Statistics Canada Statistique Canada

A Framework for Developing Environmental Statistics

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Canada

Introduction

Environment is fast becoming an important domain. Discussions of environmental issues are no longer limited to the confines of the scientific community. Today, acute environmental challenges are areas of high interest for ordinary citizens and decision makers alike. Governments at all levels are expected to address these challenges.

The increasing prominence of evidence-based approaches to informing policy decisions emphasize the need for high quality statistics in support of the policy making process. Unlike economic statistics, however, environmental statistics have, up to now, been collected in a largely *ad hoc* fashion. Statistical data collection and reporting have mostly been conducted to suit the needs of individual policy initiatives, following the ebb and flow of environmental concerns.

The 1970s, for example, saw the emergence of air pollution statistics in response to early concerns over smog and acid rain. Two decades later, concerns about environment-health linkages, along with legislation assuring people's "right to know" about environmental quality, led to the measurement of toxic emissions. In spite of the obvious links between these issues, there is little resemblance between the respective data sets. Air pollution and toxic emission data are not integrated in the way that other statistics are – especially economic statistics – but exist largely independent of one another.

Such an approach has produced a patchwork of environmental statistics. Some parts of the patchwork are of good quality, others less so. Other parts are missing altogether. This situation may serve the needs of some policies reasonably well but in no way do existing statistics form a unified system of broad policy relevance. As a result, the overall quality of environmental statistics has suffered, frequently lacking one or more of the standard attributes of high quality statistics: relevance, accuracy, timeliness, accessibility, interpretability and coherence.

The existence of *ad hoc*, widely dispersed environmental statistics with varying degrees of quality clearly underlines the need for a ***framework***—a basic organizing structure to guide environmental statistics. A framework provides guidance on what should be collected and how to ensure quality: quality of the datasets and quality in the execution of statistical activities.

This paper offers a starting point for discussion among various stakeholders. It outlines the development of a framework for environmental statistics. It evaluates how existing environmental statistics available to policy and decision makers stack up against quality standards. The paper also illustrates a practical application of the framework by outlining how it could be used to address key policy issues such as climate change.

1 Development of a framework: lessons from economic statistics

The Great Depression of the 1930s and the threat of the Second World War stimulated the efforts to develop sound economic statistics in both the domestic and international arenas. The pressing need to maintain economic stability and promote growth in the post-war years provided further motivation for economists, statisticians and politicians to work towards more robust economic statistics.

Attention was first turned in the 1930s – mainly by economists – to formulating a more refined understanding of macroeconomic development. The theory that resulted succeeded in providing a rigorous *conceptual* framework for economic statistics. This, in turn, stimulated the creation of a *statistical* framework, the *System of National Accounts* (SNA), which came into its own in the 1940s and 50s. The SNA remains the most important force guiding economic statistics to this day. In it, economic statistics collected from hundreds of sources are integrated through an elaborate process of estimation and aggregation into, among others, the influential and familiar macroeconomic indicator, gross domestic product (GDP).

The combination of the new theory for macroeconomic development and its statistical counterpart, the SNA, offered a new *framework for economic statistics*. Beginning in the 1940s, this framework provided a consistent, systematic set of principles, concepts and methods for economic statistics where none had existed before. It allowed a better understanding of the complex economic system. It provided a structure with which to ensure that the concepts and measures in various parts of the statistical system were comprehensive and coherent. In sum, it helped guarantee that basic economic statistics would work together as a useful statistical system.

With a clear and widely accepted framework to guide them, economic statistics evolved from the patchwork of limited utility that existed prior to the Second World War to the highly accurate, complete and coherent system we enjoy today. Though the original theoretical understanding of the macroeconomy that drove the creation of the system in the 1940s has been refined since, the framework has remained relevant and its contribution to the management of the economy over the last half century is widely acknowledged.

Perhaps the most important lesson learned in the development of economic statistics was how, throughout the years, policy needs drove the creation of the SNA and how the SNA, in turn, improved policy. With the appropriate mechanisms in place, the same could happen in environmental statistics.

The same benefits realized by economic statistics following the adoption of a framework would be available to environmental statistics. Of course, such benefits cannot be realized overnight. It has taken more than half a century in the case of economic statistics and there remain challenges to face. Even if not as lengthy a process as that, it is certain that improving environmental statistics will require a long-term commitment. For the process to begin at all, the view here is that a framework must first be developed. The paper now turns to exploring what this framework might be.

2 A framework for environmental statistics

2.1 Elements of quality and environmental statistics

Attributes of quality

Before exploring how the introduction of a framework might increase the quality of environmental statistics, it is helpful first to outline some general characteristics of good statistics. Existing environmental statistics can then be lined up against them to identify some of their main deficiencies.

Statistics Canada is not the only source of environmental statistics. There are many collectors of environmental data, the most prominent ones include the national and sub-national departments of environment, natural resources, agriculture and fisheries. It should also be noted that many of the environmental datasets collected on a regular basis by public agencies at various levels of government are not intended specifically for statistical monitoring and reporting. Rather, they are developed in response to program requirements.

Regardless who is responsible for their production, however, good quality statistics all share the characteristics listed below.[1]

- **Relevance and comprehensiveness** – Good statistics shed light on issues that are important to users. They reflect the full universe of phenomena relevant to the measurement of a given variable. They also capture all required variables in order to understand a given issue.

- **Accuracy** – Good statistics reflect as closely as possible the actual values of the variables they are intended to measure.

- **Timeliness** – Good statistics are available as soon as practically possible following the period to which they refer and, in the case of high-profile statistics, are released according to publicly pre-announced schedules.

- **Accessibility** – Good statistics are readily accessible to all potential users.

- **Interpretability, methodological soundness and transparency** – Good statistics are based on professionally accepted methods that are transparent to anyone using them. Transparency is essential if

[1] For additional information on the elements of quality, refer to the Statistics Canada Quality Guidelines, Catalogue No. 12-539-XIE, 2003.

independent verification of soundness is to be possible. Availability of supplementary information necessary to interpret and appropriately utilize the statistical information is also a key attribute of good statistics.

- **Coherence** – Good statistics are *internally* coherent, meaning that a given variable is measured in the same manner in all instances of its occurrence. Internal coherence is particularly important across time, as it ensures that observed trends are not simply statistical artifacts. Good statistics are also *externally* coherent, meaning that variables of one type are measured such that they may be meaningfully compared and combined with variables of other types. External coherence is essential if environmental statistics (such as greenhouse gas emissions) are to be linked with other statistics (such as industrial production and expenditures on pollution reduction) to analyze the relationships.

Do existing environmental statistics measure up to quality standards?

If existing environmental statistics are compared with the above list, they are found wanting in a number of ways. To start with, they commonly suffer from a lack of **methodological rigour**, especially in sample design. Water quality data in Canada, to choose one example, are not representative of the whole country because they are collected at monitoring sites located with no national statistical design in mind.

The **accuracy** of environmental data may be compromised by a variety of factors, including methodology, respondent error and scientific uncertainty. National forest statistics, for example, are less accurate than they might be because they are derived from provincial statistics that are not all collected at the same time or in the same way. The national forest inventory for 2001 is, in fact, an amalgam of provincial forest inventories taken over many years. Rather than a sharp portrait of the forest in 2001, it resembles more a collage of different aged images. The mammoth task of observing all of Canada's forests at once – especially in the time before satellite imagery – explains this shortcoming.

Environmental statistics are, generally speaking, not as **timely** as their economic and social cousins. Environment Canada's *National Inventory Report*[2] on greenhouse emissions, arguably the most important environmental report today, is not released in its final form until nearly two years after the reference year. Statistics Canada's related greenhouse gas emissions account is even less timely. It is not available in final form until four years after the reference year. Another flagship report, the *Canadian Environmental Sustainability Indicators* jointly published by Environment Canada, Statistics Canada[3] and Health Canada, presents indicators that are two years old at the time of publication.

[2] http://www.ec.gc.ca/pdb/ghg/ghg_home_e.cfm

[3] Following Strategic Review in 2007, Statistics Canada no longer participates in the release of this report.

A similar point can be made with respect to the **accessibility** of environmental statistics. Their collection by many departments at various levels of government means that they are generally more cumbersome to access than social and economic statistics. Not only must users know where to go to access a particular statistic, but they must accustom themselves with numerous dissemination channels.

The above weaknesses are serious and certainly worthy correcting to the extent possible. However, it is with respect to the last two quality characteristics – comprehensiveness and coherence – that the greatest weaknesses are found. Here too lie the greatest potential benefits if a framework were put in place to guide the collection of environmental statistics.

Relevance and comprehensiveness are a concern for environmental statistics in both of its dimensions. They fail in some cases to properly capture all required variables needed to explain a particular issue. They fail in others to measure all variables relevant to a particular issue. Statistics on pollution emissions are a good example to use in illustrating both shortcomings.

The *National Pollutant Release Inventory* is a primary source of statistics on toxic pollutant emissions from industrial facilities. An important and valuable characteristic of this inventory is that it makes emissions data for individual industrial sites available to the public. This is done in an effort to give Canadians knowledge of the pollutants emitted "in their backyards." In spite of this strength, the methodology used to compile the inventory is such that it fails to reflect the full universe of industrial emitters. Thus, for any given toxic pollutant, the inventory captures only a portion of the emissions from all industrial sources. It therefore fails along the first dimension of comprehensiveness noted above.

Industrial facilities are important sources of toxic pollutant emissions, but not the only ones. Households, governments and foreign economies all engage in activities that result in toxic pollutants entering the Canadian environment. Yet current statistics do not, for the most part, account for the emissions from these other sectors. In this way they fail along the second comprehensiveness dimension; they do not reflect all variables relevant to understanding toxic emissions in Canada.

Looking at environmental statistics from a **coherence** perspective, weaknesses are again apparent in important areas. For example, even if detailed national statistics on common air pollutants have been compiled regularly in the *Criteria Air Contaminants Inventory* since the 1980s, there has been no time series for this inventory, until recently. This is because the methodology used to compile the inventory was revised a number of times during the 1980s and 1990s. Each time, the new methods were implemented without revising the historical statistics. In 2008, a time series of these data was finally prepared, but only at the expense of a considerable loss of industrial detail.

Catch and effort statistics on Canada's fisheries offer another example. The current standards, data sources and methods used to compile these statistics are mainly region-specific, making a coherent national picture difficult to prepare. In the economically important lobster fishery, for example, fishing vessel logbooks – the main source of catch and effort data – are not subject to mandatory submission in all regions. Logbooks that are submitted often come late and their return rates differ from year to year. These inconsistencies have a significant impact on the quality of catch and effort statistics for the fishery.[4]

The two previous examples demonstrate the lack of *internal* coherence in environmental statistics. *External* coherence is also a concern. Environmental variables often cannot be meaningfully compared and combined either with other environmental variables or with variables from other statistical domains.

The coherence of environmental statistics with statistics from other domains is particularly low. The statistical elements that guarantee coherence – common definitions, classifications and methods – are not often shared between them. Industrial classifications, for example, are sometimes quite different. To give one example, data in the *Criteria Air Contaminants Inventory* are published using a purpose-built industrial classification that is quite distinct from the standard *North American Industrial Classification System* used to organize nearly all economic statistics.

It is perhaps not surprising that environmental statistics lack coherence with statistics in other domains. It may be more surprising that they are often not coherent with each other, sometimes even when collected by the same department. The national greenhouse gas and criteria air contaminant inventories mentioned above offer a good example of this. While these inventories share the same basic purpose – the estimation of airborne pollutant emissions from businesses, households and governments – they approach their task in very different ways. A notable difference, already alluded to, is in their classifications of economic sectors. The greenhouse gas inventory uses a classification in which five manufacturing industries are uniquely identified. In contrast, over three dozen manufacturing industries are specified in the criteria air contaminants inventory. The classifications differ in numerous other ways as well.

Coherence between data sets collected by different departments is also a concern. Statistics Canada, for example, produces a set of environmental accounts linked with the national accounts in which greenhouse gas emissions are reported. The estimates in Statistics Canada's accounts are not directly comparable with those in Environment Canada's national greenhouse gas inventory. Differences in underlying data sources are one reason. Another is that scope of the estimates is not the same. Environment Canada's estimates include

[4] Fisheries and Oceans Canada, 2007, Framework for Statistical Integration of Fisheries Information, Draft Requirements Analysis Report.

emissions of methane from landfill sites whereas Statistics Canada's do not, to cite one distinction.[5]

It is worth bearing in mind, however, that the sorts of problems noted here have been seen before. Though economic statistics may be the gold standard today in terms of quality, this was not always the case. Economists and statisticians faced many challenges in the early part of the 20th century. During that time, they were not equipped with an empirical framework for studying the economy. Indeed, "Canada's economic statistics in the 1920s offered little real insight into [the economy's] workings."[6] In 1931, the head of the statistical bureau, Robert Coats, admitted that "statistics [on national wealth] are suggestive and indicative rather than strictly accurate...".[7] The lessons learned in building modern economic statistics from these shaky beginnings demonstrate the value of a clear framework in setting the process off on the right foot.

2.2 Identifying the primary purpose of the framework

It is important to emphasize that the proposal here is not for an *economic* framework for environmental statistics, but for an environmental framework that borrows the best features from economic statistics. Applying the lessons learned from economic statistics, a framework for environment statistics is proposed that would, if implemented, exhibit features similar to that for economic statistics.

The first step in this direction is the identification of the primary purpose of the framework; that is, the high-level policy objective it will inform. Identifying a single, tightly focused policy objective guides the framework's scope and its appropriate conceptual foundation. The high-level objective must be defined in very general terms and must be one that enjoys broad social and political acceptability. Otherwise, the framework will not stand the test of time.

In the SNA experience, the focus was clear: to measure economic production and income in the name of ensuring economic stability and growth. In the realm of environmental statistics, such an objective might be simply stated as "the maintenance of environmental quality." An average Canadian would identify intuitively with this, as the quality of the environment is now widely understood to be interlinked with human wellbeing. Moreover, if the policy frameworks within government departments responsible for environmental matters were distilled, their essence would be very much about maintaining environmental

[5] The purpose of Statistics Canada's greenhouse gas emissions account is to measure emissions associated with current economic activity. Since landfill emissions are the result of activity that occurred in the past, they are excluded from the account.

[6] McDowall, D., 2008, *The Sum of the Satisfactions: Canada in the Age of National Accounting*, McGill-Queens Press, p. 31.

[7] Dominion Bureau of Statistics, 1931, *Report on the National Wealth of Canada and its Provinces as in 1929*, publication II-D-20, p. 1, as quoted in McDowall, *op. cit.*

quality. Indeed, Canada's most important environmental law, the *Canadian Environment Protection Act*, cites this objective directly in its preamble:[8]

> "…the Government of Canada recognizes the importance of endeavouring, in cooperation with provinces, territories and aboriginal peoples, to achieve the highest level of environmental quality for all Canadians…"

The key words in this objective statement are "environmental quality" in the same way that "income" was the key word in the objective identified for economic statistics in the 1930s.

2.3 Specifying the target variables

Key target variables are the most important variables that need to be measured in support of the high-level objective. During the development of the SNA, economic production was the focus of economic policy. Therefore, the elements that comprise production were identified as the key target variables in the SNA. Measuring these variables and their components became the goal toward which nearly all economic statistical efforts were devoted in one way or another.

Just as the target variables associated with economic production and income had to be defined for the economic framework, so too must those associated with environmental quality be defined here. To do this, it is necessary to turn to the work of science.

The earth's environment is seen by ecologists, geographers and other physical scientists as comprising four principal "spheres:"

- **the atmosphere** – the gaseous layer surrounding the planet;
- **the biosphere** – the collection of all living organisms together with the decaying organic matter produced by them;
- **the hydrosphere** – the water found on and below the planet's surface in oceans, lakes, rivers, soils, snow/ice and groundwater; and
- **the lithosphere** – the upper layer (100 km) and surface of the planet's solid mass, comprising the continental and oceanic crusts in which earthquakes, mountain building, volcanoes and continental drift occur.

These spheres or systems do not exist independently but interact constantly through the exchange of matter and energy. In perhaps the most obvious example, water vapour in the atmosphere condenses and falls to the ground where it joins the hydrosphere to nourish plants and animals in the biosphere.

While fundamental in and of themselves, the four principal spheres make their greatest contribution to environmental quality through their interactions. The

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[8] *Canadian Environmental Protection Act, 1999,* (1999, c. 33) [Retrieved January 14, 2009, http://laws.justice.gc.ca/en/C-15.31/text.html?noCookie]

interaction of the biosphere with the other three spheres is, literally, essential to life as we know it. Acknowledging the importance of the systems created through this interaction, scientists have given them a special label: **ecosystems**.

Ecosystems are collections of living organisms, decaying organic matter and the inanimate (or abiotic) environment (soil, rocks, water, gases) within which the organisms live. They are divided into three major groups: terrestrial, freshwater and marine ecosystems. Each is further subdivided according to the unique features that exist on land and in water. For example, terrestrial ecosystems are divided into forest, grassland, tundra, desert and alpine ecosystems. Agricultural and urban land also qualify as terrestrial ecosystems, with the particular feature of very strong human influence.

Ecosystems are extraordinarily important from an ecological point of view. They perform specific functions—biochemical cycling, photosynthesis and cleansing of air and water—that are fundamental to the survival of every species in the planet. Ecosystems also serve as sources of natural resources and raw materials. These functions merit further elaboration.

Among the important functions ecosystems provide is the global "biogeochemical cycling" of carbon, oxygen, nitrogen, phosphorus, sulphur and other fundamental elements. These cycles ensure that the elemental building blocks of life are distributed across the planet in a way that fits the needs of the biosphere. The biggest of these cycles, the carbon cycle, ensures that carbon is continually moved among the four principal spheres, preventing its build-up in the atmosphere. Such a build-up would disrupt the climate, among other things.

Photosynthesis, the process by which plants use the sun's energy to combine atmospheric carbon dioxide and water into their basic building blocks, is another central function of ecosystems. It is one of the few ways in which the sun's energy is captured and stored for use on the planet. The plant matter that is created though photosynthesis serves as the energy source for all other life forms in the biosphere, none of which has the ability to extract energy directly from the sun.

The cleansing of water is yet another fundamental role of ecosystems. As water passes from the hydrosphere to the biosphere and atmosphere and back again, both natural and manmade contaminants are removed from it. In the absence of properly functioning ecosystems, the decay of plant and animal matter, erosion and other natural processes can cause water to become polluted and unfit for life. Additional pollutants introduced by human often make matters worse. Fortunately, most of the water on the planet remains fit for life because ecosystems have evolved processes by which pollutants are continually removed. Much of this is accomplished by micro-organisms that are adapted to using the contaminants as sources of energy.

Similarly, processes in ecosystems ensure that pollutants, both natural and manmade, found in the atmosphere are kept in check and not allowed to accumulate to dangerous levels. The reality, however, is that the ecosystem processes that assure clean water and air are occasionally overwhelmed by the burden imposed on them by human activities. Excess pollutants from households and businesses can, and increasingly do, lead to degraded water and air quality because ecosystems have insufficient capacity to absorb them. Human disturbances to ecosystems through modifications to land or water bodies can also diminish their capacity to absorb pollutants, making them less effective as purifiers of water and air.

Most obviously, ecosystems serve as sources of natural resource products: wood and other plant matter, fish, game, water, minerals, fossil fuels[9] and genetic material. These products help provide the necessities of life: shelter, food and energy. Less obviously, but no less importantly, ecosystems offer services with a variety of benefits. The provision of clean air and water used by households and businesses, already mentioned above, comes quickly to mind. Less apparent examples include the flood protection offered by alpine forests to valley dwellers and the pollination services of honeybees enjoyed by crop farmers. Also worth noting are the simple pleasure of a walk in the woods or, less directly, the satisfaction some find in the knowledge that a culturally important landscape exists.

One could envision "ecosystems" in the proposed environmental statistics framework as the equivalent of the "elements of the economic production" in the SNA. The previous examples suggest strongly that ecosystems are the appropriate target variables for a framework focused on the maintenance of environmental quality. They are essential to ensuring the continued supply of the ecological products and services that are basic to the wellbeing of human and non-human species alike; this, it is argued, is the essence of the need to maintain environmental quality. Thus, the somewhat abstract high-level objective "maintain environmental quality" can be thought of in more rigorous terms as the need to maintain the quality of ecosystems.

The proposed set of key target variables is illustrated below. Drawing an analogy, once again, with the economic framework, these target variables are akin to the main elements of economic production in the SNA, namely, consumption, investment, government spending, exports and imports.

High-level objective	*Maintenance of environmental quality*				
Key target variables	*Freshwater ecosystem quality*	*Marine ecosystem quality*	*Terrestrial ecosystem quality*	*Air quality*	*Water quality*

[9] It is debatable whether minerals and fossil fuels should be seen to be derived from ecosystems. More correctly, they are part of the lithosphere. Their use is, however, associated with ecosystem quality in important ways. Their extraction often requires significant inputs of ecosystem products (freshwater use in the oil sands, for example) and usually results in ecosystem disturbance of some sort. For these reasons, they are included in the framework proposed here.

It will be noted immediately that air and water quality have been added as target variables in addition to the quality of the three main categories of ecosystems. Though the atmosphere and the hydrosphere are not ecosystems, the quality of their principal constituents (air and water) is included to acknowledge their significance to humans and other species.

Air and water quality would more correctly have been measured in association with the three ecosystems. For example, ground-level ozone, which can damage crops, would fit conceptually under the heading of terrestrial ecosystem quality as one of the abiotic components of that ecosystem. Placing it there would have given it less prominence in the framework, however, not to mention being unintuitive for non-scientists.

2.4 Identifying the sub-components (stocks and flows)

The five key target variables identified for the framework are all state (or stock) variables. Yet ecosystems are highly dynamic, not static. They undergo constant change from season to season and year to year. This suggests that stock variables alone are insufficient to capture all that is important in understanding ecosystem quality.

Flows between ecosystems and the human sphere (sometimes called the anthroposphere) are also important. They are essential variables related to the dynamic processes that bring about ecosystem change. These dynamic processes mainly involve flows of matter and energy within and between ecosystems. In many parts of the world today, human-induced flows of matter and energy are the dominant forces determining ecosystem quality. The localized nature of these flows and their impacts suggest the importance of spatially-detailed measurement in environmental statistics.[10]

Given the dynamic nature of ecosystems, the set of key target variables given above must be further broken down into relevant stock *and* flow **component variables.** These components will ultimately be the targets of measurement in the statistical system. In an ideal world, the component variables would be measured, weighted and aggregated together to yield statistically robust measures of the key target variables. This is what is done in the SNA, where the components of each target variable are measured in dollars and then added together to arrive at a robust estimate of the target variable itself.

The absence of shadow prices in the environment domain makes it impossible to aggregate all the components of the key target variables. Environmental variables must be measured using scientific methods and it is still rare for weights to exist allowing different variables to be aggregated. However, by populating various parts of the framework with the relevant high quality datasets, policy makers could, themselves, make the tradeoff decisions based on the statistics and indicators presented. Thus, the individual scientific measures of

[10] The advent of geographic information systems (GIS) technology in the last decades has made the compilation of spatially referenced statistics much easier.

pollution flows, natural resource extraction and the other detailed component variables could effectively serve as the principal statistical outputs of the system.

Ecosystem quality is a complex, evolving topic. Elaborating all of the stock and flow components of the five key target variables proposed for the environmental statistics framework requires consultations with stakeholders. It cannot be achieved without further deliberations and discussions with the main producers and users of environmental statistics. It is possible, however, to present broad categories that illustrate the component variables associated with each of the key target variables. This is done in the next table.

High-level objective	*Maintenance of environmental quality*				
Key target variables	*Freshwater ecosystem quality*	*Marine ecosystem quality*	*Terrestrial ecosystem quality*	*Air quality*	*Water quality*
Examples of sub-components (stocks and flows)	*• Freshwater species diversity* *• Extent and number of invasive freshwater species* *• Stocks of freshwater resources by type* *• Extraction of freshwater resources by type*	*• Marine species diversity* *• Extent and number of invasive marine species* *• Stocks of marine resources by type* *• Extraction of marine resources by type*	*• Terrestrial species diversity* *• Extent and number of invasive terrestrial species* *• Stocks of terrestrial resources by type* *• Extraction of terrestrial resources by type*	*• Ambient concentrations of air pollutants, including greenhouse gases* *• Air pollution, including greenhouse gases, by source*	*• Ambient concentrations of water pollutants* *• Water pollution by source and type of pollutant* *• Water withdrawal by purpose*

It has been suggested above that the purpose of an environmental statistics framework is to guide the development of statistics to effectively inform public policy. The high-level objective of environmental policy has been suggested to be the maintenance of environmental quality or, more rigorously, the maintenance of the quality of key ecosystems. Human activities have been noted as one of the central determinants of this quality.

Such a focus on ecosystem quality as the objective of environmental policy and on the human role in influencing it is known as *ecosystem-based management*. Broadly speaking, this is an integrated management approach that considers entire ecosystems, linkages among them and the impacts on them of different human activities. Its aim is to sustain the quality of ecosystems so they continue to carry out the functions basic to human and non-human well-being. In the face of the dynamic nature of ecosystems and the variety of human activities that occur within them, ecosystem-based management's goal is not to fully understand ecosystems' inner workings nor to perfectly predict the consequences of management actions. Rather, its aim is to produce management systems that emphasize precaution and are adaptive in the face of the significant uncertainty about ecosystem dynamics.[11]

The focus of ecosystem-based management on understanding not just ecosystem dynamics but also the role of human activities in influencing them reinforces a point made earlier about the importance of coherence. If the environmental statistics framework is to provide policy makers with the information needed to implement modern management approaches like ecosystem-based management, it cannot ignore the need to ensure coherence between environmental and other statistics. This point has important implications for the way in which measurement should be carried out within the environmental statistics framework.

2.5 From concepts to measurement

The SNA was noted earlier as the statistical component of the framework for economic statistics. What is needed here is an environmental likeness of the SNA; that is, a system that will provide a consistent, systematic set of statistical principles, concepts and methods for the collection of environmental statistics. Again, it must be emphasized that it is not simply the SNA in environmental garb that is sought. Rather, it is a practical system to guide the collection of environmental statistics that emulates the best characteristics of the SNA.

The proposed framework is, in essence, a logical structure for classifying and organizing complex environmental information. By using the five key target variables as a starting point, one can then extend or adapt the framework to allow cross-links to other frameworks. These cross-links could simply be treated as another dimension of the environmental statistics framework. For example, the internationally-recognized *System of Environmental and Economic Accounts 2003 (SEEA)*, founded on the natural capital model, currently provides the best cross-link to the economic accounts. To the extent possible, the stocks and flow variables in the SEEA accounts follow the structure and the methods found in the SNA.

The framework proposed here is robust yet flexible enough to allow grouping of sub-component variables into broad categories based on other commonly-used analytical models, including pressure-state-response, drivers-impacts-mitigation-adaptation, etc. Such a framework ensures that the logic behind the identification of objectives, target variables and corresponding sub-components is consistent across various environmental policy issues.

[11] Kappel, Carrie V. and Rebecca G. Martone, 2006, "Ecosystem-based management." In: *Encyclopedia of Earth*, Eds. Cutler J. Cleveland, Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [Retrieved January 9, 2009, http://www.eoearth.org/article/Ecosystem-based_management]

2.6 Climate change: linking the framework to policy

Of particular interest to users and stakeholders, is, undoubtedly, the utility or practical application of such a framework. Could the framework, for example, be used to address environment-related policy issues? The remainder of this section demonstrates how the framework could be used for the statistical measurement and monitoring of a highly relevant, cross-cutting environmental issue: climate change.

In the policy context, one example of an analytical model for climate change is the grouping of the stock and flow variables into four broad categories, namely, drivers, impacts, mitigation and adaptation.

First, the framework provides a concrete reference point. The broad categories could then be defined based on this reference point. For instance, if maintaining environmental quality is the high-level policy objective in addressing the issue of climate change, then the above categories could be defined as:

- drivers – human activities that cause change in the key target variables;
- impacts – changes in the quality of the key target variables due to changes in the climate;
- mitigation – reducing the drivers; and
- adaptation – living with the impacts.

Although far from being complete, some examples are shown in the next table in terms of which parts of the system will be able to provide information and what kinds of data are pertinent and could be collected. The statistical requirements of other cross-cutting policy issues such as biodiversity could also be evaluated through the proposed framework.

Environmental issue: Climate Change						
High-level objective	*Maintenance of environmental quality*					
Key target variables	*Freshwater ecosystem quality*	*Marine ecosystem quality*	*Terrestrial ecosystem quality*	*Air quality*	*Water quality*
Drivers			*Land-use change*	*Greenhouse gas emissions*	
Impacts	*Water availability* *Biodiversity*	*Rising sea levels* *Shrinking glaciers* *Biodiversity*	*Deforestation* *Habitat loss* *Biodiversity*	*Average temperatures, rainfall pattern* *Meteorological systems*	*Water renewal and water balance*
Mitigation			*Reforestation* *Aforestation*	*Clean fuels* *Renewable and alternative energy*	
Adaptation	*Species mix* *Redirecting water systems, waterways,* *Alternative irrigation mechanisms*	*Species mix* *Restructuring seawalls* *Changes to navigation routes*	*Species mix* *Land use*	*Changes to infrastructure (e.g., structure of dwellings in Northern communities)* *Adjustments to agricultural cycles (e.g., planting and harvesting seasons)*	*Water use changes* *Altering water treatment systems*

3 Using the framework to assess gaps and weaknesses in existing environmental statistics

It was argued above that a central function of statistical frameworks is to identify the full scope of statistics needed to inform a given high-level policy objective. Identifying this scope serves two purposes. First, it defines the boundaries of the statistical system, clearly marking those variables that fall inside it and those that fall outside. Second, it provides a basis for assessing the gaps and weaknesses in existing statistics. This, in turn, can help set the direction for wisely investing scarce statistical resources in new data collection.

Two examples will be used to illustrate the use of the framework to assess gaps and weaknesses: statistics on water quality and statistics on air quality as it relate to climate change.

3.1 Assessing water quality statistics

The proposed framework includes water quality as one of its key target variables. In order to maintain water quality, a variety of policy objectives are pursued by public agencies today. These fall into three groups:

- policies that aim to reduce the discharge of pollutants into bodies of water;
- policies designed to manage the provision of municipal drinking water and the treatment of municipal wastewater; and
- policies designed to ensure that sufficient water is available where and when it is needed for economic and ecological functions.

Water quality is broken down into more specific component variables (stocks and flows) along these lines below.[12]

Key target variable	*Water quality*		
Broad policy objectives	***Reduce water pollution***	***Manage drinking water and wastewater***	***Assure availability of clean water***
Examples of component variables Quality rating:[1] ****excellent ***good **acceptable *poor n/a not available	*Ambient concentrations of water pollutants**	*Household behaviours related to perceived water quality (bottled water, water filtration)***	*Water availability*** *• rainfall by location*** *• streamflow***
	*Water pollution emissions by source and type of pollutant**	*Effluents in municipal wastewater** *Drinking water plant characteristics**	*Water use by purpose:** *•agriculture** *•industry*** *•households***

Adapted from: Deputy Ministers' Committee on Economic Prosperity, Environment and Energy. 2008. *Protecting Canada's Water Resources: Overview and Potential Priority Areas for Future Work.*
1. Excellent quality implies adherence to all of the quality parameters defined in Section 1. Good quality implies weakness in no more than two of the parameters. Acceptable quality implies weakness in up to four parameters. Poor quality implies general weakness across all of the parameters.

The sub-components presented in the above table have been chosen to illustrate the range of quality that exists in water quality statistics today. Notably, none of the component variables listed merits an "excellent" rating, meaning that none adheres fully to all the dimensions of quality given at the outset of this paper. Several of them merit "good" ratings however. Data on rainfall by location and streamflow, provided by the Meteorological Service of Environment Canada, are of good quality, although they could be made better by expanding their coverage.

[12] Note that each of the key target variables in the framework would be similarly broken down in a full elaboration of the framework.

Data on the industrial use of water, collected by Statistics Canada, are considered "acceptable. " Expanded industrial coverage could improve them. The time series for these data is also very short at the moment. Statistics Canada's data on agricultural water use are considered "poor," though a new survey being developed should improve them with time. Household water-use data, collected by Environment Canada, are "acceptable" but suffer from low survey response rates and methodological weaknesses. The result of all these weaknesses is that water-use data overall can only be rated as "poor. "

Even though none of the component variables of water quality is listed as "not available," there are, in fact, places where important data are incomplete. A good example is water pollution emissions by source and type of pollutant. The *National Pollutant Release Inventory* is the main source of these data at the moment. As noted, this inventory suffers from methodological problems affecting its relevance and comprehensiveness. These problems mean that there are sources of water pollution emissions for which no data exist. The result is a "poor "rating overall for this component.

3.2 Assessing air quality statistics as they relate to climate change

Key target variable	***Air quality – climate stability***		
Broad policy objectives	***Reduce greenhouse gas emissions***	***Increase sequestration of greenhouse gases***	***Adaptation to climate change***
Examples of component variables **Quality rating:[1]** ******excellent** *****good** ****acceptable** ***poor** **n/a not available**	*Emissions of greenhouse gases from industrial processes, agriculture, transportation, households**** *Greenhouse gas emissions from natural sources***	*Extent and quality of land cover***	*Investments to adapt to climate change n/a*
	*Energy use by type****		*Changing operating and living costs n/a*

1. Excellent quality implies adherence to all of the quality parameters defined in Section 1. Good quality implies weakness in no more than two of the parameters. Acceptable quality implies weakness in up to four parameters. Poor quality implies general weakness across all of the parameters.

A breakdown similar to that for water quality is shown above for air quality, specifically for the components related to climate change. Notable in this assessment are the "not available" ratings for statistics relating to climate change adaptation. Essentially nothing is known statistically about this set of issues.

Emissions statistics in support of policies to reduce greenhouse gas emissions are rated as "acceptable" to "good." Their main shortcoming, as noted in the earlier discussion of data quality, is their lack of coherence with other environmental data and, especially, with economic data. This restricts their usefulness in the kind of modeling often done to evaluate emissions abatement policies.

Assessments similar to the two above could be done for the other key target variables in the framework. If done, they would reveal gaps in existing environmental statistics across the full scope of the framework. In so doing, they would set out the areas in which investment is required to build an environmental statistics system reflecting the ideal defined by the framework.

4 Conclusion and next steps

The state of environmental information in Canada and around the world, by most accounts, falls short of that of social and, especially, economic information. Environmental statistics lack coherence with one another, let alone with other types of statistics. They tend to be incomplete and not consistent over time. This situation unnecessarily restricts the public and private capacity to carry out environmental policy. As the need to pursue these policies becomes more urgent, this situation will become increasingly problematic. More coherent and comprehensive environmental information of the sort offered by the framework proposed here will become more and more sought after.

Clearly, the challenge of creating high-quality environmental information is not insignificant. It is reasonable to question whether the framework proposed here, or any framework for that matter, is up to the challenge. Even if the framework itself was well crafted, improved statistics would flow from it only if it were well implemented.

Two features would help assure the quality of its implementation. One is simply the framework's comprehensiveness. Because it would lay out clearly what a complete set of environmental statistics should look like, it would be apparent to anyone interested whether a given implementation was comprehensive or not. The other is the motivation provided by the success of the SNA. Over many decades of effort, economic statisticians have established an enviable record of preparing comprehensive and coherent statistics on the economy. This should serve as an encouragement toward excellence for those who would implement the environmental framework.

The next steps involve two main activities surrounding the proposed framework. The first is a full discussion of the framework with stakeholders at both domestic and international levels. If the framework is successful in gaining traction and capturing the interest of stakeholders, then the next step would be to begin the development of the components, i.e., to fully flesh out the component variables and to define the concepts, classifications and organizing rules that will be used in implementing the framework.

One practical way of carrying out the discussion of the framework among stakeholders would be through a conference on environmental statistics. There the framework could be simultaneously presented to a wide audience and input sought from users of environmental statistics. Community building need not be restricted to the domestic scene. There are opportunities to seek comments and input on the framework and at the same time, to potentially improve the basis for internationally comparable environmental decision making. It is not only in Canada where there are weaknesses in environmental statistics. There is, as yet, no internationally agreed upon framework for them, especially at the conceptual level.

None of the above can be undertaken by any single department. Thus, one of the first actions following acceptance of the framework would be the formation of an interdepartmental steering committee tasked with fleshing it out more substantially and charting the course for its implementation.