge on Arctic contamination to determine whether or not these contaminants were a problem in the Arctic. In retrospect, the unique contribution of the committee was to bring together scientists from multiple disciplines. Based on cross-disciplinary communication during committee meetings and during other interactions between committee members, the scientists on the committee rapidly connected...
the key components of a ‘new’ problem, as follows (Selin and Eckley 2003): (1) there was widespread contamination in the Arctic, (2) this contamination came from non-Arctic sources, (3) these contaminants were present in many traditional foods of northern peoples, and (4) there were potentially severe human health and environmental implications.

They concluded that contamination was “serious and widespread” throughout the Arctic and that there was a definite need to address contaminants in the Arctic (Technical Committee on Contaminants 1989). Based on the committee’s understanding of the extent and intensity of the contamination, it agreed that it was unlikely that the DEW line sites were responsible; the sources of contamination probably lay outside the Arctic (Technical Committee on Contaminants 1989). This was the key insight that led to the identification of an international POPs problem, and it resulted in codification of the first POPs problem-framework.

The framework that emerged portrayed the POPs problem in the Arctic as one of non-Arctic sources causing Arctic contamination. The realization that POPs contamination most likely did not originate from local sources implied some form of long-range transport from southern Canada and elsewhere. This in turn implied that the Arctic contamination problem was not a purely domestic problem; it was an international problem. However, the problem was still conceived as one of general environmental contamination; specific effects of POPs on the Arctic ecosystem were as yet undocumented. While it was assumed that humans might also be affected, there was no direct evidence to support this hypothesis. Also, as mentioned above, the literature review suggested that POPs contamination in the Canadian Arctic was widespread, though there were considerable uncertainties (Technical Committee on Contaminants 1989).
In summary, the Technical Committee on Contaminants’ synthesis in 1985 marks the close of the first POPs time-period. Its deliberations resulted in formulation of the first POPs problem-framework. This framework then provided the lens with which the newly discovered POPs problem was viewed during the subsequent time-period, Period II. The framework defined the problem as one of the contamination of the Arctic environment by a group of synthetic substances with physiochemical properties that allowed them to be transported over long distances in the atmosphere and deposited in the Arctic, and to bioaccumulate and biomagnify in the environment with unknown wildlife and human health effects.

**Knowledge types**

The dominant knowledge types during Period I were:

- existence knowledge (of the problem and of aspects of the problem),
- extent-intensity knowledge (geographical extent and ecosystem contaminant levels), and
- causal knowledge (transboundary sources cause contamination).

The most significant development in POPs science during Period I was the discovery of the existence of a problem (i.e., creation of existence knowledge). The existence of a widespread and seemingly international problem (specifically, long-range transport of contaminants to the Arctic resulting in high concentrations in wildlife and potentially affecting human health) was identified toward the end of Period I (Selin and Eckley 2003) and is the event signaling the end of the first period.
The second dominant knowledge type during Period I was extent and intensity knowledge. Basic understandings of the extent and intensity of the POPs problem, in terms of geographic extent and contaminant levels in the Arctic ecosystem, were gained in the period ("widespread" but still uncertain and "serious" though the consequences were not known). Bowes and Jonkel (1975), for instance, found PCB and DDT contamination throughout the Arctic environment.

The third dominant knowledge type was causal knowledge. The cause of Arctic contamination was hypothesized to be the release of chemicals into the environment that had physical and chemical properties which allowed them to be transported into the Canadian Arctic and to accumulate there12 (Oehme and Ottar 1984). Based on the extent and intensity of contamination throughout the Canadian Arctic, and the lack of emission sources in the Arctic, the committee concluded that the sources of the contamination almost certainly lay outside the Arctic (Technical Committee on Contaminants 1989, 2). It was known at the time that many OCs were persistent (Tatton and Ruzicka 1967), bioaccumulate (Hunt and Bischoff 1960; Robinson et al. 1967; Jensen 1969), biomagnify (Hunt and Bischoff 1960; Robinson et al. 1967; Jensen 1969), and could be transported in the atmosphere (Tatton and Ruzicka 1967; Goldberg 1975; Rappe 1975). However, major uncertainties remained; for instance, specific sources of contaminants and their pathways to the Arctic were unknown.

Conclusions were drawn and a problem ‘discovered’; however, the scientific knowledge upon which these conclusions were based was highly uncertain. One reason for this uncertainty was limitations in the analytical methods used to detect and measure POPs. Much of the early research was plagued by difficulties. Effective techniques for the

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12 In this case, causal knowledge is a product of three forms types of character knowledge: behavior in the abiotic environment, behavior in the biotic environment, and sources.
separation of individual substances had not been available until the mid-to-late 1960s. Complexity and variance in the mixtures that make up many POPs were difficult to deal with since chemical ‘signatures’ sometimes interfered with one-another (Shifrin and Toole 1998). Finally, standard procedures for the analysis of POPs were sometimes lacking (for instance, there was no standard method for PCB analysis until 1982 (Shifrin and Toole)). As a consequence of these methodological difficulties, there was a high degree of uncertainty associated with scientific knowledge related to POPs in the Arctic ecosystem.

Knowledge actions

The dominant knowledge actions of scientists during Period I were:

- knowledge creation (random and synthesis),
- knowledge transmission (intra-disciplinary and cross-disciplinary), and
- knowledge translation (for policymakers).

Scientists’ key actions during Period I relate to the formation of the first POPs problem-framework. Scientific knowledge about long-range transport, persistence, bioaccumulation, biomagnification, and effects of POPs in the environment was created long before a coherent problem-framework was formed. Thus, until the end of Period I knowledge creation was undirected (i.e., scientists were not trying to fill gaps in the literature with respect to the POPs problem), and was unconnected (i.e., scientists were not trying to connect the various pieces of knowledge). Most of the scientific knowledge came from research projects that focused on non-Arctic regions of the world (e.g., the Baltic Sea, California, and
the Great Lakes), and on select phenomena (e.g., long-range transport, contaminant levels in Arctic fauna, and biological effects of OCs).

Transmission of knowledge allows scientists to build upon the work of others. The most common methods of transmission within academic disciplines are academic journals, conferences, and personal communication. In Period I, these transmission activities were important for they provided scientists with a base of knowledge and reference material from which they could work. In my analysis, however, I found that these intra-disciplinary transmission activities were not what brought forth the first POPs problem-framework; it was a synthesis of knowledge based on cross-disciplinary transmission of knowledge. This synthesis was in a sense a creation, not of new knowledge per se, but of a new perspective on ‘old’ knowledge.

DIAND’s Technical Committee on Contaminants brought together scientists from a variety of academic disciplines, and in the course of their work they quickly connected relevant scientific knowledge from many fields related to Arctic contamination (Selin and Eckley 2003). The final integration occurred primarily through face-to-face knowledge transmission between scientists from different academic disciplines at the committee’s meetings. Thus, a synthesis of already existing knowledge achieved through cross-disciplinary knowledge transmission between scientists within the confines of the committee was the key knowledge action that led to the discovery of the POPs problem.

Translation of scientific knowledge related to the work of the Technical Committee on Contaminants for science managers and policymakers also played an important part in Period I. Communication with policymakers occurred through, for instance, departmental
channels in government (e.g., through summaries of publications, which are passed to science managers, policymakers, and sometimes to other government departments).

A knowledge action which played a minor role during Period I was the translation of scientific knowledge for the general public. Some of the scientific developments on POPs were translated, via the media, for the general public. This created some awareness of POPs-related pollution issues, particularly in some of the pollution hot spots in Canada. Newspaper articles, for instance, discussed the sources of pollution in the Great Lakes (much of it from long-range atmospheric transport) and consequences (fish advisories, quality of drinking water, the closure of beaches, and potential effects on human health). However, overall, scientists’ interaction with the mass media was not significant relative to the newly discovered POPs problem.

Influence on policy decisions

During Period I, the major Canadian policy decisions were: (a) general policy decisions with respect to pollution (e.g., to ban toxaphene in 1985), (b) establishment of an inter-agency committee (i.e., the Technical Committee on Contaminants) to determine whether Arctic contamination was an issue, and (c) the decision, based on the committee’s findings, to continue investigating the issue through a research and monitoring program.

Canada’s first policy decisions related to POPs were made before the ‘discovery’ of the transboundary POPs problem. These decisions related to regional concerns over certain chemicals (e.g., dioxins in the St. Claire River), but since many of these chemicals had been regulated, the problems were seen as small scale and, for the most part, under control. With respect to the chemicals that would be later categorized as POPs, Canada had regional
policies for pollution hotspots like the Great Lakes, where the pollution included many POPs. Most Canadian research on OC contamination centered on this region during Period I. Some individual substances were regulated (e.g., toxaphene, mirex, and PCBs), but since the focus was on the local or regional level, contaminant issues were dealt with domestically or in cooperation with the United States (e.g., through the International Joint Commission).

Despite the scientific research available on the substances that would later be categorized as POPs, the long-range transport and accumulation of POPs in the Arctic food web was not identified as a major issue until the end of Period I. All of the main components of the problem were known, yet they remained disconnected. For example, Bowes and Jonkel (1975) described contamination by OC pesticides of unknown origins throughout the Canadian Arctic, and the enhanced deposition of pesticides by cold Arctic temperatures was described by Rappe (1974).

In hindsight, we can say that the first major policy decision related to the future international/global POPs problem was the decision to establish the Technical Committee on Contaminants. This decision was made in 1985, and was triggered not by scientific knowledge or the actions of scientists per se but by the concerns of northerners over the cleanup of the DEW line sites. In particular, the cleanup raised questions about contaminants in traditional diets. The committee surveyed the literature, synthesized existing scientific knowledge into the first POPs problem-framework, and, hence, “discovered” the problem of widespread POPs contamination. It was only after this event that scientists and scientific knowledge become directly influential on policy decisions.

The first POPs-related decision that we could say was directly influenced by science was the Technical Committee on Contaminants’ decision in 1985 to recommend a four-year
research and monitoring program to determine the extent of contamination of traditional foods. This program’s emphasis was to be not so much on biological effects but rather on further investigating occurrences of these pollutants in the Arctic environment and on assessing “all aspects of the problem” (Technical Committee on Contaminants 1989, 3). This decision can readily be explained in terms of the influence of science; specifically the influence of existence, extent and intensity, and causal types of scientific knowledge, the high levels of uncertainty associated with this knowledge, and scientists’ actions in terms of cross-disciplinary transmission of knowledge. Essentially, we can say that Period I ends in 1985 with the simultaneous creation of the first POPs problem-framework and the first direct influence of science on a POPs-related policy decision (namely, establishment of the research and monitoring program).

**Period II: 1985-1989**

**Summary of scientific developments**

The main developments related to the science of POPs during Period II were:

- the measurement of contaminants at all levels of the Arctic food chain,
- the mapping of trends in the geographical distribution of OC contamination in the Arctic,
- the gathering of evidence supporting long-range atmospheric transport as a major route of POPs to the Arctic, and
- the transformation of the Arctic contamination problem into a human health issue through research demonstrating contaminant concentrations in human blood and breast milk.
In 1985, the Technical Committee on Contaminants began its four-year research and monitoring program to determine the extent of contamination of traditional food sources in the Arctic. The scope of the program expanded during its lifetime to include OCs, acids, radionuclides, and metals. The program’s major focus was on the extent of contamination in the Arctic rather than the biological effects or causes of the contamination, although research continued on these questions as well (Technical Committee on Contaminants 1989). In addition, other scientific research continued, some inspired by the findings of the committee and some completely independent of it.

In the mid-1980s, Derek Muir et al. (1988) began a study to “identify all major organochlorines” in three trophic levels in the Arctic food web, and to analyze their bioaccumulation. Samples were collected from Arctic cod, ringed seals, and polar bears. Muir et al. found higher levels of chlordane in Harp seals from northern Baffin Bay than in seals from the Gulf of St. Lawrence and rapid biomagnification between trophic levels. Their results provided a base-line for the determination of biological effects in seals and polar bears.

Ross Norstrom et al. (1988), following the work of Bowes and Jonkel (see Period I), used polar bears to look at trends in the geographic distribution of OCs in the Canadian Arctic. With improved analytical techniques, they studied a wider range of OCs than Bowes and Jonkel (1975), including heptachlor, chlordane-related compounds, PCBs, DDT (and its breakdown products), chlorobenzenes, and hexachlorohexanes. Once again, by associating contaminants levels found in individual polar bears with the geographic range of their sub-population, general distribution patterns of OCs in the Canadian Arctic were determined.
Norstrom et al. found OCs throughout the Arctic, suggesting “long-range transport, rather than point-source input, is the dominant vector for OC contamination of the Canadian Arctic and sub-Arctic marine ecosystems” (Norstrom et al. 1988, 1069). In general, OC contamination increased from south to north.

Evidence of atmospheric transport as a major source of POPs in the Arctic was reinforced by the research of Hoff and Chan (1986), who measured OC pesticides (chlordane and nonachlors) in Arctic air during June and July, 1984 at Mould Bay, Northwest Territories, and by the research of Terry Bidleman et al. (1989), whose determination of OCs in air collected over two summers at an ice island in the Canadian Arctic showed that, of various polychlorinated camphene congeners, the most volatile “were preferentially transported to the Arctic” (Bidleman et al. 1989, 309).

Until the late 1980s, human health consequences of Arctic POPs contamination were uncertain. It was assumed that contamination of traditional foods would lead to human contamination, but there were no human health studies verifying this hypothesis. Two studies in the late 1980s confirmed human contamination in Arctic populations.

The first study, conducted between 1986 and 1988 by a team led by Éric Dewailly, examined women from Quebec who had just given birth. Most of the samples came from around Montreal, an urban, industrialized area. Dewailly planned on using samples from Nunavik as blanks to compare breast milk from “an unexposed population to an urban one” (Cone 2005, 30). Breast milk samples were collected and analyzed for PCB concentrations. Dewailly et al. (1989) concluded that PCB levels in Inuit women were approximately five times the levels found in Caucasian women, and “among the highest ever reported” (Dewailly et al. 1989, 643). Preliminary results from the study identified for the first time
that POPs were a major human health issue in the Arctic; however, these results were not published until 1989, after the results of a second study hit the headlines.

The second study, by David Kinloch and Harriet Kuhnlein (1988), looked at PCB consumption by Inuit between 1985 and 1988 in the community of Broughton Island (now part of Nunavut). PCB concentrations were measured in the blood and breast milk of participants. More than 18% of the participants exceeded Health and Welfare Canada’s “tolerable daily intake” of PCBs in their diet – 6% of adult males, 39% of women of childbearing age, 30% of women over 45, and 63% of children’s blood samples contained PCB concentrations above the “tolerable” levels (Kinloch and Kuhnlein 1988).

The results of this study were leaked to the media before publication, and drew considerable attention. The Globe and Mail, for instance, reported the results on the front page. The article quoted government officials saying “the Inuit might have to go on a diet of chicken and beef” (Fisher 1988, 1). This sensationalist media attention caused panic in some northern communities. People were reported to have stopped eating traditional foods and breastfeeding infants (Furgal et al. 2003).

Dewailly et al. and Kinloch and Kuhnlein’s work transformed the Arctic contamination issue from a general environmental contamination issue with largely unknown consequences to a human health issue (though considerable uncertainty about the actual human health effects in the Arctic remained). This transformation marks the shift between the first and second problem-frameworks. The second problem-framework now defined the problem as one of the contamination of the Arctic environment and Arctic indigenous people by a group of synthetic substances with physiochemical properties that allowed them to be
transported over long distances to the Arctic, and to bioaccumulate and biomagnify in the environment with unknown wildlife and human health effects.

Elsewhere, a number of research projects examined the effects of synthetic chemicals on the endocrine systems of wildlife and humans. As previously noted, a number of scientists in the late 1970s, including Glen Fox of the Canadian Wildlife Service, documented abnormal parenting behaviors in Lake Ontario herring gulls. Abnormal behaviors included alterations in their nest defense and incubation behaviors, both of which would have impacts on reproductive success (Fox et al. 1978). Lab studies showed that some OCs could induce behavioral abnormalities, and that the behavioral abnormalities in Great Lake bird populations may be due to these contaminants (McArthur et al. 1983).

In 1980, Sandra and Joseph Jacobson (1985), psychologists at Wayne State University, began a long-term longitudinal study (i.e., a study in which repeated measurements from the same group of people are taken over a long period of time) looking at the effects of pre-natal exposure to PCBs. Children of mothers who consumed Lake Michigan fish were studied to determine the neurological effects of pre-natal PCB exposure. Lake Michigan sports fish are fatty and contain unusually high concentrations of PCBs. By testing children’s visual recognition memory, Jacobson and Jacobson (1985) found an association between pre-natal PCB exposure and cognitive function. Jacobson and Jacobson continued their study well into the 1990s.
Knowledge types

The dominant knowledge types during Period II were:

- extent-intensity knowledge (geographic extent, ecosystem contaminant levels, and human contaminant levels),
- character knowledge (behavior in the biotic environment and sources),
- consequence knowledge (human exposure), and
- causal knowledge (atmospheric transport to Arctic, accumulation, leading to potential human health risks).

In terms of gaining a response from policymakers, the documentation of contaminant levels in the Arctic ecosystem (extent-intensity knowledge), mounting evidence of long-range atmospheric transport (character knowledge), and evidence of human contamination by POPs in the Arctic (consequence knowledge) were key. However, each of these knowledge types influenced policymaking differently.

Extent-intensity and character knowledge influenced policy indirectly during Period II, primarily by confirming earlier findings and reducing scientific uncertainty. The determination of POPs concentrations at multiple levels in the Arctic food web and throughout the Arctic provided base-line knowledge about the extent and intensity of the POPs problem. The work of Norstrom et al. (1988) showed similar concentrations over a wide geographic area, suggesting that long-range atmospheric transport was the dominant source of POPs in the Arctic (as opposed to point sources).

Consequence knowledge (i.e., the discovery of domestic human health consequences in Canada) in conjunction with greater certainty of the causal chain leading to human
impacts, on the other hand, influenced policy directly, especially through the media attention it received (Matthew Fisher 1988, 1). It is unlikely that, in the absence of documented human consequences, the Canadian government would have devoted significant attention to POPs. That POPs affected “charismatic mega-fauna” such as polar bears and affected species that are culturally and nutritionally important for northern indigenous peoples such as caribou, seals, and Arctic char, convinced many important political actors (namely, northern indigenous groups, scientists, and policymakers) that action on POPs was necessary; however, it is not at all clear that this alone would have spurred political action by the Canadian government, especially action in the international arena. One interviewee pointed out, for instance, if only zooplankton were affected by POPs, it is unlikely that action would have been taken. In other words, action was justified by the non-human consequences of POPs, but it was the potential human health consequences that prompted political action.

The final dominant knowledge type was causal knowledge. In Period II, the causal chain from Period I (i.e., the release of chemicals into the environment that had physical and chemical properties which allowed them to be transported into the Canadian Arctic and to accumulate in the Arctic ecosystem) was extended by one trophic level to include human contamination from eating traditional foods (Technical Committee on Contaminants 1989). Major uncertainties remained, however, especially with respect to the sources of POPs in the Arctic environment, and the specific effects of these contaminants on wildlife and human health.
Knowledge actions

The dominant knowledge actions of scientists during Period II were:

- knowledge creation (random and directed),
- knowledge transmission (intra-disciplinary and cross-disciplinary), and
- knowledge translation (for policymakers and for the general public).

Knowledge creation was important in uncovering the contamination of northern indigenous peoples, measuring the extent and intensity of Arctic contamination through the four-year research and monitoring program, and generating the foundation of scientific knowledge that would later come together to form the foundation for the environmental endocrine hypothesis. Some of this research was coordinated by policymakers (e.g., through the Technical Committee on Contaminants’ research and monitoring program), while other research was conducted independently (e.g., human health studies, and the work on endocrine disruptors). Some knowledge was co-produced with Arctic indigenous people (discussed later).

The transmission of scientific knowledge to other scientists within the same discipline continued to be important because it allowed the scientific community to continue building on the foundation of existing knowledge. Each academic discipline, sub-discipline, or field of study has its own set of journals, through which members present their findings. Knowledge about contaminants in the Great Lakes (many of which would later be categorized as POPs) was often reported in the *Journal of Great Lakes Research*. Some Great Lakes research was also presented in journals for atmospheric scientists, such as *Atmospheric Environment* or the *Journal of Geophysical Research*. Since scientific journals generally have a target discipline,
scientific knowledge presented in them does not generally reach scientists from other disciplines. A journal for wildlife biologists, for instance, will not necessarily reach health scientists, though their research may be related.

Cross-disciplinary transmission of knowledge continued to be important during Period II, but played a less significant role than in Period I. New scientific knowledge from a variety of disciplines continued to contribute to the POPs issue, and cross-disciplinary transmission of knowledge aided in integrating this knowledge into the POPs problem-framework. A scientific evaluation meeting held at the end of Period II (discussed below) resulted in the integration of new knowledge from a variety of academic disciplines into a new, more coherent problem-framework.

Translation of knowledge for policymakers, which occurred, for instance, at the scientific evaluation meeting at the end of Period II, resulted in later policy action. Specifically, communicating to policymakers that people in the Arctic, thousands of kilometers from the sources of POPs, were contaminated at levels exceeding the “tolerable level” set by Health and Welfare Canada, helped re-define POPs as an issue with potentially significant human health implications. The translation of scientific knowledge for the general public also played an important role in transforming the Arctic POPs contamination issue. Media coverage provoked a strong reaction among northern Aboriginal peoples (and others). Consequently, northern Aboriginal organizations (e.g., the Inuit Circumpolar Conference), and other organizations and individuals, put pressure on the Canadian government to take meaningful action. The influence of non-science factors on Canada’s POPs policy are not the focus of this study, however it is necessary to understand that science and scientists did not influence Canadian policy in a vacuum. Scientists were only one group of actors among
many, and there were numerous other factors that make up the context in which Canadian policy was made. The Inuit Circumpolar Conference, for instance, played an important role in bringing the issue to the general public (in southern Canada) through the media, and actively lobbied the government for meaningful action on POPs.

**Influence on policy decisions**

During Period II, the major policy decisions were: (a) general domestic policy decisions with respect to pollution (e.g., regulating the release of dioxins by pulp mills), (b) the decision to assess and synthesize the scientific data on Arctic contamination through a scientific evaluation meeting, and (c) the decision to host a workshop to develop a comprehensive policy on Arctic contaminants. Canadian policy decisions on POPs during Period II were domestic, not international. Until the end of the period, the science was not sufficiently understood to warrant the development of foreign policy. Uncertainty about the extent and consequences of POPs contamination in the Arctic was the primary concern; hence, the Canadian government concentrated its efforts on domestic research. As in Period I, local and regional contaminant issues unassociated with the POPs problem were still a concern (e.g., in the immediate areas surrounding pulp mills, and in the Great Lakes), and regulation of contaminants was conducted domestically and, in cross-border issues, in cooperation with the United States. However, even though these local and regional contaminant issues dealt with some of the same substances being found in the Arctic, they were considered a separate issue (of localized environmental problems resulting from agricultural and industrial discharges into the Great Lakes basin), not part of the larger POPs
problem (long-range transport to, and accumulation in, sites distant from industrial and agricultural sources).

Results of human health studies during Period II showed high POPs exposure levels in northern Aboriginal people (Kinloch and Kuhnlein 1988; Dewailly et al. 1989). Largely in response to this troubling consequence knowledge, policymakers held a scientific evaluation meeting in Ottawa (in February 1989) to synthesize and assess the data for a strategy meeting to be held in December (i.e., policymakers asked scientists to synthesize their data into a coherent problem-framework and to translate and assess these results so that they could make informed decisions at their workshop to develop a comprehensive contaminants policy). Approximately 40 Canadian scientists were present. Through this meeting, scientists representing a variety of academic disciplines communicated their work to each other and to policymakers. The meeting resulted in a report summarizing scientific knowledge related to Arctic contamination (Technical Committee on Contaminants 1989). This synthesis and summary, in the terminology of this thesis, also defined the second POPs problem-framework, the main characteristics of which were: (a) increased evidence of long-range atmospheric transport as a dominant source of POPs in the Arctic, (b) documentation of POPs throughout the Arctic and at multiple trophic levels, and, most importantly, (c) the documentation of human contamination. Although the meeting was, for the most part, a congregation of Canadian scientists, representatives (for the most part, scientists) from each of the other seven Arctic states were present. To the best of my knowledge, DIAND's decision to host this meeting and to invite foreign representatives constitutes the first international decision on the part of the Canadian government that was directly related to POPs.
Period II ends with the scientific evaluation meeting. The follow-up strategy meeting in December 1989 to plan a long-term interagency research and monitoring program kicks off Period III and is discussed below.

Period III (1989-1996)

Summary of scientific developments

The main developments related to the science of POPs during Period III were:

- continued work on long-range transport of POPs to the Arctic,
- wildlife studies looking at the concentration and effects of POPs at all levels of the food chain, and showing alarmingly high concentrations in beluga whales, and
- the development of the environmental endocrine hypothesis.

Increasing confirmation of long-range atmospheric transport as the primary source of POPs in the Arctic in Period III established POPs as an international problem. Scientific research on sources and pathways of contaminants in the Arctic was one of the priorities of the Northern Contaminants Program (NCP; the major Canadian research and monitoring program for Arctic contaminants, including POPs, discussed later) between 1991 and 1997. Atmospheric monitoring stations throughout the Arctic (e.g., at Alert, Tagish, Dunay Island) recorded atmospheric concentrations of many POPs, while other scientists compiled emissions inventories (for example, a global, spatially gridded, time-dependent inventory of POPs emissions). Atmospheric monitoring provided strong supporting evidence of long-range atmospheric transport, and the construction of global emission inventories allowed the
development of atmospheric models to better understand atmospheric transport mechanisms, atmospheric transformation processes, and long-term trends of POPs in the Arctic.

In the early 1990s, Derek Muir led a team conducting a circumpolar survey of beluga whales to further clarify geographic trends of POPs contamination in the Arctic (Muir 1992). His results showed similar contaminant levels throughout the Arctic, again indicating that long-range atmospheric transport was the dominant source of contaminants in the Arctic. In another study, Muir (1992) found higher concentrations of toxaphene and hexachlorocyclohexane (HCH) in the surface water of the Arctic Ocean than in the north Atlantic despite the lack of local sources, providing further evidence for long-range transport.

In 1993, Don Mackay and Frank Wania put forward the hypothesis of global fractionation (Wania and Mackay 1993). As discussed in Chapter 3, the global fractionation hypothesis states that semi-volatile compounds accumulate in cooler climates, and that more volatile compounds are preferentially transported over long distance. The more volatile constituents of toxaphene, for instance, are found in greater concentrations in the Arctic than constituents with lower volatilities (Bidleman et al. 1989). Compounds are “latitudinally fractioned according to their volatility” (i.e., semi-volatiles undergo fractional distillation on a global scale) (Wania and Mackay 1993, 16). The global fractionation hypothesis highlighted the global implications of POPs, and made clear the need for global (as opposed to regional) regulation.

Wildlife research in Period III continued to document POPs contamination throughout the Arctic environment (Muir et al. 1990; Muir 1992; Hargrave et al. 1992; Kidd et al. 1995). Karen Kidd et al. (1990), for instance, documented extremely high concentrations of toxaphene in Lake Laberge, Yukon Territory. Toxaphene levels in fish
were high enough to be considered a health hazard. Health Canada put out fish consumption advisories and the native subsistence, sports, and commercial fisheries were closed (Kidd et al. 1993, 1995). Kidd et al. (1995) reported that these toxaphene concentrations resulted entirely from long-range atmospheric transport and deposition into Lake Laberge, followed by biomagnification. The food chain in Lake Laberge is exceptionally long, and POPs bioaccumulate at each level eventually resulting in the high levels found there.

Meanwhile, in southern Canada, Pierre Beland et al. (1993) of the St. Lawrence Institute of Ecotoxicology found that St. Lawrence beluga whales were heavily contaminated by POPs. He associated POPs contamination with lesions in the digestive tract, rare tumors, and immune suppression. Media coverage of his work resulted in headlines such as “Belugas don’t die of old age in this river” (The Ottawa Citizen 6 July 1994), and “Toxins fill belugas: St. Lawrence 500 at risk” (The Province 22 July 1996). Beland’s statements characterizing St. Lawrence belugas as toxic waste provided a strong and clear illustration of the environmental impacts of POPs, and put additional pressure on government to act.

In human health studies, Walter Rogan and Beth Gladen (1991) had begun a longitudinal study in 1978 into the effects of PCBs and DDE (a breakdown product of DDT) on psychomotor development in North Carolina children born between 1978 and 1982. The participating families were deemed representative of the general population, as they were not selected based on any particular exposure. Rogan and Gladen measured psychomotor development at 6, 12, 18, and 24 months of age, and found delays in psychomotor development were still detectable at 24 months. Results showing effects at 24 months of age were published in 1991.
Jacobson and Jacobson (see Period II) continued their study into the effects of pre-natal PCB exposure on cognitive development. New results showed poorer visual recognition memory in infants, and poorer intellectual function in children exposed to higher levels of PCBs at four years of age. These results indicated that the effects of pre-natal exposure continued throughout early childhood (Jacobson and Jacobson 1990). In Jacobson and Jacobson’s study, the average concentration of PCBs in cord serum was $2.5 \pm 2.0$ nanograms per milliliter. In comparison, 43% of blood samples of Inuit mothers in Nunavut and the Northwest Territories collected in 2001 exceeded 5 nanograms per milliliter (Walker 2001; as cited in Van Oostdam et al. 2003). It should be noted, however, that actual effects of POPs on human health in the Arctic were not observed until 2005, after the time-span covered in this analysis.

As discussed in Periods I and II, evidence of endocrine disrupting effects of synthetic chemicals, including several POPs, had been accumulating since the 1970s. John McLachlan (1987; McLachlan et al. 1982), an endocrinologist, was one of the first to identify synthetic chemicals as endocrine disruptors (Krimsky 2000). McLachlan was trying to determine whether synthetic hormones such as diethylstilbestrol (DES) and DDT behaved similarly to natural hormones in sexual development, and in inducing cancer. Although McLachlan’s results were published in leading scientific journals, his work generated little attention in the media or other scientific disciplines, and was seen mostly as “funky science” (Krimsky 2000). Human development studies, however, emanated from this work (see above, Jacobson and Jacobson 1985; Rogan 1986), but the connection with wildlife research was weak. Even though wildlife biologists also found endocrine effects from synthetic chemicals in the
environment (Fox et al. 1978; Fry and Toone 1981; McArthur et al. 1983), the human health and wildlife strands of research remained separate.

The two strands came together to yield an integrated hypothesis on environmental endocrine disrupters in the late 1980s and early 1990s (Krimsky 2000). Theo Colborn, a scientist working with the Conservation Foundation, found that the majority of wildlife effects resulting in population decline in the Great Lakes region were related to developmental effects associated with endocrine disruption in the offspring of contaminated species rather than cancer, as had been previously assumed. Colborn made three major contributions to the development of the environmental endocrine hypothesis: (1) she associated individual effects that had previously been described in the literature into a larger, cross-disciplinary, generalized causal hypothesis of endocrine disruption, (2) she organized interdisciplinary workshops to connect academic disciplines whose research was related through the environmental endocrine hypothesis, but whose members were, for the most part, unaware of research in each other’s fields, and (3) she disseminated her conclusions widely, within academia (through the academic literature and the interdisciplinary workshops), to governments (through reports), and to the general public (through the popular book Our Stolen Future).

Colborn pieced together most of the existing evidence into an environmental endocrine hypothesis between 1987 and 1991. In 1991 she hosted her first interdisciplinary workshop. Until she brought scientists from a variety of scientific disciplines together at the Wingspread Work Session in 1991, there was no comprehensive formulation of the environmental endocrine hypothesis (despite fifteen years of research). Wingspread was “the
first time that wildlife biologists and human health scientists had had an opportunity to talk with one another” (Krimsky 2000, 27)).

Workshops continued throughout the 1990s. Between 1991 and 1996, evidence for the environmental endocrine hypothesis accumulated as connections were made between scientific communities. *Our Stolen Future* was published in 1996 and reaction to it was mixed. For instance, industry groups dismissed the hypothesis as “junk science”. However, *Our Stolen Future* generated significant media attention and brought the hypothesis to non-scientific audiences.

The environmental endocrine hypothesis, as presented in *Our Stolen Future*, marks the shift from the second to the third problem-framework. The third problem-framework now defined the POPs problem as one of contamination of cold environments (especially the Arctic environment) and Arctic indigenous peoples by a group of synthetic substances with physiochemical properties that allowed them to be transported over long distances in the atmosphere and deposited in the Arctic, and to bioaccumulate and biomagnify in the environment with *potential endocrine disrupting effects* on wildlife and human health *even at very low concentrations*. Thus, Period III ends with the publication of *Our Stolen Future* and the formation of the third problem-framework.

**Knowledge types**

The dominant knowledge types during Period III were:

- causal knowledge (atmospheric transport to Arctic, accumulation, leading to potential human health risks through endocrine disruption at very low concentrations)
- consequence knowledge (wildlife effects and potential human health effects),
character knowledge (behavior in the biotic environment, behavior in the abiotic environment, and sources), and

- extent-intensity knowledge (geographic extent, ecosystem contaminant levels, and human contaminant levels).

Causal knowledge continued to play an important role in Period III. Once again, the causal chain was extended from previous periods to include potential wildlife and human health effects (most notably, endocrine disruption). Major uncertainties remained, including identifying specific mechanisms of cause and effect of contaminants in wildlife and human health.

In Period III, the developing environmental endocrine hypothesis put forward a variety of potential endocrine-related effects of POPs on wildlife and human health (Jacobson et al. 1990; Colborn et al. 1996). Knowledge about specific (real and potential) wildlife and human health effects (as opposed to mere exposure knowledge) further justified regulatory action and brought additional attention to the issue.

Scientific developments during Period III firmly established POPs as an international problem by identifying long-range atmospheric transport (from around the globe) as the primary source of contaminants in the Arctic (character knowledge with respect to behavior in the abiotic environment, and sources), and by documenting the extent of POPs contamination in the global Arctic (extent knowledge) (Muir 1992). Canadian scientists and policymakers re-defined the Arctic POPs problem in 1989 as an international issue and as a human health issue (Dewailly et al. 1989; Technical Committee on Contaminants 1989; see Period II, above). Thus, Period III was characterized not only by the establishment of POPs
as an international environmental issue but also by the first major international efforts to regulate POPs (discussed below).

The characterization of POPs as an international environmental and human health problem that could have adverse effects at very low concentrations through endocrine disruption directly led to proposed solutions. For instance, based on new knowledge about endocrine-disrupting effects of OCs, the Great Lakes Science Advisory Board of the International Joint Commission recommended that Canada and the US take a precautionary approach by immediately regulating the release of endocrine disrupting substances, including many POPs, into the environment, as opposed to waiting until a cause and effect relationship was unequivocally proven (a nearly impossible task) (Great Lakes Science Advisory Board 1991). Contamination in the Great Lakes was still considered a separate issue (of contamination from nearby sources), but their advice on endocrine disrupting substances applied equally to POPs in the Arctic.

Three key requirements for solving the problem were identified by scientists\(^{13}\): the precautionary approach (since it is practically impossible to unequivocally prove a cause-effect relationship for specific endocrine-disrupting chemicals), global regulation (based on the sources of POPs and their ability to be transported), and virtual elimination (because emissions of POPs from anywhere on Earth can end up in the Arctic, accumulate, and can have effects at extremely low concentrations).

In summary, developments in the science of POPs added considerably to the international regulatory efforts during Period III by establishing POPs as an international problem, solidifying existing knowledge (e.g., about the long-range transport of POPs),

\(^{13}\) These three elements appear repeatedly in scientific assessments, and all eventually found their way into regulatory schemes related to POPs (including the Stockholm Convention,).
filling gaps in knowledge (e.g., sources and pathways of POPs), providing new information on specific substances (for instance, heptachlor was added to the LRTAP protocol after new information justified its inclusion), revealing potential adverse consequences for wildlife and humans from POPs exposure (e.g., neurological effects from low level pre-natal exposure to PCBs), and by revealing potential solutions to the POPs problem (i.e., global regulation).

**Knowledge actions**

The dominant knowledge actions of scientists during Period III were:

- knowledge creation (directed, co-production),
- knowledge transmission (intra-disciplinary, cross-disciplinary, and inter-organizational), and
- knowledge translation (for policymakers).

As discussed earlier, the creation of knowledge continued to play an important role in Period III by establishing POPs as an international issue, filling gaps in knowledge, providing detailed information on specific substances, and increasing our knowledge of real and potential adverse effects in wildlife and humans. The transmission of knowledge also continued to play an important part, since it allowed the further development of the science.

Communication between the scientific community and northern Aboriginal organizations was a key part of the NCP—Canada’s primary research program contributing to POPs science (NCP 1997). Scientists were required to work with northern Aboriginal organizations (depending on their project), and were encouraged to communicate their results to community groups and to community leaders (Interview, August 5, 2005). Several
interviewees mentioned the influence of Aboriginal culture on their research. Traditional ecological knowledge provided valuable information about, for instance, the best times and places to collect biological samples. One interviewee discussed how working with northern Aboriginal peoples even influenced which species were studied. Communication between scientists and northern Aboriginal organizations improved the science, and made it more relevant to northerners. Many research projects that were conducted through the NCP were classic examples of the co-production of knowledge (i.e., co-produced by scientists and non-scientists).

The transmission of knowledge between organizations dealing with POPs, such as the NCP, the Arctic Monitoring and Assessment Program (AMAP; discussed below), LRTAP, the Oslo-Paris commission, the Helsinki Commission, and UNEP was a new form of scientific knowledge transmission that first appeared in a significant way during Period III. Many of the scientists involved in the LRTAP Task Force on POPs, for instance, were also involved in AMAP and the NCP, facilitating the communication of scientific knowledge and cooperation between these organizations. AMAP and the NCP, for instance, cooperated in the production of their assessment reports, which both supported the LRTAP regulatory process and progress towards the formation of a global regime on POPs.

Cross-disciplinary transmission of knowledge continued to play an important role in Period III. Cross-disciplinary transmission of knowledge stimulated research in other scientific disciplines (e.g., vom Saal, after talking with Theo Colborn, began studies into the behavior of synthetic chemicals as endocrine disruptors during fetal development (Krimsky 2000)). Cross-disciplinary transmission, as seen in previous periods, was instrumental in integrating scientific knowledge from diverse fields of research into a coherent framework.
Noteworthy in this regard is the special issue of the academic journal *Science of the Total Environment* on POPs published in 1992. The issue contained several review articles dealing with different aspects of the POPs problem (e.g., on the sources, occurrences, and pathways of Arctic contaminants) and integrated the existing knowledge on POPs. Similarly, the development of the environmental endocrine hypothesis involved the integration of knowledge from toxicology, endocrinology, cognitive psychology, biology, and biochemistry. The addition of the environmental endocrine hypothesis to the science of POPs could not have occurred without this type of transmission.

The dissemination of the environmental endocrine hypothesis also occurred, to a large extent, through cross-disciplinary transmission of knowledge. A few key players, including Theo Colborn, Pete Myers, and John McLachlan, were instrumental in communicating between disciplines, both actively (e.g., through workshops) and passively (e.g., through the media).

The translation of scientific knowledge by Canadian scientists for policymakers continued to influence not only the development of Canada’s domestic and foreign POPs policies during period III, but also the international POPs policymaking processes (Shearer and Han 2003; Selin and Eckley 2003; Rodan et al. 1999). Canadian scientists, through their participation in AMAP, NCP, LRTAP, and UNEP assessment processes, were very active in generating, integrating, and translating scientific knowledge for policymakers. Programs like AMAP and the NCP were instrumental as channels of communication between scientists and policymakers. An evaluation of the NCP, for instance, credits the NCP with helping to “[establish and strengthen links] between research results and policy-making in Canada” (DIAND 2002, 19). The communication of new information through these channels justified,
for example, the inclusion of new chemicals in international regulations (Selin and Eckley 2003), and provided support for negotiations.

The communication of scientific knowledge to policymakers was significant in several ways. First, by passing on the most recent scientific knowledge to policymakers through assessments, reports, workshops, or, more commonly, through departmental channels, scientists directly and indirectly influenced policy by expanding the scope of the problem (e.g., to include new potential human health effects). Second, new knowledge in turn justified a number of changes in international policy (e.g., the selection of substances to be regulated). Finally, new research results from Period III (as already discussed) were the basis for justifying international action.

New institutions dealing with POPs and the Arctic environment (to be discussed below) provided funding for research and helped coordinate not only the production and integration of knowledge, but also the translation of these results for policymakers. In other words, these institutions formed new channels through which scientists could communicate their research results directly to policymakers. A number of interviewees, for instance, described the NCP as instrumental in communicating their results to policymakers.

In my analysis, I found that other knowledge actions during Period III, such as the translation of scientific knowledge for the general public, played less significant roles than in previous periods (see below, Influence on policy decisions). The translation of knowledge for community groups, NGOs (e.g., the Inuit Circumpolar Conference), and to a lesser extent, the media, helped inform the public, and put pressure on the federal, provincial, and territorial governments to act. The NCP held results workshops every year, where scientists conducting research for the NCP could present their results to other scientists, community
leaders, and policymakers. In addition, many scientists working with the NCP were encouraged to go on tours to communicate their research results to northern communities (Interview, July 26, 2005).

**Influence on policy decisions**

During Period III, the major policy decisions were the domestic and foreign policy decisions to: (a) form Canada’s first comprehensive policy on POPs—the Strategic Action Plan on Northern Contaminants (which includes the establishment of the Northern Contaminants Program (NCP)), (b) expand the Technical Committee on Contaminants to include northern Aboriginal groups, (c) integrate the Northern Contaminants Program (NCP) into Environment Canada’s Green Plan, and (d) press the need for international regimes for POPs (e.g., through LRTAP and UNEP).

Period III saw the emergence of POPs as an issue first on national stages (e.g., Canada and Sweden), then on regional stages (e.g., the North Sea), and finally, on the global stage. For simplicity’s sake, the policy developments for Period III will be discussed in the following manner. First, developments in Canada’s POPs foreign policy are outlined. Second, Canada’s roles in regional initiatives on POPs are discussed, including LRTAP and AMAP. And third, Canada’s role on the global stage in working toward the creation of the Stockholm Convention is discussed. Canada’s POPs foreign policy decisions correspond with Canada’s regional and global roles in POPs regime formation. This thesis is concerned with the influence of scientific knowledge and scientists’ actions on Canada’s policy decisions. It is not concerned with the influence of scientific knowledge and scientists’ actions on regional and global regime formation, and thus, they are not analyzed in depth.
here. Despite this, because Canada played a leadership role in the regional and global regime formation processes, an analysis of the influence of science on Canada’s foreign policy decisions provides an excellent window into the influence of science on the larger scale policy dynamics.

**Canadian foreign policy**

Spurred by the results of its scientific evaluation meeting in February 1989, the Technical Committee on Contaminants (expanded to include representatives from five northern Aboriginal groups) held a workshop in Toronto to create a long-term interagency research and monitoring strategy. The workshop resulted in a Strategic Action Plan on Northern Contaminants (including radionuclides, heavy metals, and POPs). This was Canada’s first comprehensive environmental policy on POPs. The plan outlined the priorities in Canada’s POPs policy (both domestic and international) and was “the foundation for what would become the Northern Contaminants Program” (Furgal et al. 2003, 14). The expanded Technical Committee on Contaminants was, in essence, the beginning of the Northern Contaminants Program (NCP), though it was only ‘formally’ established in 1991 (as part of Canada’s Arctic Environmental Strategy). Domestically, Canada focused on “providing timely health advice to northern people” (Furgal et al. 2003, 15) and continued research to address uncertainties, with a focus on contaminant levels in wildlife, and sources and pathways of POPs in the Arctic. Little research conducted during the first phase of the NCP focused on human health.

The Strategic Action Plan on Northern Contaminants contains Canada’s first POPs foreign policy statements, and therefore represents Canada’s first major POPs foreign policy
decisions. The central focus of this foreign policy was prioritizing the establishment of international agreements on POPs. In my judgment, science was the major factor in this initial formation of Canada’s foreign policy on POPs. The synthesis and assessment report on the state of scientific knowledge that resulted from the evaluation meeting in February 1989 (discussed in the previous section on Period II) was pivotal in Canadian government officials’ decision to formulate foreign policy on POPs. The key knowledge types influencing this decision (as already discussed in the previous section on Period II) were evidence of long-range atmospheric transport as the dominant source of POPs in the Arctic (character knowledge), documentation of POPs throughout the Arctic and at multiple trophic levels (extent-intensity knowledge), documentation of human exposure (consequence knowledge), and the spelling out a plausible cause-and-effect chain of actions that occurred throughout the Arctic from atmospheric transport to potential human health risks (causal knowledge).

The key knowledge actions by scientists were synthesizing, assessing, and translating for policy makers the implications of these and other types of scientific knowledge. Also in 1989, the Canadian federal government began consultations for a new national environmental plan: the Green Plan for a Healthy Environment. Through these consultations, northerners (informed directly and indirectly by scientists) introduced the issue of Arctic contamination, and, consequently, the Green Plan which was launched in 1990 included an Arctic Environmental Strategy (AES) that addressed a variety of issues, including contaminants (POPs, radionuclides, and heavy metals).

In 1991, the Northern Contaminants Program (NCP) was established/integrated into the AES to help the Canadian federal government fulfill its commitments towards dealing
with Arctic contaminants under the Green Plan. The first phase of the NCP, assessing “the risk to northern ecosystems and human health from the long-range transport” of POPs (Shearer and Han 2003, 44), was to end in 1997.

The creation of new institutions dealing with POPs and the Arctic environment (e.g., the NCP and AMAP; discussed below) is another key characteristic of Period III. These new institutions provided channels for the translation and transmission of knowledge for policymakers.

The newly unveiled NCP included the old Technical Committee on Contaminants and added a new Science Managers Committee responsible for supervising NCP funding and policy. The Science Managers Committee included representatives from five northern Aboriginal organizations, thus giving northerners indigenous peoples a strong voice in the operation of the NCP. As a result of this cooperation with northern Aboriginal organizations, and as already mentioned, traditional ecological knowledge played an important part in guiding NCP research.

It is interesting to note that elected officials (e.g., members of parliament), though supportive of Canada’s POPs policy, played only minor roles in the development of Canada’s environmental foreign POPs policy (R. Shearer, Personal Communication, 20 September 2005.). There were several changes in government during the time-span of this analysis. For instance, there were four Prime Ministers of Canada between 1980 and 2001 (Pierre Trudeau (Liberal), Brian Mulroney (Progressive Conservative), Kim Campbell (Progressive Conservative), and Jean Chrétien (Liberal)). Yet these changes had little effect on POPs policymaking, as it was driven mostly by scientists and government bureaucrats.
Canada's role in regional initiatives: LRTAP and AMAP

By 1989 it had been generally agreed that the sources of Arctic POPs contamination were global in nature and that most POPs were transported to the north via ocean currents and atmospheric winds (Technical Contaminants Committee 1989). Since the problem would require international action, Canada attempted to initiate the process of forming international controls on POPs. Canadian officials from INAC approached the OECD, FAO, WHO, and UNEP about regulating POPs.

Scientific knowledge about the sources of Arctic POPs contamination still contained many uncertainties (about the geographic extent, sources and pathways, and effects), and the OECD, FAO, WHO, and UNEP “did not yet understand the scientific foundation of why POPs were a long-range pollution problem” (Selin and Eckley 2003). None of these organizations showed much interest, and Canadian officials were forced to look elsewhere.

In 1989, Canadian officials talked to the Working Group on Effects for the LRTAP convention about regulating POPs. The Working Group on Effects showed interest in POPs, but needed more information to assess the need for action. To fulfill this request, Canada prepared a working-paper on “atmospherically transported hazardous organic substances” (the term POPs had still not yet been defined). Canada presented the working-paper to the Working Group on Effects in 1990. The issue was referred to the LRTAP Executive Body, which decided to investigate the issue further. The Executive Body set up a Task Force on Persistent Organic Pollutants (to the best of my knowledge, this is the first use of the term “persistent organic pollutant”), headed by Canada and Sweden, to investigate and prepare a report on POPs. Scientists played an important role in the Task Force on POPs by
transferring knowledge between various organizations (many of the scientists involved in the Task Force were also involved in AMAP; see below), communicating between and synthesizing knowledge from a variety of academic disciplines to summarize the issue, and translating and communicating this knowledge to policymakers. In the early 1990s, we begin to see a shift in the dominant role of scientists in influencing policy from being knowledge creators to being knowledge translators and communicators.

In 1994, the Task Force returned to the Executive Body with their report. The report, the first to define “persistent organic pollutants”, framed the issue as an international problem, a problem “of long-range transport, persistence, bioaccumulation, and toxicity” (Selin and Eckley 2003, 26). The Executive Body reviewed the report, and, based on the scientific knowledge presented in it decided that international controls on POPs were warranted. The Task Force Report was passed on to UNEP to further press the case for global action on POPs and was instrumental in convincing UNEP that a global convention on POPs was necessary.

Not all LRTAP countries were prepared to begin negotiations based only on the work of the Task Force, however, so the Executive Body set up an Ad Hoc Preparatory Working Group to further assess the issue and prepare for negotiations. Based on the available scientific knowledge, the Preparatory Working Group identified options for regulation and management of POPs, wrote a draft text for a protocol to LRTAP, formed a priority list of POPs, and prepared screening criteria for the inclusion of additional substances. Screening of substances began in 1995.

Knowledge about individual substances played an important part in selecting substances for regulation under LRTAP. Insufficient or uncertain data about individual
substances, in some cases, led to their exclusion. Heptachlor, for instance, was eliminated from LRTAP's tentative list of substances due to the lack of evidence for long-range transport (later, during negotiations, it was returned to the list (as a result of new data)). Other substances which passed the screening, but were subject to debate during LRTAP negotiations included lindane, pentachlorophenol, and short-chain chlorinated paraffins. LRTAP's tentative list of substances, as it stood in 1995, was used by UNEP as the initial group of substances to be regulated under a global convention.

Meanwhile, in 1991, the eight Arctic nations—Canada, the U.S., the U.S.S.R., Norway, Sweden, Denmark, Iceland, and Finland—agreed on a common strategy, the Arctic Environmental Protection Strategy, to combat the emerging issue of Arctic pollution. Part of the plan was to set up an Arctic Monitoring and Assessment Programme (AMAP) “to monitor the levels of pollutants and to assess their effects in the Arctic environment” (Reiersen et al. 2003, 61). All Arctic nations agreed to support the formation of international regulations on POPs through the LRTAP protocol on POPs.

The inter-linkages between the various international organizations were complex, and knowledge was frequently shared. Much of the knowledge generated through the NCP and AMAP, for instance, was passed on to LRTAP and UNEP. The chair of AMAP, David Stone (a Canadian), for instance, was also co-chair of the LRTAP Task Force on POPs. This greatly accelerated the transfer of information to LRTAP. Many of the scientists involved in the Task Force, too, were involved in AMAP. Similarly, much of the knowledge generated by LRTAP was passed on to UNEP (e.g., the Task Force Report and preliminary list of substances to be regulated by LRTAP were conveyed to UNEP).
Canada’s role in the Stockholm Convention

Iceland, a member of AMAP, presented a report in 1995 to a meeting in preparation for the Washington Conference to establish the Global Plan of Action for the Protection of the Marine Environment from Land-Based Activities (for UNEP). The report, ("which included much material from the LRTAP and AMAP sources" (Stone 2005)) explained the need for international action on POPs. Iceland’s synthesis made a strong case, and the UNEP Governing Council passed a resolution calling for an assessment of 12 POPs. This “dirty dozen” was selected from LRTAP’s tentative list of substances, which “was circulated and agreed to rapidly, with little if any domestic deliberation by countries not involved in [LRTAP]” (Selin and Eckley 2003, 35).

In contrast to LRTAP, the initial selection of substances under UNEP was almost exclusively a political decision, though assessments were later carried out to determine if scientific data justified the inclusion of all twelve substances. On behalf of UNEP, the International Programme on Chemical Safety (IPCS)\(^{14}\) within the framework of the Inter-Organization Programme for the Sound Management of Chemicals (IOMC) conducted an assessment of the 12 selected POPs in 1995. The IPCS reported their findings in the Ritter report, presented to UNEP later in that year (Ritter et al. 1995). In addition, UNEP asked the Intergovernmental Forum on Chemical Safety (IFCS)\(^{15}\) to recommend whether or not international action on POPs was necessary. The United Nations Economic Commission for

\(^{14}\) The IPCS is a program coordinated by the World Health Organization, the International Labour Organization, and UNEP. Its primary function is to “establish the scientific basis for safe use of chemicals, and to strengthen national capabilities and capacities for chemical safety” (WHO. 2006b). The IFCS, on the other hand, is an inter-governmental organization.

\(^{15}\) The IFCS is an inter-governmental forum whose purpose is to “develop and promote strategies and partnerships among national governments, intergovernmental and non-governmental organizations” (WHO. 2006a).
Europe, while preparing for the LRTAP negotiations at the time, was actively involved in these IFCS discussions (Nordberg 1997). IFCS replied in 1996 that global action was required.

Also in 1996, Colborn et al. published *Our Stolen Future* (see above), which translated a wide body of scientific knowledge about the endocrine-disrupting properties of certain synthetic chemicals, including POPs, for the general public. *Our Stolen Future* sparked debate in both academia and in government, and received considerable attention in the media, and added a new dimension to the POPs problem. Despite the controversy and media attention, I found little evidence that the publication of *Our Stolen Future* in and of itself directly influenced Canada’s POPs policy. NCP researchers highlighted the potential endocrine disrupting effects of POPs (in humans) much earlier, in 1991, the first year of the NCP, and endocrine disrupting effects in wildlife were well known long before that. Despite this, Period III ends with the publication of *Our Stolen Future* and the dissemination of environmental endocrine hypothesis to the general public.

**Period IV: 1996-2001**

*Summary of scientific developments*

The main developments related to the science of POPs during Period IV were:

- monitoring of temporal trends of POPs in the physical and biological environments,
- identification of new POPs,
- further research into health effects associated with POPs,
- further development of the environmental endocrine hypothesis, and
• publication of two major assessment reports.

During Period IV there were fewer major new scientific discoveries. Much of the scientific work during this period involved refining previous work. In general, the scope of the POPs problem expanded.

New POPs were identified. For instance, polybrominated diphenyl ethers (PBDEs), short chain chlorinated paraffins (SCCPs), and polychlorinated naphthalenes (PCNs) were added to the already long list of known POPs (Alaee 2003). The concentrations of some of these (e.g., PBDEs) were found to be increasing in the Arctic, and were measured in wildlife (Stern and Addison 1999) and breast milk (Darnerud et al. 2001). Despite this discovery they were not immediately influential on Canada’s POPs policy.

In the field of human health, Gina Muckle (2001a; 2001b) of the University of Laval began a longitudinal study similar to those Jacobson and Jacobson, and Rogan and Gladen (as discussed above). Muckle began observation of mothers and their infants in 1997 to determine the influence of a variety of pre-natal factors including, for instance, exposure to contaminants (POPs, metals, etc.), and maternal alcohol consumption, on infant and childhood development. As of 2001 only exposure data were released.

A number of potential effects of POPs contamination at existing levels in northern Aboriginal peoples were identified during Period IV. Arnold et al. (2001), for instance found, in some Inuit populations, concentrations of toxaphene that have been associated with adverse effects on immune function and infant size in other studies. Dewailly et al. (2000) associated POPs contamination with Inuit infants’ susceptibility to infections through immunological effects (Inuit infants suffer higher levels of infections than the general
Canadian population). Despite these developments, considerable uncertainty about the effects of POPs on human populations remained in 2001 when the Stockholm Convention was signed (DIAND 2002).

The end of the first phase of the NCP in 1997 coincided with the publication of two major assessment reports: The Canadian Arctic Contaminants Assessment Report (CACAR) published by INAC and EC (NCP 1997), and the State of the Arctic Environment Report (SOAER) published by the eight Arctic nations involved in AMAP (AMAP 1997). Dozens of scientists were involved in the publication of these reports; for instance, to write sections or sub-sections, or to put together chapters. Both of these reports were influential translations of scientific knowledge for policymakers at the international level and provided support for Canada’s position during negotiations (Interview, July 25, 2005).

The CACAR report, accompanied by a highlights report, summarized the most recent Canadian research on Arctic contamination (within Canada), including POPs, radionuclides, and heavy metals. The report presented the state of knowledge on POPs, with chapters on physiochemical properties (e.g., sources and pathways), the biological environment (e.g., geographic trends), and human health (e.g., contaminant levels, and sources of exposure). The CACAR report concluded that concentrations of POPs in the Arctic were not likely high enough to cause ill health to the adult population but that accumulated POPs might affect pre-natal development, resulting in subtle effects such as reduced immune function or neurological problems (Northern Contaminants Program 1997; Shearer and Han 2003).

The SOAER report, too, summarized the state of scientific knowledge on POPs, but considered the Arctic as a whole. The SOAER report concluded that for some contaminants, Arctic people are among the most heavily exposed in the world and that many of these
chemicals arrive in the Arctic via long-range transport. The SOAER report recommended that the Arctic nations support the UNEP process and “work vigorously for the expeditious completion of [the LRTAP] negotiations” (AMAP 1997, xii). AMAP, which published the SOAER report, continued to be an important vehicle for translating science to policymakers at the international level throughout Period IV. AMAP’s SOAER report (AMAP 1997) and AMAP Assessment Report: Arctic Pollution Issues (AMAP 1998) summarized and updated the science of POPs in the Arctic for policymakers.

**Knowledge types**

Through my analysis, I found that new scientific knowledge did not influence policymaking during Period IV to the same extent as in previous periods (see below, *Influence on policy decisions*). Rather than new knowledge, it was synthesis and assessment of existing knowledge that was influential, as represented by the CACAR and SOAER reports discussed above. I found that most of the scientific developments during Period IV filled gaps in existing knowledge, decreased uncertainty, and laid the groundwork for future influence (after the completion of the LRTAP Protocol and the Stockholm Convention), as opposed to directly influencing Canada’s environmental foreign policy. New knowledge was not necessary to justify international action since both the LRTAP and UNEP processes were already in progress by the beginning of Period IV, and the foundation of scientific knowledge upon which they were based was already in existence. New and existing scientific knowledge continued to play a part in Canadian foreign policy by reinforcing the Canadian position during the LRTAP and Stockholm negotiations; however, it didn’t add new dimensions to it.
Knowledge actions

The dominant knowledge actions of scientists during Period IV were:

- knowledge transmission (inter-organizational), and
- knowledge translation (for policymakers).

As with knowledge types, I found that the actions of scientists were noticeably less influential on Canada’s environmental foreign policy once formal negotiations began for the LRTAP POPs Protocol and the Stockholm Convention. Scientists were consulted during negotiations, but their influence was less as compared with earlier periods. However, the assessment function (action) of scientists continued to have influence (especially through the CACAR and SOAER reports). In addition, the transmission of knowledge between organizations involved in POPs such as the NCP, AMAP, LRTAP, and UNEP, continued to play a role during Period IV. Knowledge about specific substances, for instance, was passed from organization to organization (e.g., LRTAP, Oslo-Paris Commission, the Helsinki Commission), and justified their inclusion or exclusion from negotiations. Canadian scientists continued to advise and translate scientific knowledge for policymakers. Translation of scientific knowledge for policymakers, however, was now directed at the international community as well as Canadian government officials, and occurred through assessment reports (AMAP and CACAR), departmental channels, organizational channels (AMAP and NCP), and, in some cases, personal communication.

Other knowledge actions of scientists during Period IV included knowledge creation, knowledge transmission (within academic disciplines), cross-disciplinary transmission of
knowledge, and translation of knowledge for the general public, though (as I found in my analysis) these played relatively minor roles.

**Influence on policy decisions**

During Period IV, the major policy decisions were: (a) the decision to renew the NCP, (b) the continuation of the decision from the previous period to pursue international regime-formation processes for POPs, (c) to support the LRTAP negotiations, (d) to ratify the LRTAP Convention, (e) to support the UNEP negotiations, and (f) to ratify the Stockholm Convention.

Domestically, Canada’s only major policy decision with respect to POPs was the renewal of the NCP. Through consultations with all stakeholders (northern communities, aboriginal organizations, scientists, etc.), the NCP established priorities to direct research through to the end of Phase II in 2003. Priority knowledge included human health, biological, and physical data to address immediate health concerns of northern peoples, as well as to support international processes for the regulation of POPs (Shearer and Han 2003).

The shift in policymaking from the national level to the international/global level that occurred during Period III continued throughout Period IV. During Period IV, Canada made no groundbreaking foreign policy decisions on POPs. It continued to vigorously lobby for development of regional and global regulation of POPs. Canada was instrumental in initiating international efforts to regulate POPs (in Period III), and Canada’s foreign policy during Period IV was a continuation of its support for the LRTAP and Stockholm Conventions through their respective negotiation processes. Thus, throughout Period IV
Canada maintained its international leadership role. Policymakers took center stage during negotiations while scientists receded into the background.

Canadians (both scientists and policymakers) were prominent in efforts to convince UNEP of the need for international action on POPs. A Canadian, David Stone, was both co-chair of the LRTAP Task Force on POPs (whose report was instrumental in convincing UNEP), and the chair of AMAP. The Ritter report, summarizing what was known about the 12 substances to be regulated under the Stockholm Convention, was written by Canadian consultants for the IOMC.

Based on the IFCS’s conclusion that scientific knowledge supported the need for global regulations on POPs, the UNEP decided, in February of 1997, that “international action, including a global legally binding instrument, is required to reduce the risks to human health and the environment arising from the release of the 12 POPs” (Sundén-Bylhéén 1997). Negotiations began after the conclusion of the negotiations for the Rotterdam Convention on the Prior Informed Consent Procedure For Certain Hazardous Chemicals And Pesticides In International Trade (in March 1998). In June 1998 negotiations began. Canada played a leadership role throughout these negotiations. For instance, in March of 2000, Canada was the first country to provide funds to support capacity-building in less developed countries to reduce emissions of POPs. The fund was thereafter known as the Canada Fund.

Formal LRTAP negotiations began in January 1997, and concluded in February 1998. The LRTAP POPs Protocol was signed by 36 countries in June of that year, and in December, Canada became the first country to ratify the protocol. Negotiations for the Stockholm Convention began in June 1998 and ended, after five international negotiating sessions, in December 2000. The convention was signed by 91 countries and the European
Union in May 2001. Once again, Canada was the first country to ratify the agreement.

This concludes my case study of POPs. In Chapter 5 the key findings from each of the four time-periods are summarized and compared. I then present a refined categorization scheme of knowledge types and actions that contributes to better understanding the influence of scientists and scientific knowledge on policy development.
Chapter 5. Discussion

In Chapter 4, the influence of scientific knowledge types and actions was analyzed in relation to Canada's domestic and foreign policy decisions on the transboundary POPs issue. In this chapter, their influence is compared across time-periods in order to derive a picture of their evolution over the time-span of the case study (mid-1980s to 2001). Following this, I present a refined categorization scheme of knowledge types and actions.

Evolution of the influence of science on Canada’s POPs foreign policy

In this section, by comparing the influence of the various knowledge types and actions between time-periods, I derive a historical portrait of their influence on Canada’s foreign POPs policy.

Knowledge types

Scientific knowledge about POPs accumulated throughout the time-span of my analysis and, likewise, the number of influential knowledge types increased. Different knowledge types tended to influence policy in different ways. The dominant knowledge types influencing policy during each time-period are summarized in Table 5.1 (see below). In this section, the dominant knowledge types for each period are summarized, followed by a discussion of the patterns observed for each knowledge type.
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<td>Atmospheric transport to Arctic, accumulation, leading to potential human health risks through endocrine disruption at very low concentrations</td>
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<td><strong>Character</strong></td>
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<td><strong>Extent-intensity</strong></td>
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Period I

The dominant knowledge types during Period I were existence knowledge (stating the existence of the previously unrecognized problem of Arctic POPs contamination), causal knowledge (postulating that the majority of the POPs found in the Arctic were of non-local origin), and extent-intensity knowledge (delineating the geographical extent of the problem, and the contaminant levels found in the Arctic ecosystem). These three knowledge types set the scene: a previously unknown problem of OC contamination was found to exist, the sources of the contamination were unknown but were decidedly non-local (some of them probably lay outside Canada), and the contaminants were widespread—they could be found throughout the Arctic. There were many uncertainties, however, so the Technical Committee on Contaminants decided, in 1985, to recommend a four-year research and monitoring program.

Period II

The dominant knowledge types during Period II were extent-intensity knowledge (notably, data further documenting the geographic extent), character knowledge (evidence supporting the hypothesis of long-range atmospheric transport as the dominant pollutant pathway into the Arctic), consequence knowledge (the first direct evidence of human exposure to POPs), and causal knowledge (atmospheric transport to Arctic from non-local sources, leading to accumulation in the Arctic, leading in turn to potential human health risks). Of these knowledge types, knowledge about human exposure to POPs was most influential on policy during Period II. The main policy decisions were to host an evaluation workshop and, more importantly, a workshop to develop a comprehensive policy on Arctic contaminants.
Period III

The dominant knowledge types during Period III were consequence knowledge (increasing evidence of wildlife and human health effects, most notably potential interference with the endocrine system), character knowledge (the development of models to predict the long-term behavior of chemicals in the environment (e.g., atmospheric transport) and the accumulation of data illustrating the behavior of POPs in the biotic environment and the abiotic environment, most notably long-range transport and global fractionation), extent-intensity knowledge (for instance, evidence of the geographic extent of contamination in the international Arctic environment, as opposed to the Canadian Arctic), and causal knowledge (atmospheric transport to the Arctic, leading to accumulation in the Arctic environment, in turn leading to potential human health risks through endocrine disruption, even at very low concentrations). Extent-intensity and character knowledge reinforced, during Period III, Canada's decision to pursue international regulation of POPs, and supported Canada's efforts to convince the international community that such action was required.

Period IV

No significant new knowledge types were identified for Period IV, and scientific knowledge did not result in any significant changes in Canadian foreign POPs policy.

Knowledge type patterns

Existence knowledge

The discovery of the POPs problem (existence knowledge) came about through the synthesis of knowledge that already existed related to various aspects of the problem (e.g., geographic extent, contaminant levels in the Arctic ecosystem, bioaccumulation potential).
Once these aspects of the problem were connected, the larger picture of the transboundary POPs problem emerged. It may seem obvious, but without this discovery, Canada would not have developed a POPs foreign policy. However, knowledge about the existence of the POPs problem was insufficient, in itself, to result in a comprehensive POPs foreign policy. It was existence knowledge in combination with other knowledge types (character knowledge and extent-intensity knowledge) that, in retrospect, resulted in Canada’s first foreign policy decision on POPs (the establishment of a research and monitoring program). Knowledge about the existence of the problem itself and various aspects of the problem (e.g., bioaccumulative potential, persistence, and long-range transport) was important in the early stages of the development of Canada’s POPs foreign policy, but became progressively less so as the issue developed.

*Causal knowledge*

An initial outline of the causal chain related to POPs, from sources to effects, was put together at the end of the first period. New data in subsequent periods provided further evidence supporting and lengthening the chain to include specific sources, pathways, and consequences of contamination. However, for the most part, the causal chain developed during the first period remained intact. Causal knowledge was most influential in the mid-to-late 1980s (Period II). During this period, the causal chain was extended to include potentially significant effects on human health. This knowledge was pivotal in Canada’s decision to pursue global regulation of POPs. During the third period, the causal chain was used by Canadian officials to justify the need for regime formation.
Consequence knowledge

Consequence knowledge (with respect to human exposure and effects) played a lead role starting around the time that human contamination by POPs was discovered (at end of Period II) and continued to influence policy through to the end of the case study. Consequence knowledge with respect to human exposure convinced the Canadian government that action on POPs was necessary and was used throughout the third and fourth periods to justify international action (along with data showing the geographic extent of contamination in the Arctic and evidence of long-range transport).

Extent-intensity knowledge

Extent-intensity knowledge played a lead role starting around the end of Period II and continued to influence policy through to the end of the case study. The knowledge of widespread contamination throughout Arctic Canada, and the Arctic as a whole, was used throughout the third and fourth periods to justify international action (along with evidence of long-range transport and the potential human health consequences).

Character knowledge

Character knowledge, in terms of behavior in the abiotic environment (e.g., persistence, long-range transport) became influential in the third and fourth periods. Character knowledge, with respect to the behavior of POPs in the abiotic environment (especially evidence of long-range transport and global fractionation), was instrumental in Canada’s efforts to convince the international community that global action was necessary. Character knowledge (e.g., about the properties and behavior of specific substances) played an important role in negotiations by influencing the form the regulations took (e.g., in terms of the selection of chemicals).
**Knowledge actions**

**Period I**

The dominant knowledge actions of scientists during Period I were knowledge creation. This was relatively random, in that it was not directed towards an Arctic POPs problem and synthesis, in that knowledge generated for other purposes was synthesized revealing the larger picture of Arctic POPs contamination. Knowledge transmission occurred by intra-disciplinary and cross-disciplinary means. The POPs problem as a coherent whole remained unidentified until the end of Period I, and all research (knowledge creation) before this point had not, therefore, been directed towards shedding light on an Arctic POPs problem; it had ‘randomly’ accumulated for almost a century. Through cross-disciplinary communication, existing knowledge about various aspects of the problem were pieced together (synthesized) creating a new knowledge: existence knowledge about the Arctic POPs problem. Cross-disciplinary communication resulted in the ‘discovery’ of the problem, and consequently, cross-disciplinary communication was the most influential knowledge action on policy during Period I.

**Period II**

The dominant knowledge actions of scientists during Period II were knowledge creation (random, as in Period I, and directed, in that research was directed by government officials (and scientists themselves) to shed light on the newly discovered Arctic POPs problem); knowledge transmission (intra-disciplinary and cross-disciplinary); and knowledge translation (for policymakers and for the general public). Of these knowledge actions, cross-disciplinary communication was most influential on policy during Period II. Through government-directed cross-disciplinary communication, scientists generated a synthesis of
the knowledge about Arctic contamination (including POPs, acids, radionuclides, and metals) as a foundation for the Canadian government to make policy decisions.

Period III

The dominant knowledge actions of scientists during Period III were knowledge creation (directed, and co-produced with northern Aboriginal peoples), knowledge transmission (intra-disciplinary, cross-disciplinary, and inter-organizational), and knowledge translation (for policymakers). Inter-organizational communication became a prominent knowledge action during Period III, as a variety of organizations functioned as channels for scientists in communicating their results to policymakers—such as AMAP, the NCP, the Oslo-Paris Commission, the Helsinki Commission, and the LRTAP working groups. These groups channeled this information to various national and international level policymakers.

Period IV

The dominant knowledge actions of scientists during Period IV were knowledge transmission (inter-organizational), and knowledge translation (for policymakers). Scientists were much less influential during Period IV, as their role primarily consisted of providing knowledge to support the ongoing international negotiations, advising policymakers, and generating data that would not be influential until after the signing of the Stockholm Convention (e.g., identifying new POPs). Canada’s environmental foreign policy on POPs did not undergo any significant changes during this period.

Dominant knowledge actions of scientists in influencing policy during the time-span of my analysis are presented in Table 5.2 (see below). Five knowledge actions were most prominent: knowledge creation, intra-disciplinary knowledge transmission, cross-disciplinary
Table 5.2 Dominant knowledge actions in influencing policy by time-period

<table>
<thead>
<tr>
<th>Period</th>
<th>Creation</th>
<th>Transmission</th>
<th>Translation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (Pre-1985)</td>
<td>Random (e.g., research on OCs in the Great Lakes, Baltic sea, and the North Sea)</td>
<td>Cross-disciplinary</td>
<td>For policymakers (e.g., through departmental channels in government)</td>
</tr>
<tr>
<td>II (1985-1989)</td>
<td>Directed (e.g., through the four-year research and monitoring program)</td>
<td>Cross-disciplinary</td>
<td>For the general public (e.g., Globe and Mail articles)</td>
</tr>
<tr>
<td>III (1996-1996)</td>
<td>Directed (e.g., through the four-year research and monitoring program)</td>
<td>Cross-disciplinary</td>
<td>For policymakers</td>
</tr>
<tr>
<td>IV (1996-2001)</td>
<td>Directed (e.g., through the four-year research and monitoring program)</td>
<td>Cross-disciplinary</td>
<td>For policymakers</td>
</tr>
</tbody>
</table>

knowledge transmission, inter-organizational knowledge transmission, and translation of knowledge for policymakers. In Period II, the translation of knowledge for the general public also played an important role. Each influenced policy differently, and at different times.
Knowledge action patterns

Knowledge creation

Knowledge creation and transmission played significant roles throughout the time-span of this study. Much of the knowledge created through biological studies in the Arctic involved the co-production of knowledge with indigenous peoples. Traditional ecological knowledge played an important part in guiding when and where samples were collected, and from which species. Knowledge transmission between scientists within academic disciplines (intra-disciplinary communication) was important in building up a knowledge base on POPs throughout the time-span of analysis.

Cross-disciplinary transmission

Cross-disciplinary transmission of knowledge played a significant role during the first and second time-periods, when many of the pieces of the POPs puzzle were being put together. In the third period, cross-disciplinary communication was important in the development of the environmental endocrine hypothesis, but played a less direct role in influencing policy. As the POPs issue developed, cross-disciplinary transmission of knowledge became progressively less influential on policy because it became the norm not the exception, and because after the development of the endocrine disruptor hypothesis it did not result in the discovery of politically potent ‘new’ scientific knowledge.

Inter-organizational transmission

In the third and fourth periods, the transmission of knowledge between organizations dealing with POPs became a dominant knowledge action. Scientists and policymakers were often members of several organizations, working groups, or task forces. Consequently, the
transmission of knowledge between these organizations through these individuals became one of the primary channels through which knowledge flowed.

Translation for policymakers

Like knowledge creation and transmission, the translation of scientific knowledge for policymakers played an important part throughout the time-span of analysis. In the early stages, translation of scientific knowledge for policymakers was influential because it allowed policymakers to coordinate and direct research to fill gaps in the knowledge they felt was necessary to assess the risk of Arctic POPs contamination. Later, the translation of scientific knowledge for policymakers provided Canadian officials the knowledge necessary to justify international action on POPs and provide support in negotiations.

Translation for the general public

In this case study, the translation of scientific knowledge for the general public (and consequent influence on policymakers) played only a minor role in influencing policy. Aside from specific instances mentioned in Chapter 4, the POPs issue did not receive much media attention, especially when compared with other international environmental issues such as global climate change or ozone depletion. In the Arctic, though, the impacts of media attention were sometimes extreme (e.g., some women stopped breast-feeding their babies; see Chapter 4). Arctic indigenous people influenced the science through the co-production of knowledge, and had a “real and acknowledged influence” on the negotiation of the Stockholm Convention (Fenge 2003). But for the most part, the general public and elected officials (as opposed to policymakers involved in the NCP, LRTAP, AMAP, and UNEP) played only minor roles in the formation of Canada’s environmental foreign policy on POPs.
A refined categorization of knowledge types and actions

Based on this case study, I suggest a refined categorization of knowledge types and actions beyond what is found in the literature.

Existence knowledge can be divided into two sub-categories: (1) knowledge about the existence of a problem, and (2) knowledge about aspects of the problem (e.g., persistence, bioaccumulation, long-range transport). Extent-intensity knowledge can be divided into three sub-categories: (1) geographic extent and trends, (2) ecosystem contaminant levels (e.g., the concentration of mirex in glaucous gull eggs), and (3) human contaminant levels.

Three sub-categories of character knowledge were identified: (1) behavior in the biotic environment (e.g., bioaccumulation, ecosystem interactions), (2) behavior in the abiotic environment (e.g., persistence, transport pathways), and (3) sources (e.g., local, regional, international). Four sub-categories of consequence knowledge were identified: (1) wildlife exposure (knowledge that wildlife are exposed to contaminants), (2) wildlife effects (knowledge about specific effects of contaminants on wildlife), (3) human exposure (knowledge that humans are exposed to contaminants), and (4) human health effects (knowledge about potential effects of contaminants on human health). Effects and exposure were separated because very little knowledge about the effects of POPs (e.g., on human health) was available for most of the time-span of this study. No studies illustrated the impact of POPs on human health in the Arctic before 2005. In terms of knowledge actions, the importance of cross-disciplinary and inter-organizational transmission of knowledge (both sub-categories of knowledge transmission) were unexpected results, and, consequently, they were not included in my original categorization scheme presented in Chapter 2. Translation of knowledge has been divided into two separate knowledge actions: translation for
policymakers, and translation for the general public. Knowledge translation was originally presented as a single action. Table 5.3 presents my refined categorization of knowledge types and actions.

**Influence of science on policy**

A summary of the scientific knowledge types and actions that influenced Canada’s major foreign policy decisions with respect to POPs between the discovery of the POPs problem in 1985 and the completion of the Stockholm Convention in 2001 is presented in Table 5.4.

Although DIAND’s decision in 1985 to assess Arctic contamination was directed by non-science factors (the cleanup of the DEW line and concerns about contaminants raised by northerners), DIAND turned to scientists to answer questions about possible contamination. Scientists were the first to identify and define the POPs problem. The decision to form a research and monitoring program to further investigate the issue was based on these scientists’ findings (through their survey of the scientific literature) and formulation of the problem (through cross-disciplinary communication). Following this, policymakers decided in 1989, based on the scientific knowledge generated since 1985 (e.g., knowledge about human exposure, long-range atmospheric transport), that policy action was necessary. The need to assess the science “was a priority to ensure that a solid assessment of the data took place. Only then can the problem be fully defined and clarified, without which responsible
Table 5.3 Refined categorization scheme of knowledge types and actions

<table>
<thead>
<tr>
<th>Knowledge types</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Cause</td>
</tr>
<tr>
<td>(2) Character</td>
</tr>
<tr>
<td>a. Behavior in the biotic environment (bioaccumulation, biomagnification, etc.)</td>
</tr>
<tr>
<td>b. Behavior in the abiotic environment (persistence, transport mechanisms, etc.)</td>
</tr>
<tr>
<td>c. Sources</td>
</tr>
<tr>
<td>(3) Consequences</td>
</tr>
<tr>
<td>a. Wildlife exposure</td>
</tr>
<tr>
<td>b. Wildlife effects (including endocrine effects)</td>
</tr>
<tr>
<td>c. Human exposure</td>
</tr>
<tr>
<td>d. Human health effects (including endocrine effects)</td>
</tr>
<tr>
<td>(4) Existence</td>
</tr>
<tr>
<td>a. Of problem</td>
</tr>
<tr>
<td>b. Of aspects of a problem (long-range transport, bioaccumulation, persistence, endocrine effects, etc.)</td>
</tr>
<tr>
<td>(5) Extent-intensity</td>
</tr>
<tr>
<td>a. Geographic extent and trends</td>
</tr>
<tr>
<td>b. Ecosystem contamination levels</td>
</tr>
<tr>
<td>c. Human contaminant levels</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Knowledge actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Knowledge creation: The type of knowledge generated through scientific experiments or observations.</td>
</tr>
<tr>
<td>(2) Knowledge transmission:</td>
</tr>
<tr>
<td>a. Intra-disciplinary communication; transmission most commonly through peer-reviewed journals, conferences, and, to a lesser extent, personal communication.</td>
</tr>
<tr>
<td>b. Cross-disciplinary (either active, through conferences, meetings, personal communications, etc., or passive, through the news media).</td>
</tr>
<tr>
<td>c. Inter-organizational; transmission by scientists and/or transmission of scientific knowledge.</td>
</tr>
<tr>
<td>(3) Knowledge translation:</td>
</tr>
<tr>
<td>a. For policymakers: Through plain language summaries, presentations, meetings, assessments, and reports.</td>
</tr>
<tr>
<td>b. For the general public: Through plain language publications, the media, presentations, and meetings.</td>
</tr>
</tbody>
</table>
Table 5.4 Influence of dominant knowledge types and actions on Canada’s major foreign policy decisions on POPs

<table>
<thead>
<tr>
<th>Date</th>
<th>Major policy decisions</th>
<th>Knowledge types</th>
<th>Knowledge actions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>Formation of the Technical Committee on Contaminants to review the literature</td>
<td>No influence observed</td>
<td>No influence observed</td>
<td>A domestic decision; Committee formed as a result of concerns raised by northerners about DEW line</td>
</tr>
<tr>
<td>1985</td>
<td>Decision to conduct research and monitoring program</td>
<td>Existence (of the problem), extent-intensity (geographic extent, and ecosystem contaminant levels), and causal knowledge</td>
<td>Cross-disciplinary communication, which led to the synthesis of the 1st POPs problem-framework</td>
<td>--</td>
</tr>
<tr>
<td>1989</td>
<td>Scientific evaluation meeting to synthesize scientific knowledge on Arctic contaminants</td>
<td>General accumulation of knowledge: extent-intensity (geographic extent, and ecosystem contaminant levels), character knowledge (long-range atmospheric transport), consequence knowledge (human exposure)</td>
<td>Knowledge creation, intra-disciplinary communication, translation for policymakers</td>
<td>The decision to hold a scientific evaluation meeting was primarily based on the need for a solid scientific foundation for the development of policy</td>
</tr>
<tr>
<td>Year</td>
<td>Event Description</td>
<td>Consequence Knowledge</td>
<td>Cross-disciplinary Communication</td>
<td>Notes</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------------------------------------------------------</td>
<td>------------------------------------------------</td>
<td>------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>1989</td>
<td>Formation of Strategic Action Plan on Northern Contaminants</td>
<td>Consequence knowledge (human exposure) and character knowledge (long-range transport)</td>
<td>Cross-disciplinary communication (through the scientific evaluation meeting), which synthesized the available scientific knowledge</td>
<td>--</td>
</tr>
<tr>
<td>1989</td>
<td>Inclusion of northern Aboriginal people in the management of the NCP</td>
<td>No influence observed</td>
<td>No influence observed</td>
<td>The inclusion of northerners in the management of research greatly influenced the scientific results, which, in turn, influenced policy</td>
</tr>
<tr>
<td>1989</td>
<td>Initiation and support of the international regime-formation processes for POPs</td>
<td>Consequence knowledge (wildlife, human exposure), extent-intensity knowledge (geographic extent), and character knowledge (behavior in the abiotic environment: long-range transport)</td>
<td>No influence observed</td>
<td>Canada pressed the case for the international regulation of POPs from 1989 until 1996, when UNEP decided that global regulation was necessary</td>
</tr>
<tr>
<td>1991</td>
<td>Integration of the NCP into the Green Plan</td>
<td>No influence observed</td>
<td>No influence observed</td>
<td>Part of the federal government’s plan to address Arctic environmental issues</td>
</tr>
<tr>
<td>Year</td>
<td>Event</td>
<td>Knowledge</td>
<td>Result</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
<td>-----------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>Support for the LRTAP negotiations</td>
<td>Consequence knowledge (wildlife, human exposure), extent-intensity knowledge (geographic extent), and character knowledge (behavior in the abiotic environment: long-range transport)</td>
<td>No influence observed</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>Ratification of the LRTAP POPs Protocol</td>
<td>Same as above</td>
<td>No influence observed</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>Support for the UNEP negotiations</td>
<td>Same as above</td>
<td>No influence observed</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>Ratification of the Stockholm Convention</td>
<td>Same as above</td>
<td>No influence observed</td>
<td></td>
</tr>
</tbody>
</table>
policy decisions cannot be made” (Technical Committee on Contaminants 1989, 3). The results of the 1989 scientific evaluation meeting (generated through cross-disciplinary communication) were used later that year as the basis for the Strategic Action Plan on Northern Contaminants, Canada’s first comprehensive policy on POPs, and Canada’s first POPs policy decision that included a foreign policy element.

The decisions to integrate the NCP into the Green Plan, and to include northern Aboriginal peoples in the management of the NCP were not directly influenced by scientists or scientific knowledge, but both decisions had major impacts on scientific research, which, in turn, had impacts on policy. The NCP, as formulated (and funded) under the Green Plan transformed the old Technical Committee on Contaminants into a major channel through which scientists could direct their research results to policymakers at multiple levels of government and policymaking (e.g., the community, territorial/provincial, federal, and international levels). The inclusion of northern Aboriginal peoples in the management of the NCP resulted in greater integration of traditional ecological knowledge into scientific research in the Arctic and to a certain extent even altered the focus of research.

The decision to initiate the international regime-formation process was the most significant policy decision related to POPs during the time-span of this analysis. This decision was based on the transboundary character of the problem (long-range transport), the fact that emission sources were distributed throughout the world, the geographical extent of contamination, and the real and potential wildlife and human health consequences. Regime formation started through the LRTAP Convention, a regional forum, and, as scientific knowledge improved, regime formation at the global level began (through UNEP).
Chapter 6. Conclusion

In the previous chapter I compared the influence of knowledge types and knowledge actions across time-periods and presented a refined categorization scheme of knowledge types and actions. In this chapter I summarize the major conclusions of this study relevant to understanding the role of science in development of foreign policy and regimes, and present suggestions for future research.

Lessons and implications with respect to the science-policy interface

Based on my analysis of the influence of scientists and scientific knowledge on Canada’s environmental foreign policy on POPs, three major conclusions can be drawn: (i) scientific knowledge cannot be treated as a whole; (ii) the scientific community is not a monolith, it is composed of distinct disciplines and sub-disciplines, thus communication between academic disciplines is a critical action related to policy influence; and (iii) different knowledge types and actions affect policy differently during the various stages in policy development. Each of these three conclusions is discussed below.

First, as discussed in Chapter 2, social scientists who study the influence of science on regime formation have generally treated scientific knowledge as a whole. Knowledge, however, is not homogenous; policymakers use (and value) certain knowledge types more than others. As can be seen in the above discussion of the evolution of the influence of scientific knowledge types on policy over the four time-periods, the dominant knowledge type changed during each period. For instance, in the case of POPs, causal knowledge was
less influential in convincing policymakers that political action was necessary to address an environmental problem than evidence of the problem's real and potential consequences. Also, knowledge about the atmospheric transport potential of heptachlor, for instance, was not a factor in the Canadian government's decision to initiate international action, whereas this same knowledge was a deciding factor in the decisions of several LRTAP countries that heptachlor should be included in negotiations.

In studying the science-policy interface, treating knowledge as a whole may lead to misunderstandings about the influence of scientific knowledge on policy. As pointed out by Dimitrov (2003b), many social scientists, based on examples of policymaking in cases with high degrees of scientific uncertainty, have concluded that scientific knowledge cannot explain policy decisions. This misunderstanding derives largely from the treatment of scientific knowledge as a whole. To quote Dimitrov (2003b, 129): “Previous analysts of the ozone regime are preoccupied with the uncertainty about the extent of depletion and bypass the reliable information and scientific consensus on the shared consequences of the problem”. Thus, in analyses of the influence of scientific knowledge on policy, scientific knowledge cannot be treated as a whole.

The second conclusion drawn from my data analysis is that the scientific community can not be treated as a single monolithic entity. My primary evidence for this comes from the fact that communication between academic disciplines turned out to be a vital action undertaken by scientists that influenced policy and that some parts of the “community” didn’t know what other parts knew. By treating the scientific community as a single entity, it is easy to miss the decisive role of communication between academic disciplines.
Prior to 1985, the POPs issue was a jumble of disconnected data and hypotheses. Research from the 1960s informed scientists of physical-chemical properties of POPs and of wildlife effects. It was known that many organochlorine pesticides and industrial chemicals undergo long-range atmospheric transport, but it was the extent of contamination in the Arctic that displayed, in dramatic fashion, the power of long-range transport of POPs to contaminate the environment. Most of this knowledge was available long before 1985, but no one had really examined the issue in detail. The cross-disciplinary connections made by the Technical Committee on Contaminants in 1985 to a large extent, defined the issue.

Defining the problem and making these connections was clearly a very important and influential contribution by scientists. Yet many analyses of international environmental policy overlook the importance and complexity of the initial definition of an environmental problem, focusing instead on the role of scientific assessments, uncertainties, and the influence of expert communities during the formation of multilateral environmental agreements. But long before the formation of a multilateral environmental agreement the problem needs to be defined, and, as we have seen, how an environmental problem is framed influences what type of action is taken by governments. If an environmental problem is not framed as an international problem, international cooperation to form a multilateral environmental agreement is unlikely.

Defining an international environmental problem is sometimes quick and fairly straightforward. But many environmental issues are multi-disciplinary and cannot be adequately defined within a single discipline. POPs, for instance, are a problem involving physical-chemical properties and a wide variety of biological mechanisms, ecosystem interactions, and human effects. While scientific disciplines do overlap and interdisciplinary
research does take place, many scientists are not exposed to research from different academic disciplines frequently. Most of the scientists I interviewed stated that they rarely communicate with scientists from other academic disciplines and that they heard about POPs research conducted by scientists in other academic disciplines mainly through conferences and meetings, and occasionally through departmental channels and the media. Scientists who study long-range atmospheric transport are in a very different field of research than those who study toxicity, and for the purposes of research there often seem to be few reasons to communicate with each other. For multidisciplinary environmental issues such as POPs, however, there needs to be some method of integrating research from these diverse fields of research into a coherent idea to present to policymakers.

For POPs, this integration was achieved partially by individual scientists and partially, and more significantly, by the DIAND-chaired Technical Committee on Contaminants. AMAP and the NCP were formed later in the process, and largely took over this role.

Evidence from other environmental problems show a similar pattern: a detailed formulation of the environmental endocrine hypothesis, for instance, did not arise until Theo Colborn brought scientists from a variety of scientific disciplines together at the Wingspread Work Session in 1991. It was “the first time that wildlife biologists and human health scientists had had an opportunity to talk with one another” (Krimsky 2000, 27). John McLachlan, an endocrinologist and participant in the Wingspread Work Session stated “Theo pulled us together... We hadn’t read each others’ literature” (Krimsky 2000, 26). The “first detailed formulation of the [environmental endocrine] hypothesis” (Krimsky 2000, 27) was a consequence of this cross-disciplinary communication. Scientists in a variety of academic
disciplines had been working on different aspects of the problem of endocrine disruptors for fifteen years before it was realized that their research was all connected. That the cross-disciplinary communication which proved to be vital in generating the environmental endocrine hypothesis and uncovering the POPs problem is so rare presents a hurdle to the timely identification of environmental issues.

The third conclusion is that different knowledge types and actions affect policy differently during the various stages in policy development. In this case study, I associated two knowledge types (consequence knowledge, with respect to wildlife exposure and human health effects, and character knowledge, with respect to the behavior of POPs in the abiotic environment, specifically long-range transport) and one knowledge action (cross-disciplinary transmission of knowledge) with specific developments in Canada’s policy on POPs. First, knowledge about the consequences of POPs (with respect to wildlife exposure and human health effects) was associated with the formation of Canada’s first comprehensive policy on POPs (the 1989 Strategic Action Plan on Northern Contaminants). Had POPs not affected culturally and nutritionally significant species, it is unlikely that the Canadian government would have formed a comprehensive POPs policy.

Second, knowledge about the international nature of the problem (through evidence of long-range atmospheric and marine transport) was associated with policymakers’ decision that POPs could only be controlled through international regulations. As a consequence of this decision, Canada put significant effort into convincing the international community that the global regulation of POPs was necessary. Canada’s decision to pursue international regime formation was based on scientific knowledge about the wildlife and human health
consequences of POPs (thus, the need for regulatory action), and the international nature of the problem (thus, regulatory action on the international stage)\textsuperscript{16}.

Finally, cross-disciplinary communication was the key knowledge action that led to the discovery of the POPs problem, and its expansion to include new elements (e.g., the endocrine-disrupting effects of some POPs).

**Limitations of research and suggestions for future research**

There are four major limitations of this study: First, it only focuses on the period of time prior to the signing of the Stockholm Convention. Using the same methodology as in this case study, but starting at the signing of the Stockholm Convention in 2001, one could analyze the relationship between scientific knowledge, scientists, and the effectiveness of the Stockholm Convention. As discussed in previous chapters, the Stockholm Convention contains provisions for monitoring POPs in the environment and for the addition of new chemicals; thus, scientists and scientific knowledge will continue to play an important role in the international management of chemicals.

Second, this study is a single case study and analyzes the environmental foreign policy of only one country for only one environmental issue. Analyses of other international environmental problems should be conducted to identify knowledge types and actions not identified in this case study. Such a study may reveal trends in the influence of specific knowledge types and actions. Similarly, by analyzing the development of the foreign environmental POPs policies of different countries (e.g., Sweden), a comparison could be

\textsuperscript{16} Dimitrov (2002, 2003a, 2003b) came to a similar conclusion in the cases of ozone depletion, deforestation, and the protection of coral reefs, and Wilkening (2004; see chapter 9) in the case of Japan’s
made to determine whether knowledge types and actions influenced policy development similarly.

Third, this study is quite general in that it does not focus on any one particular knowledge type or action. In-depth analyses on the influence of specific knowledge actions (e.g., cross-disciplinary transmission of knowledge) may shed light on their impacts on policy. Both cross-disciplinary and inter-organizational transmission of knowledge were unexpected results of this study, and were identified only through interviews with scientists. Further probing of these knowledge actions may shed light on the importance of these actions in international regime formation. For instance, a comparative analysis of the role of cross-disciplinary communication in the development of several complex environmental issues (e.g., POPs, climate change, desertification, and deforestation) may reveal additional details about the general role of cross-disciplinary communication in the development of environmental issues, particularly early in the development of these issues.

Finally, this study only looks at the influence of two factors (scientists and scientific knowledge) on Canada's foreign environmental policy formation. There are many other factors that influence the formation of policy in Canada. For instance, non-governmental organizations like the Inuit Circumpolar Conference and the Pesticide Action Network played significant roles by drawing media attention to the issue, and by focusing policymakers attention. The media played a major role early in the development of the issue by provoking a strong reaction among indigenous peoples in northern Canada.

In addition, some factors that influenced the science and scientists indirectly affected policy. For instance, Indigenous peoples' cultures and knowledge affected which species were studied, and how these species were studied. Funding sources (such as the NCP) forced

foreign policy in relation to the transboundary acid rain problem in East Asia.
scientists to spend time communicating with the general public, and with scientists in other academic disciplines.

A comparative analysis of the influence of scientists, scientific knowledge, and some of the other factors influencing Canadian foreign environmental policy may illustrate the relative influence of scientists and scientific knowledge on Canada’s policymaking process.

As the world’s human population increases, and as wealthy nations become more affluent, more and more substances (POPs, greenhouse gasses, carcinogens, endocrine disruptors, etc) are being released into the environment each year. The behavior and fate of these chemicals in the environment are poorly understood and, in the last few decades, global consequences of these emissions have become apparent (e.g., stratospheric ozone depletion, acid rain, POPs, heavy metal contamination). Climate change is expected to complicate these issues further, by changing wind patterns and environmental conditions. Consequently, science is becoming increasingly valuable in identifying, understanding, and addressing these problems.

It is necessary to have a better understanding of the science-policy interface so that effective, responsible policy decisions can be made quickly. It is essential, therefore, to understand which types of knowledge are most necessary to initiate policy development, and which actions of scientists are most influential in the development of policy. As this thesis demonstrates, different types of scientific knowledge influence policy in different ways, and specific activities of scientists can be pivotal in the identification and characterization of complex environmental problems.
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