MONITORING LONG-TERM ECOLOGICAL CHANGES THROUGH THE ECOLOGICAL MONITORING AND ASSESSMENT NETWORK: SCIENCE-BASED AND POLICY RELEVANT

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Abstract. Ecological monitoring and its associated research programs have often provided answers to various environmental management issues. In the face of changing environmental conditions, ecological monitoring provides decision-makers with reliable information as they grapple with maintaining a sustainable economy and healthy environment. The Ecological Monitoring and Assessment Network (EMAN) is a national ecological monitoring network consisting of (1) about 100 case study sites across the country characterized by long-term multi-disciplinary environmental work conducted by a multitude of agencies (142 partners and counting); (2) a variety of less comprehensive yet more extensive monitoring sites; (3) a network where core monitoring variables of ecosystem change are measured; and (4) geo-referenced environmental observations. Environment Canada is the co-ordinating partner for the network through the EMAN Co-ordinating Office. EMAN's mission is to focus a scientifically-sound, policy-relevant ecosystem monitoring and research network based on (a) stabilizing a network of case-study sites operated by a variety of partners, and (b) developing a number of cooperative dispersed monitoring initiatives in order to deliver unique and needed goods and services. These goods and services include: (1) an efficient and cost-effective early warning system which detects, describes and reports on changes in Canadian ecosystems at a national or ecozone scale; and (2) cross-disciplinary and cross-jurisdictional assessments of ecosystem status, trends and processes. The early warning system and assessments of ecosystem status, trends and processes provide Environment Canada and partner organizations with timely information that facilitates increasingly adaptive policies and priority setting. Canadians are also informed of changes and trends occurring in Canadian ecosystems and, as a result, are better able to make decisions related to conservation and sustainability.

Keywords: assessments, core variables, early warning systems, ecology, ecosystems, monitoring

1. Introduction

Environmental issues have often been addressed scientifically through the use of information derived from ecological monitoring and its associated research programs. This article defines ecological monitoring and discusses the evolution of Canada's Ecological Monitoring and Assessment Network (EMAN) towards developing an early warning system of ecological changes and providing interdisciplinary and/or inter-jurisdictional assessments of ecosystem status, trends and

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processes on an ecozone or national basis. This article reviews the Ecological Monitoring and Assessment Network of Environment Canada – its history from 1994–1998, and the changing opportunities identified through an audit and peer review process, and the strategic factors providing context and focus for EMAN. The paper turns to recent focused EMAN activities describing the integration of environmental networks in Canada and the important reporting requirements, particularly Advisories of Ecosystem Changes, which allow EMAN to be truly science-based and policy-relevant.

1.1. A HISTORY OF ECOLOGICAL MONITORING IN CANADA

Our collective knowledge about the threats from environmental changes has been increasing throughout the years. Where environmental concerns were primarily focused on local air and water pollution in the late 1960s, by the 1990s regional, national and even global issues had become major concerns for Canada's ecosystems. Environmental issues have also been increasing in complexity – it is now accepted that many of the issues interact causing synergistic or cumulative changes. Thus the need has shifted from understanding not only single-cause, single-effect issues, but also multiple-cause, multiple-effect issues.

Multidisciplinary environmental studies, particularly at the small watershed level, have been carried out in Canada for several decades. Governments and academic institutions initiated studies usually to deal with environmental problems of interest to the specific location. For example, in the 1960s, the Canadian Government initiated studies on lake eutrophication at the Experimental Lakes Area near Kenora, Ontario (Hecky *et al*., 1994); Laval University began the Centre for Arctic Studies at Kuujjuaq Research Centre (Nunavik) which has focused on arctic and sub-arctic ecological processes; and studies on nutrient processes in surface waters began at Kejimkujik National Park, Nova Scotia. The Last Mountain Lake site in Saskatchewan was established as a National Wildlife Area in 1887 to study the conservation and protection of wildlife species. As new issues emerged, sites, such as Turkey Lakes in Ontario and Duschenay in Quebec, were established in response to the need for more information on acid rain. These multi-year, integrated monitoring studies were very effective in resolving the scientific and policy questions set out by the supporting agencies.

This complexity has given rise to the need to address these issues in a similarly complex fashion – an integrated, interdisciplinary, and co-operative approach to monitoring which is termed as *ecological monitoring*. The most popular and successful use of this approach on an issue of national concern to Canada was the acid rain issue. Initially, Canada's acid rain program was used to develop an understanding of the effects of acid-forming air pollutants and recommending ways of alleviating undesirable impacts on the environment close to the source of pollutants. As the full dimensions of the concern became more apparent (especially the spatial extent of the problem), however, broader-scale monitoring and assessment were demanded.

A comprehensive study of the effects of acidification and a number of research programs were initiated. At least five locations (Kejimkujik National Park Ecological Monitoring and Research Centre, N.S; Lac Laflamme, QC; Dorset Environmental Science Centre, ON; Experimental Lakes Area (ELA), ON; and Turkey Lakes Watershed, ON) in Canada with calibrated watersheds similar to the Hubbard Brook experiment (Likens, 1995) were established to investigate a suite of effects of acidic deposition on the environment – water, land, and biota. A wide range of variables was monitored; process research was undertaken; and manipulation research was conducted as to how the environment would respond to human stress applied under controlled conditions. Information from these activities was used to establish a *target load* for the amount of wet sulphate that could be deposited on Canadian ecosystems to protect all but the most sensitive species. Regulations were drafted based on this load (that is, based on the results of the research and monitoring activities) and Canada has completed over ten years of sulphur dioxide reductions cutting its 1980 sulphur dioxide emissions in half. The success of Canada's acid rain control program and global recognition of value of integrated ecological monitoring led to a desire for continued comprehensive monitoring and assessment activities.

2. Ecological Monitoring

Monitoring means maintaining regular surveillance by making measurements at regular time intervals over an indefinite, but usually long period of time. The length of time is fundamental to the design and purpose of all environmental monitoring programs. Two fundamental reasons for monitoring the natural environment are, to establish baselines representing the current status of ecosystem components and second, to detect changes over time, and particularly, any changes that are above the natural variation in these baselines. Closely associated with these reasons is the desire to define why the observed changes are occurring. Traditionally, environmental monitoring fall into four broad categories – (i) simple monitoring; (ii) survey monitoring; (iii) surrogate or proxy monitoring; and (iv) integrated monitoring. This article restricts to the monitoring programs that are carried out within the natural environment and does not include the industrial plant compliance monitoring, which measures the content of effluents to determine total emissions and their value relative to legally established limits.

2.1. Simple monitoring

Simple monitoring records the values of a single variable at one geographical point over time. In practice, however, such single parameter monitoring is often expanded to include measurements at many geographical locations. Air temperature data

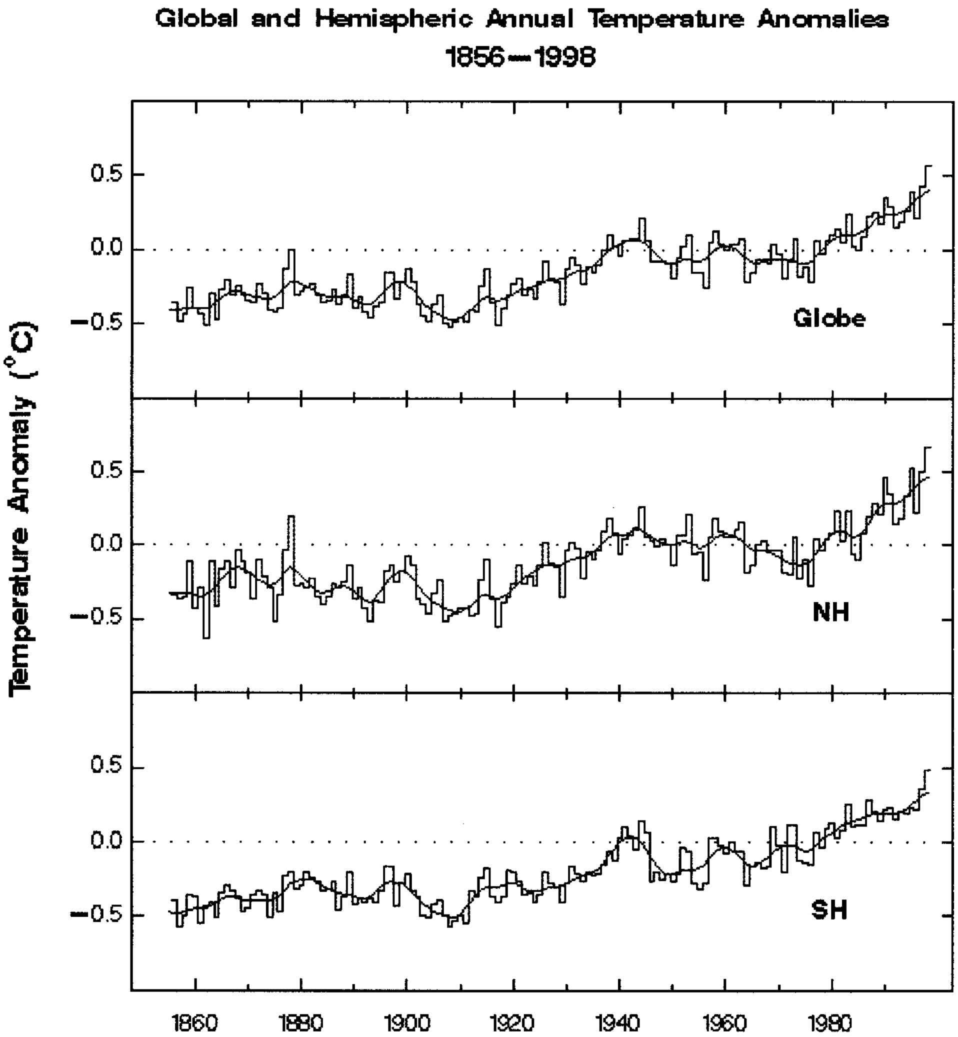

Figure 1. Global and atmospheric annual temperature anomalies 1856–1998. (Source: P. D. Jones, T. J. Osborn and K. R. Briffa, University of East Anglia, Norwich, U.K., D. E. Parker, Met. Office, Bracknell, Berkshire, U.K.)

from around the world, is one of the keystone measurements in the global warming/climate change issue. The graphs in Figure 1 represent the longest temperature records which has been used to show the increase in average global air temperature over the past 150 yr.

Another example of simple monitoring is the measurement of atmospheric concentrations of carbon dioxide, the dominant greenhouse gas. The long-term monitoring record from the observatory at Mauna Loa, Hawaii, U.S.A., is shown in Figure 2. It clearly shows the increasing concentrations and this observation has

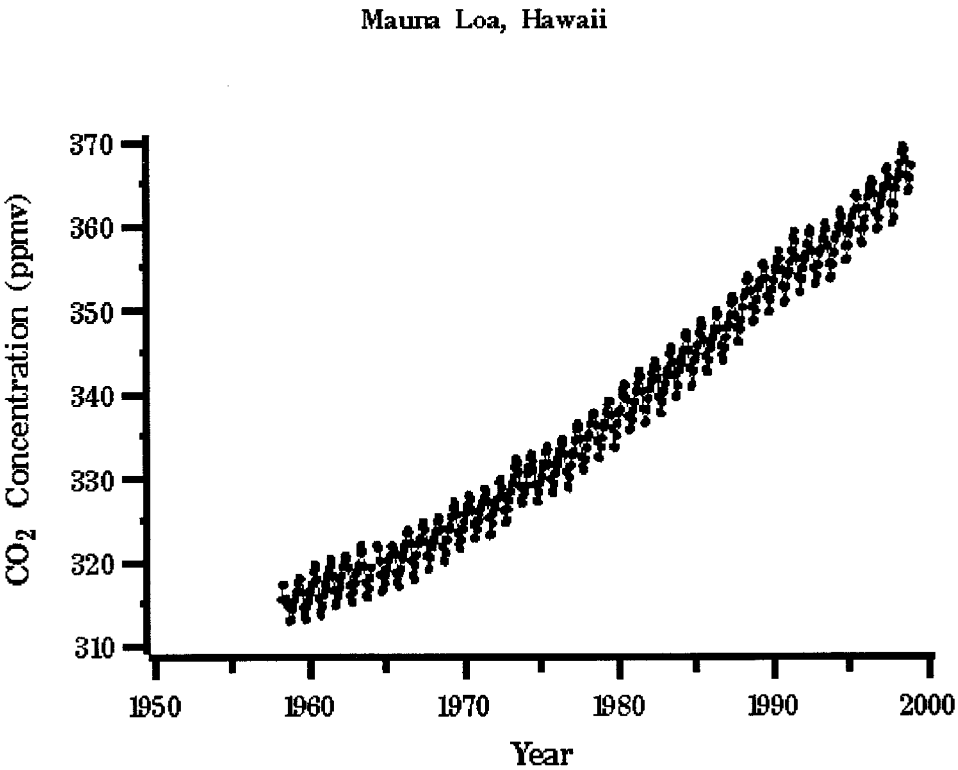

Figure 2. Atmospheric carbon dioxide concentrations at Mauna Loa, Hawaii. (Source: Dave Keeling and Tim Whorf, Scripps Institution of Oceanography.)

been very influential in the global warming issue. This simple monitoring approach has been extended to the point where atmospheric carbon concentrations are now measured at many sites around the world.

2.2. Survey monitoring

In many cases, environmental problems have become obvious without any historical monitoring record of the changes that led up to the problem. The absence of an historical record can be replaced by a survey of current conditions over a geographical area. The monitoring survey is designed to include areas that are affected and areas not affected by the observed problem. The affected areas are assumed to have had similar environmental characteristics as the unaffected areas at some unknown time in history. An example of eutrophication (excessive algae growth) in Lakes Erie and Ontario became obvious in the 1960s. An historical monitoring record might have shown concentrations of phosphorus and algae simultaneously increasing. However, no such monitoring had been undertaken. Vollenweider (1968) overcame the lack of historical data by comparing current survey data on algae growth with nutrient levels for many lakes showing a range of eutrophic states. He developed a relationship between total phosphorus loading and algae growth in both affected and unaffected lakes and applied this to Lakes Erie and Ontario making the assumption that their historic nutrient and algae concentrations were similar to currently unaffected lakes.

This reasoning, based on survey monitoring data from the lakes, supported by laboratory and field experimental data, was applied to establishing scientifically defensible phosphorus control programs for these lakes (International Joint Commission, 1969). These control programs have been successful in reducing phosphorus concentrations and the corresponding algae growth (Dobson, 1994).

2.3. Surrogate or Proxy Monitoring

Another way to compensate for the lack of long-term monitoring records involves using surrogate or proxy information to infer historical conditions in the absence of actual measurements of the desired variable. In this approach, data are obtained from information 'stored' in the environment that relates to the desired variable. For example, to evaluate global warming trends, the ideal condition would have temperature records from the beginning of time. This being impossible, several surrogates for temperature have been used to construct long historical records.

Information stored in Arctic ice cores has been used to infer air temperatures over very long periods of time. Dansgaard *et al*. (1993), reported on results for two ice cores, drilled in central Greenland that represented the accumulation of ice for 250 000 yr. The ice cores were 3028.8 m long. The ratio of oxygen^8 to oxygen^6 stable isotopes of the air trapped in snow particles is a function of the air temperature at the time of deposition of the snow. The deposited snow becomes packed into ice and the oxygen isotope ratios trapped air bubbles preserve a 'temperature' record in the built-up ice layers over thousands of years. Measurements of this ratio from the ice cores were used to compare the extent and rates of change of the inferred temperature over this very long period of time. The authors concluded that the temperature has been remarkably stable during the past 10 000 yr; but, prior to that, instability dominated the North American climate.

In the 1970s, lakes and rivers in eastern Canada were observed to have unexpectedly low pH and high sulphate concentrations. Acid rain was postulated as the cause. However, there was a serious lack of data to show that the historical pH values had in fact been higher. Critics of the acid rain 'theory' postulated that the observed conditions were natural and did not represent recent acidification. It was known that the fossil remains of some diatoms and chrysophyte algae species accumulated in the sediment layers at the bottom of lakes. It was further shown that the relative numbers of these species changed with lake pH. Combined with the ability to determine when the sediment layers were deposited, a method to infer the historical lake pH was developed using the algae species composition in the sediments. The technique has been applied extensively in Eastern Canada

(Jeffries, 1997) where large geographical areas, containing thousands of lakes, have been damaged by acid rain. Specifically, it has been shown that acidity and metal concentrations began to increase about 1920 in the lakes near the large sulphur dioxide and metal sources at Sudbury, Ontario, Canada (Dixit *et al*., 1992).

In 54 lakes in south central Ontario, all lakes with present measured pH less than 6.0 had acidified since approximately 1850 (Hall and Smol, 1996) according to the pH inferred from the diatom assemblages. The results show the proxy-measured decline of pH consistent with the known high local emissions of sulphur dioxide, followed by the measured recovery of pH after the emissions were reduced. These proxy measures of historical pH have been very important in establishing the reality and the long-term nature of surface water acidification caused by acid rain.

2.4. Integrated monitoring

While long term records from simple monitoring, surveys and surrogate data have provided substantial information on what has been changing in the environment, they are generally unable, by themselves, to answer the important question of why these changes are occurring. A much more detailed set of ecological information is needed to establish cause and effect relationships. The concept of integrated monitoring has been developed with the overall objectives of recording changes in the environment and of understanding and defining the reasons for those changes.

Integrated monitoring has four specific objectives: to establish cause and effect relationships; to derive scientifically defensible pollution control or resource management programs; to measure the environmental response to the control measures; and to provide early warnings of new problems. For example, much of the preliminary information on the ecological effects of acid rain on surface waters came from the data sets being gathered to study eutrophication of lakes. In recent years, substantial information on the ecological effects of climate variability/change has, in turn, been derived from integrated monitoring being conducted to measure the effects of acid rain.

The integrated monitoring sites are characterised by long term (i.e. indefinite) multidisciplinary monitoring i.e. meteorology, precipitation chemistry, runoff chemistry, and a full suite of biological factors. A centrepiece of integrated monitoring sites is frequently a ‘calibrated watershed’ where the monitoring strives to develop a detailed balance of the inputs and outputs of water and chemicals along with intensive biological monitoring of the terrestrial and aquatic components of the watershed. The resulting information is often sufficient to answer both the questions of what changes are occurring and why they are happening. The integrated monitoring is usually carried out in conjunction with detailed research projects and often in conjunction with ecological manipulation experiments. These experiments involve the deliberate alteration of the environment under highly controlled and monitored conditions. For example, nutrient additions to entire lakes, combined with integrated monitoring of the lakes, helped to resolve the question whether to reduce nitrogen or phosphorus in order to control eutrophication (Schindler, 1974). Whole lake acidification experiments (Schindler, 1980) have provided key information on the sequence of biological changes as lake pH decreased and of the relative importance of nitric and sulphuric acid (Rudd *et al*., 1990).

2.4.1. *Canada's changing ecosystems*

The nature of the ecological responses to the current suite of stresses on Canada's ecosystems poses major challenges in meeting the overall and specific objectives of integrated monitoring. Natural elements and compounds can cause problems. Essential elements, such as phosphorus, sulphur, nitrogen and carbon, can lead to significant environmental change and damage if present in the environment in excessive amounts or if in a particular form. Examples illustrate these points. Excessive amounts of phosphorus in lakes can lead to inordinate algae growth known as eutrophication (Vollenweider, 1968; Schindler *et al*., 1974). Excessive sulphur, in the form of sulphuric acid, in precipitation, can cause acidification of sensitive soils and surface waters, which leads to environmental degradation (National Research Council of Canada, 1981; Environment Canada, 1997). Ammonium and nitrates also contribute to acidification of terrestrial and aquatic systems (Reuss and Johnson, 1986; Environment Canada, 1997). Increasing amounts of carbon in the form of carbon dioxide in the atmosphere may lead to changes in global climate (Houghton *et al*., 1990). Consequently, these elements are subjected to controls in order to eliminate their negative effects.

Since these elements are essential building blocks of life, and are naturally present in the environment, it is neither possible nor desirable to reduce their concentrations to zero. Therefore, in setting objectives for these compounds in the environment, it has become the practice to apply the concept of a critical load or level that is not zero but rather is defined as the highest load/level that will not cause chemical changes leading to long-term harmful effects of the most sensitive ecological systems (Nilsson, 1986). Very detailed ecological information (largely derived from integrated monitoring data) is needed to establish these critical loads. The challenge to the monitoring programs is further complicated by the fact that some environmental changes that occur might be deemed beneficial. For example, increasing the amount of nitrogen deposition to forests may increase their growth rate (Nilsson, 1988). However, nitrogen deposition may also lead to a terrestrial ecosystem that is made up of different plant species than the natural ecosystem (Nilsson, 1986). The new plant community could be perceived by some to be less desirable and, by others, as more desirable than the natural condition.

2.5. THE NEED FOR LONG-TERM MONITORING

The very nature of ecological monitoring – to detect changes in ecosystems over time – demonstrates the importance of having long-term data records. The ecological responses to a changing environment, such as those mentioned above and the invasion of exotic species, are long-term (i.e. decades). Phosphorus, contained in raw and partially treated sewage, was discharged into Lakes Erie and Ontario since the beginning of the 20th century, yet the dense algal mats, fish kills and oxygen depletion in the bottom waters of the lakes did not become obvious until the 1960s.

Atlantic salmon began to decrease in numbers from several Nova Scotian Rivers in the 1950s and completely disappeared by 1980 (MOI, 1981). This decrease has been explained by the slow acidification of the runoff water in response to the acid deposition that began in the early part of this century. Global average temperature (Figure 1) has shown several trend characteristics. There was an increase prior to 1940, little further change or even a decrease until about 1980, and then a sharp increase until about 1984, followed by a slower increase since that time. Long-term data are needed to define these changes and to establish that there is an overall increasing trend for the total time period. Data sets of several decades can give misleading information on the long-term trends.

Ryan *et al*. (1990) have analysed tree ring growth for sugar maples in Ontario, on a regional basis. After removing the effects of ageing and weather variations, they found decreases in growth rates that they associate with environmental pollution. These growth decreases had been occurring for over 30 yr in trees that appeared healthy. Watmough *et al*. (1998) have shown that sugar maples currently observed to be in decline have experienced decreased growth rates since the 1940s.

The invasion of zebra mussel (Dreissena polymorpha) in Lake St. Clair has brought about gradual decreases, to the point of extinction, in the native mussel population as measured over an eight year study period (Nalepa *et al*., 1996). The increased water filtering capacity of the zebra mussel population has increased water clarity two-fold (Griffiths, 1993).

The responses to one stress can overlap with and aggravate the responses to another stress. For example, when watersheds affected by acid rain experience dry weather conditions, sulphuric acid can be formed by the re-oxidation of stored sulphur compounds, leading to pulses of acidic runoff and re-acidification of the receiving lakes (Keller *et al*., 1992). Thus, the warmer climate conditions accentuated the effects of another stress, acid rain in this case, with severe results.

2.6. The Value of a Dispersed Monitoring Network

The geographical areas affected by environmental stress have increased in size over time. Eutrophication of lakes was essentially a local problem although it assumed bi-national proportions in the Great Lakes of North America. Acid rain affected lakes and forests in a major part of Eastern North America and, also, in most of Western Europe and, thus, became a multi-national problem with respect to effects and controls. Stratospheric ozone depletion affects even larger geographic areas than acid rain, and, although the effects were still confined to the more southerly and northerly latitudes, emission controls affect nearly every country in the world. Climate change affects the entire globe and all countries are involved in the complex array of effects and controls.

These characteristics of natural elements causing damage/change over long periods of time, at the ecosystem level and on a global scale have made integrated monitoring essential and also very difficult.

3. The Ecological Monitoring and Assessment Network (EMAN)

3.1. EMAN 1994–1998

In April 1994, Environment Canada established the Ecological Monitoring and Assessment Network (EMAN), with an overall objective of conducting integrated monitoring and research to provide an understanding and explanation of the observed changes in ecosystems (Brydges and Lumb). This network (EMAN) is a co-operative partnership of academic, governmental (local, provincial, and federal) and private sector scientists. As of January 1998, EMAN included about 100 ecological monitoring and research sites. The EMAN was established with four specific objectives:

- to provide a national perspective on how Canadian ecosystems are being affected by the multitude of stresses on the environment;
- to provide scientifically defensible rationales for pollution control and resource management policies;
- to evaluate and report to Canadians on the effectiveness resource management policies; and
- to identify new environmental issues at the earliest possible stage.

To promote the network's business, the EMAN Co-ordinating Office (EMAN-CO) was established at the Canada Centre for Inland Waters, Burlington, Ontario, Canada. The goal of this office is to co-ordinate ecological monitoring and research to meet national, regional, and local environmental needs for environmental information on ecosystem function and change.

3.2. EMAN'S CHANGING OPPORTUNITIES IN THE NEW MILLENNIUM

EMAN's mission has been and continues to be focused on questions of *What is changing and why in Canadian ecosystems*. To respond to such a mission in a purely monitoring context demands that all aspects of the ecosystem be monitored, since no-one can predict which variable will emerge as the most critical one in explaining an observed change. This becomes very expensive and diminishes the effort directed towards interpretation and communication, especially in the context of reduced resource levels. On the other hand, to respond using a set of long-term ecosystem research and monitoring sites raises questions of how representative such a set can be and whether it is of adequate size and distribution to reliably detect ecosystem changes which might be of concern.

Rethinking the response to such a mission has resulted in a splitting of the 'What' from the 'Why' by first emphasizing the early detection and reporting of meaningful changes in Canadian ecosystems, and then following with subsequent investigation of the cause and possible management interventions. To be useful, such early warnings of change cannot await the establishment of statistical certainty but can be based on the geographical distribution of similar observations, expert opinion and the identification of risk. This has the positive result of strengthening the role of the EMAN case study sites (see below) where long term ecosystem study is conducted by a variety of EMAN partners. Their importance and relevance becomes immediately apparent as assets in responding to an identified risk by providing further data and insights and/or in providing centres for directed research – that is, in addressing the 'Why' aspects.

This additional emphasis on an early warning system responds directly to the needs of resource managers in the areas of priority setting and policy creation. For example, Environment Canada has identified business lines of operation that include:

(I) assess and report on the current state of ecosystem health (what is happening);
(II) advance the understanding of the impact of stressors (why is it happening); and
(III) contribute to actions to reduce negative human impacts (what can we do about it).

An emphasis of Environment Canada's business planning framework has been placed on the need for 'an early warning system to detect, describe and report on what is changing in Canadian ecosystems'. This has given EMAN the opportunity to redirect some of its efforts so as to contribute to, and deliver on, business plan items (I) and (II) above by building on its strengths in partnership development, 'grease and glue' resources, information technology, co-ordination and communications, as well as, on its greatest asset, the existing EMAN network. These business lines also direct that EMAN continue to focus much of its efforts toward the development of cross-disciplinary and cross-jurisdictional assessments of ecosystem status, trends and processes – a unique and needed product for Environment Canada and for other environmental management agencies interested in the integrated ecosystem information needed to assess, predict and manage natural resources.

TABLE I

EMAN successes 1994–1998 from 1998 program audit and peer review

- Developing partnerships for a new initiative
- Building a large network of monitoring sites
- Standardizing methods for monitoring biodiversity change in Canada's ecosystems
- Establishing long-term biodiversity monitoring plots
- Sponsoring the assessment of scientific data
- Hosting EMAN national science meeting
- Activating biosphere reserves
- Leveraging resources
- Communicating through the EMAN website
- Adopting and promoting the ue of the national ecological framework
- Coordinating the mercury issue in Canada

TABLE II

EMAN weaknesses 1994–1998 program audit and peer review

- The budget is too small for its scope of activities;
- The EMAN mandate appears to be not focused;
- The connection to policy is weak;
- There is weak coordination and support within Environment Canada; and
- The network's regional coordination is weak.

3.3. Audit and peer review 1998

In February 1998, a 17 member focus group audited, peer-reviewed and evaluated the performance of EMAN. The network's successes and weaknesses were identified and listed in Tables I and II, respectively. However, the network accomplishments far outweighed the shortcomings and the past year was used to focus EMAN's activities and develop a vision of its future that is linked to policy needs and other programs within Environment Canada and elsewhere – that is, to develop a program that is truly science-based and policy-relevant.

It is proposed that the increasingly focused EMAN bring together Canadian monitoring from case study sites, extensive monitoring networks, a core variable network, and observer networks in order to provide coordinated input to a Canadian Early Warning System of Ecological Changes.

3.4. Assessments of Ecosystem Status, Trends and Processes

Survey of recent ecological literature show that the overwhelming majority of study is based on two species or less in two square meters or less and for less than three years (Jim Gosz, LTER Chairman, personnel communication). Insights and information on ecosystems that transcend disciplinary lines and appropriately consider such aspects as complex species assemblages, the dynamic nature of ecosystems, cumulative effects, interactions with humans and broader temporal and spatial scales is crucial to the understanding and prediction of ecosystem changes upon which sound management decisions can be based. EMAN is in a unique position to contribute to meeting this need on behalf of Environment Canada and other environmental management agencies by providing cross-disciplinary and cross-jurisdictional assessments of ecosystem status, trends and processes based on the coordination of data interpretation and communication among its partners and sites. Such assessments would:

(i) demonstrate the utility of partnerships in meeting departmental, other government departments (OGD), partner and national objectives related to ecosystem understanding, trends and management;
(ii) improve partnership monitoring, data-base management, metadata, interpretation and communication initiatives;
(iii) allow partners to cooperate in the interpretation and assessment of observations and subsequent communications;
(iv) deliver a broad-based science which more accurately approximates the needed multi-faceted approach to ecosystems;
(v) provide a unique input to State of Environment (SOE) Reporting in order that Canadians are informed of changes and trends occurring in Canadian ecosystems and as a result are better able to make decisions related to conservation and sustainability; and
(vi) contribute to education programs in Canada.

It is proposed that the increasingly focused EMAN initiate and foster cross-disciplinary and cross-jurisdictional assessments of ecosystem status, trends and processes.

3.5. Monitoring in Support of an Early Warning System and Assessments of Ecosystem Status, Trends and Processes

3.5.1. *Case Study Sites*

When EMAN was formulated in 1994, resources were not available for an entire new network of ecological sites to be established across the country, so the EMAN focussed on existing research facilities and long-term records of available data. Existing sites were evaluated with respect to providing appropriate information for the national network, and were assessed on three criteria – existence of long-term monitoring records, multi-disciplinary monitoring in scope, and willingness to enter into partnerships and share data. Deficiencies in existing sites were addressed by integrating ecological monitoring activities that may exist close to that site but have been previously separate; and by establishing new facilities when necessary and where resources exist.

EMAN sites, or what we now call EMAN Case Study sites, are sites where intensive monitoring, that is, a relatively detailed ecological monitoring of structural and functional ecology (Freedman *et al.*, 1993), has been undertaken. These sites were corralled from the calibrated watersheds for studying Acid Rain – known as LRTAP (Long-Range Transport of Air Pollutants) sites (6); several of Canada's National Parks where monitoring the park ecosystems has been a long-standing mandate of each (17); Canada's UNESCO-recognized Biosphere Reserves (6); university research sites (17); federal (13) and provincial (20) government research sites; and other collaborating sites. The sites are primarily affiliated with other organizations in Canada with very few sites operated by Environment Canada.

The EMAN program has resources for staffing a co-ordination office, but no funds have been available to support monitoring or fund research, as is done in other countries. All of the sites' monitoring resources put together have been estimated conservatively at $30–40 million (Environment Canada, 1998) – enough resources in total for ecological monitoring in Canada, but very difficult to harness as most sites are affiliated with other agencies with differing priorities. The success of EMAN has been in the development of the loose partnership that links these sites together.

Yet, if developed, encouraged and maintained as a network based on mutually beneficial partnerships in areas of overlapping interest, an inter-organizational collection of such sites can:

- co-operate in generating an understanding of ecosystem status, trends and processes on an ecozone or national basis;
- serve as an irreplaceable resource in responding to a detected concern by providing data, interpretation and the supporting structure for responsive monitoring, surveys, research or assessment;
- provide a mechanism for interdisciplinary and inter-jurisdictional cooperation in the interpretation and assessment of observations and subsequent communications;
- serve as a basis for fostering and encouraging coordinated inter-organizational monitoring, metadata, databases and data access.

TABLE III

Strategic factors influencing the refocus of EMAN

• The science trap of statistical certainty driving all science.
• Monitoring's focus on parameters rather than effects.
• Potential for untapped schools and communities to contribute to national monitoring program.

3.6. The role for EMAN case study sites

3.6.1. *Extensive Monitoring Networks – Other Government Agencies*

In addition to the intensive monitoring sites, numerous government agencies are involved in long-term monitoring of environmental components in a more spatially extensive manner, that is, more sites located throughout the country to gain an overview of changes in the ecological character of landscapes and to detect regional trends in selected indicators (Freedman *et al*., 1993). While often effective in tracking specific components of ecosystems, these extensive sites were found to be inadequate in providing critical information on how the different components of the environment interact. Most extensive environmental monitoring programs do not provide integrated data across multiple environmental components at the various temporal and spatial scales needed to support the EMAN objectives. While the associated programs, activities and networks were established in response to specific legislation about specific resources and issues, they can be better integrated.

3.7. Strategic factors in refocusing EMAN

The strategic factors that influenced Environment Canada in the focusing of EMAN are included in Table III.

3.7.1. *The Trap of Statistical Certainty Driving All Science.* The emphasis on statistical certainty in the North American science culture, which in part is derived from the drive for peer reviewed publication, has resulted in a decreased ability to inform decision-makers of ecosystem changes in a time frame which can best contribute to sound resource management. Ecosystem monitoring routinely requires 10 or more years to demonstrate the existence of change according to this standard. One result is that there is little ability to focus attention, resources or investigation on newly emerging issues at the very time when doing so can be most effective. Nor can feedback be provided on the adequacy of management or policy initiatives. The result is that adaptive management cannot be achieved howsoever desired.

For example, bird populations were monitored at the Long Point Bird Observatory for many years. After tracking all bird species for decades, it appeared as if there were population reductions in particular species – reductions that were not examined, as the statistical certainty of the reductions was not present. By the time the statistical certainty emerged, some ten years later, the bird species had disappeared from Long Point and further study of the bird species' life cycle was impossible.

An early warning system that seeks to detect, describe and report on ecosystem changes in a timely manner must be clearly understood to be based on risk and probability and expert opinion rather than certainty.

3.7.2. *Monitoring's focus on parameters (simple monitoring) rather than effects (integrated monitoring).* With some exceptions such as bird surveys, wildlife and forest health monitoring programs, environmental monitoring networks that do persist continue to be based on parameters rather than effects, requiring augmentation if aspects such as cumulative effects or unidentified stressors are to be identified.

3.7.3. *Potential for untapped schools and communities to contribute to national monitoring programs.* It has been consistently demonstrated that communities, environmental non-government organizations (ENGOs) and educators are able and anxious to generate valid data on local ecosystems when accepted scientific protocols can be written and made available in comprehensible forms. Spin-off benefits in education, involvement and capacity-building need not enter into the analysis of the cost-effectiveness of such an approach for monitoring selected ecosystem attributes or parameters.

4. EMAN: The Path Forward

4.1. An Early Warning System of Ecological Changes

Environmental issues have been detected and effectively reported by EMAN sites in the past, and they need to continue to do so in the future. Such detection and reporting provides one information source to an Early Warning System (EWS). Other information sources for an Early Warning System include:

- the early review of data from existing sites and networks operated by partner organizations and the development of preliminary insights;
- the analysis of existing site and network databases, many of which would need to be made accessible;
- assessment of the broader implications of recent scientific literature; and
- the implementation of a set of measurements (Early Warning Variables) to be made in the same or a quantifiably similar manner across a national network by a wide variety of participants. Exceptions can exist at no less than an ecozone scale.

In order to provide an early warning system for the timely detection, description and communication of ecosystem change on a national or ecozone scale based on such information sources it is necessary that:

- Early Warning Variable data generated reside on a data base such that it can be regularly reviewed on a geographic basis to establish the presence and distribution of changes which may be of concern;
- a mechanism be established to provide advisories to decision-makers of observed ecosystem changes which may pose risks to the well-being of Canadians: these also may be derived from preliminary analyses of data from other ecosystem monitoring, survey and research activities;
- such advisories include recommendations for appropriate follow-up actions in monitoring, surveys, research, assessment or communication, thus also contributing to priority setting in these areas;
- detection, advisories and recommendations be developed and implemented through inter-jurisdictional, interdisciplinary; and
- inter-organizational co-ordination and partnerships to the extent possible; and A quality assurance system takes on an increasingly important role when involving multi-agency and multidisciplinary data and information.

The networks are numerous – see, for example, the Canadian Forest Service's Acid Rain National Early Warning System (Figure 3), Forest Insect and Disease Survey, North American Maple Project; Parks Canada's National Parks; The Geological Survey of Canada's Snow and Ice Program, MacKenzie Valley Integrated Research and Monitoring Area, Palliser Integrated Research and Monitoring Area; Agriculture Canada's Soil Quality Sites, Benchmark Sites; Fisheries and Oceans' fisheries surveys; and Indian and Northern Affairs' Northern Contaminants Program, Beaufort Environmental Monitoring Program, Hudson Bay Programme. The success of EMAN has been in getting these federal government agencies together and sharing information on their monitoring activities.

4.2. Core variable network development

With a focus on an early warning system of ecological changes, the EMAN Coordinating Office began development of a set of core variables that could be monitored at any EMAN site in Canada to track ecosystem changes over time. The objective was to select core variables, that work together as a suite, to detect and track change within the ecosystem. Selected variables: (i) should identify significant changes in ecosystems so as to trigger and guide the design of future investigations; (ii) must be suitable for measurement and comparison among a variety of sites; (iii) should be characterized by cost-effective sampling methods; and (iv) should easily fit into existing monitoring programs.

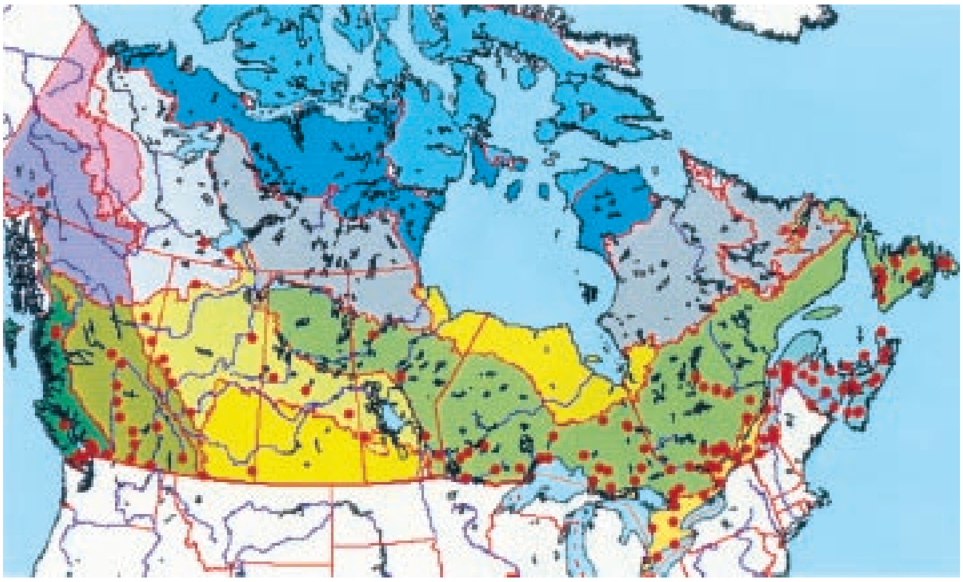

Figure 3. Canada's Acid Rain National Early Warning System (ARNEWS). Colour legend: Lightest blue (upper part – Arctic Cordillera; Light blue – Northern Arctic; Blue – Southern Arctic; Light grey – Taiga Plains; Grey – Taiha Shield; Green (right) – Boreal Shield; Grey-blue (right) – Atlantic Maritime; Light yellow (lower part) – Mixedwood Plains; Light green – Boreal Plains; Yellow – Prairies; Pink – Taiga Cordillera; Purple – Boreal Cordillera; Dark green (lower left) – Pacific Maritime; Green – Montane Cordillera; Yellow-green (center) – Hundson Plains.

These criteria were applied to 1770 monitoring variables assembled from a variety of sources that include major environmental monitoring programs around the globe (North South Environmental, 1998). A list of 188 candidate variables were selected based on its meeting all four primary criteria. (Note: the third criteria of cost-effectiveness differentiates the EMAN program from others and results in the rejection of many of the US EMAP indicators and the UK ECN indicators which are generally technically sophisticated and therefore more expensive to employ).

Additional secondary criteria related to data quality (sensitivity to change, ability to detect trend or threshold, relevance, response time, repeatability, accuracy), applicability (number of ecozones it could be applied to, integration of ecosystem components), data collection methods (well documented, specialized knowledge not required, specialized equipment not required), data analysis and interpretation (cost-effective analysis, information easily communicated), existing data and programs (years of available data, stations with available data, stations across range of ecozones, data readily available, base-line conditions established) and cost (low average annual cost) were applied to the 188 candidate variables with scores applied to each. The 37 top-ranked groups of monitoring variables are listed in Table IV.

A study (North South Environmental, 1999) was then undertaken to test the efficacy of these 37 core monitoring variables for detecting early changes in eco-

TABLE IV

List of proposed EMAN core monitoring variables following selection in 1998

Ecosystem component		Monitoring variable measure
1	Water quality	– dissolved oxygen
2	Water quality	– water clarity
3	Stream flow	– stream flow rate
4	Lake level	– lake level fluctuations
5	Air quality	– moss and lichen indicators
6	Temperature mean	– soil temperature/permafrost depth
7	Snow/ice phenology	– lake ice out/in timing
8	Lake sediment	– sediment core analysis (accumulation rate and trace metals)
9	DNA modification	– morphological asymmetry
10	Rare species	– presence of vulnerable or threatened species
11	Exotic species	– presence of specific exotic species (e.g., sea lamprey)
12	Species richness	– amphibians
13	Species richness	– birds
14	Species richness	– molluscs
15	Species richness	– mammals
16	Species richness	– macrophytes
17	Species richness	– benthos
18	Species diversity	– birds
19	Species diversity	– plants
20	Species diversity	– frogs
21	Species diversity	– herptiles
22	Species diversity	– benthos
23	Exotic species	– all exotic plants
24	Community biomass	– plants
25	Community biomass	– benthos
26	Community biomass	– microbes
27	Indicator species group	– aquatic insects (e.g., midges, mayflies, oligochaetes)
28	Indicator species group	– fish index of biotic integrity
29	Land cover change	– changes in land cover over time
30	Gross pathology	– incidence of disease in fish
31	Phenology	– first growth of plants (e.g., buds, flowers, leaves, shoots)
32	Community productivity	– productivity of fish
33	Community productivity	– trees
34	Community productivity	– phytoplankton
35	Community productivity	– plants
36	Nutrient storage	– trees
37	Landscape patch metrics	– changes in patch metrics over time (e.g., edge to interior ratio)

TABLE V

Description of stressors selected for testing

1	Endocrine disrupters
2	Invasive species
3	Global carbon cycle changes/Global climate warming
4	Increased Ultra Violet ‘B’ (UV-B) radiation
5	Habitat fragmentation
6	Transportation corridors
7	Acid rain
8	DDT
9	Eutrophication
10	Ground-level ozone
11	Pulp and paper mill effluent
12	Groundwater contamination

systems. Twelve known human-caused environmental stressors (see Table V) were selected for their importance, range of stressor type and the likelihood of information being available for their use in this efficacy test. The hope was that the suite of core monitoring variables would reliably detect the first environmental changes associated with each stressor, and thereby provide the desired early warning capability for the EMAN. The results of the test showed that each of the 37 core monitoring variables did detect some change in ecosystems (see Table VI) in response to the 12 stressors studied. Nine variables, however, provided no measure of early warning ecosystem response. (Note: the biotic structure/composition variables at the community level of organization are expected to provide the greatest number of early responses of changes to ecosystem stressors).

4.3. Observer Network – School and Community Volunteers

Over the past two years, the EMAN Co-ordinating Office has tested numerous ways of engaging Canadians in ecological monitoring to provide the ‘hands-on’ experience of collecting data about the environment as an awareness-building experience; and more importantly to EMAN, to provide extensive environmental data that can be used by scientists to track changes in Canada’s ecosystems. The decision to use volunteers in observing the environment was controversial – several meetings were held to debate the issue. In the end, it was agreed that with the proper consideration and guidance, volunteers, including students and community members, could play a large role in ‘keeping watch’ over the Canadian environment. Five principles were defined that drive the development of a volunteer observing network in Canada: ensure scientifically-valid data; ensure data is used by scientists;

TABLE VI

Core monitoring variables ranked according to the number of early ecosystem responses to stress detected

Rank	Ecosystem component	Monitoring variable measure	No. of early ecosystem responses to stress detected
1	18 Species diversity	– birds	11
2	20 Species diversity	– frogs	11
3	21 Species diversity	– herptiles	11
4	12 Species richness	– amphibians	9
5	13 Species richness	– birds	9
6	15 Species richness	– mammals	8
7	22 Species diversity	– benthos	7
8	28 Indicator species group	– fish index of biotic integrity	5
9	19 Species diversity	– plants	4
10	30 Gross pathology	– incidence of disease in fish	4
11	11 Exotic species	– presence of specific exotic species	4
12	23 Exotic species	– all exotic plants	3
13	2 Water quality	– water clarity	3
14	16 Species richness	– macrophytes	3
15	10 Rare species	– presence of VTE species	2
16	17 Species richness	– benthos	2
17	27 Indicator species group	– aquatic insects	2
18	29 Land cover change	– changes in land cover over time	2
19	34 Community productivity	– phytoplankton	2
20	37 Landscape patch metrics	– changes in patch metrics over time	2
21	1 Water quality	– dissolved oxygen	1

use existing observation programs; build partnerships; and take advantage of new technologies.

Volunteer monitoring has focussed on forest biodiversity, earthworms, plant phenology, and amphibians. In many cases, it has been shown that volunteers can collect scientifically valid and useful data on ecosystem changes in these components of the ecosystem (Scott and Herman, 1995).

4.4. Integrating Monitoring Networks in Canada for an Early Warning System of Ecological Change

A conceptual framework, borrowed and revised from the US National Science

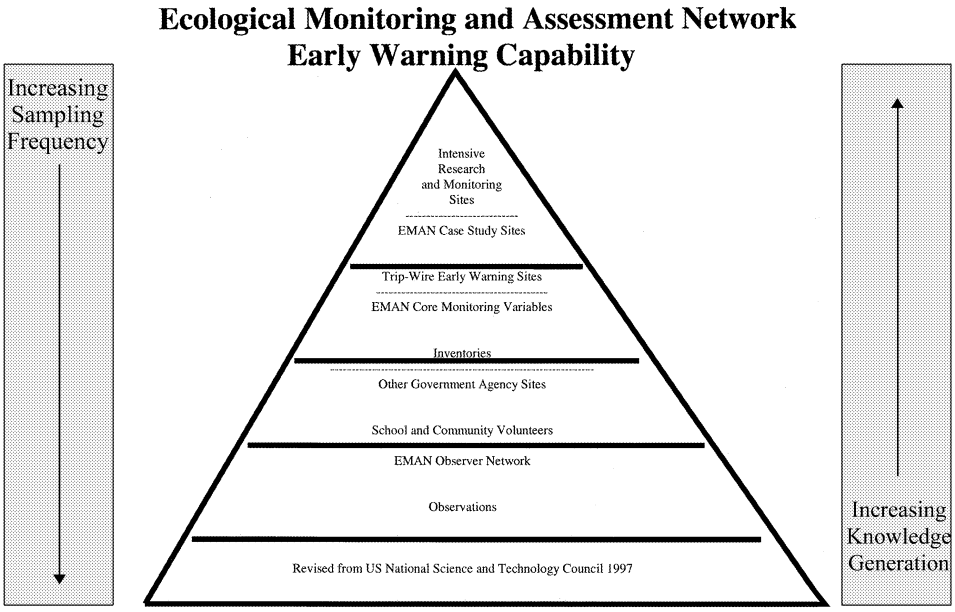

Figure 4. Ecological monitoring and assessment network early warning capability.

and Technology Council, that effectively develops an early warning capability of ecosystem changes can be assembled largely from existing networks, and attempts at integrating these networks. The Framework, as shown in Figure 4, can be represented by a triangle, with the measurement that can be made at the greatest number of sites are at the base of the triangle. The types of monitoring represented within the Framework can be divided into five general classes:

At Level 1, the peak of the triangle, Intensive Research and Monitoring Sites what we call the EMAN Case Study Sites typically provide a greater number of monitoring variables, at a high frequency of collection/observation, but at a small number of locations (93 sites). At level 2, Trip-Wire Early Warning System Sites or what we call the EMAN Core Monitoring Variable Sites are designed to capture the early warning of ecosystem change using a medium number of variables (20) balanced with a spatial resolution across Canada’s 15 terrestrial ecozones and other environmental stressor gradients. At level 3, Inventories or what we call Other Government Agency Networks, are based on methods that can census specific variables uniformly across large regions. At level 4, School and Community Volunteers or what we call the EMAN Observer Network, where simple, yet revealing, observations are conducted by groups of volunteers adhering to strict protocols following appropriate training. The spatial distribution will be high in the human populated areas of the country. At level 5, Observations or what can be explained as simple observations that individuals across the country can make about their surrounding environment, e.g. the birds are flying south earlier this year, or the trees are really

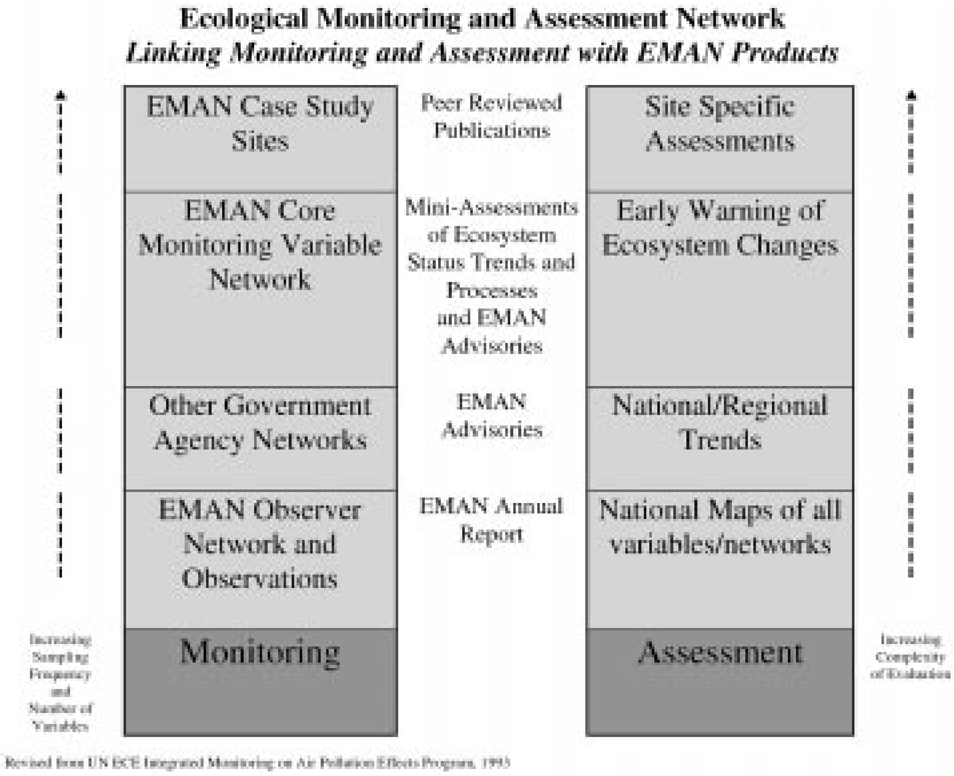

Figure 5. Linking monitoring to reporting on Canada's ecosystems.

brown this year. With the appropriate information management system (Fenech, 1999), these observations can be spatially represented and investigations initiated if necessary.

4.5. EMAN EARLY WARNING ADVISORIES OF ECOSYSTEM CHANGES MAKING THE POLICY LINKAGES

Figure 5 provides a schematic diagram of how monitoring networks meet the various reporting needs of policy through science assessment. The EMAN Advisories serve a particular role in providing early warning of ecosystem changes to the policy process.

EMAN Advisories are needed to provide advice on whether to focus attention, resources or investigation on newly emerging environmental issues. The advice needs to be timely, relevant and representative of the various agencies involved in ecosystem monitoring. EMAN Advisories are needed to provide the avenue and a forum for inter-disciplinary and inter-agency review of ecosystem changes in Canada.

EMAN Early Warning Advisories of Ecosystem Changes, commonly referred to as EMAN Advisories, are a series being launched by EMAN, contributing to reporting on the State of Canada's Environment. EMAN Advisories are short papers on the most current results of ecosystem monitoring or science. EMAN Advisories emerge from the EMAN Early Warning System of Ecosystem Change – A system derived from the application of the EMAN core monitoring variables; papers and EMAN Assessments of Ecosystem Status, Trends and Processes; and the early assessment of data derived from the EMAN partner network and from Environment Canada networks. EMAN Advisories will have a largely standardized format and content to include background, observations, expert opinion of risks posed to Canadians, recommended research and additional actions, downside risk of inaction, estimate of certainty and list of participating partners. It is anticipated that at least six EMAN Advisories will be released periodically throughout the year.

EMAN Advisories are designed to report on changes in ecosystems including the cumulative effects of stresses on ecosystems. These changes may be the result of many issues, including natural disasters, climate change, stratospheric ozone depletion, acid rain, persistent organic pollutants, natural variation, etc. Thus, EMAN Advisories will address numerous environmental issues, but their focus is on changes in ecosystems. The first advisories will deal with the 1998 ice storm in eastern Canada, the continuing effects of acid rain on forests, the effects of historical land use changes near Canada's Biosphere Reserves, use conflicts in the Crown of the Continent area, biodiversity in the Montane Cordillera, and the changing hydrological cycle in western Canada.

EMAN Advisories are short and use a language accessible to the general public. More importantly, EMAN Advisories are designed to be timely and thus require short turnaround times – times that are not available in the sphere of peer-reviewed scientific publications. In order to be timely, EMAN Advisories will be based on risk, not statistical significance, to inform decision makers of ecosystem changes in a time frame that can best contribute to sound resource management.

EMAN Advisories preparation is co-ordinated by Environment Canada staff, but each advisory represents the work of EMAN partners involved in tracking the ecosystem changes identified in the advisory. The principal EMAN partner will be recognized by name and agency on the cover of each advisory, and each partner will be recognized by agency and logo on the final page of the advisory. Based on partners, EMAN Advisories will be able to cross disciplines and jurisdictions in developing a common message which, when combined with socio-economic considerations in the description of risks posed to Canadians, approximates a true ecosystem approach.

There will be an uncompromising emphasis on the reliability and timeliness of the EMAN Advisories as well as their relevance to the priority-setting and policy-formulation processes. An example of an EMAN Advisory will be available soon at the EMAN Website at www.cciw.ca/eman/.

5. Conclusions

Environment Canada is increasingly presented with issues related to sustainability which require informed public choices. The investigation, articulation and communication of the ecosystem costs and benefits of resource management alternatives (including environmental, social and economic aspects) is emerging as a required role for government science. Such issues and such a role demand insights and investigation that are interdisciplinary and inter-jurisdictional and therefore can only be addressed through inter-organizational co-operation. Identifying and addressing ecosystem effects demands a balance between dispersed network sites for detection/description and intensive case study sites for understanding. Further, reports from these networks need to be relevant and timely, requiring a basis of expert opinion of risk, not statistical significance, to inform decision makers of ecosystem changes in a time frame that can best contribute to sound resource management. The new focus of the Ecological Monitoring and Assessment Network (EMAN) plays such a role – science-based and policy-relevant.

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