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 with no consistent dissemination vehicles. Some parts of the patchwork are of good quality and reported regularly, 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. Economic theory has 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 macro economy 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 Experiences with different frameworks for environmental statistics

The term "framework" could be used to talk about any number of approaches to organizing all kinds of information. In many subject-matter areas, terms like conceptual, measurement or statistical "frameworks" are commonly used. In the environment domain, "framework" has also been used in conjunction with reporting structures—e.g., state of the environment or state of the community reporting.

Over the years, frameworks have been more or less successful, depending who developed them, their primary purpose, the information contained therein and who supported their development (users and stakeholders). This section provides some examples of the most widely-known environmental frameworks.

2.1 Stress-response

During the 1970s and 1980s, the need to more quickly respond to environmental concerns also led to the realization that there was a need to organize environmental datasets and statistics into a structured framework.

The United Nations Statistical office in collaboration with Statistics Canada began development of a general framework for environmental statistics in the 1970s. This work culminated with the introduction of the Stress Response Environment Statistics System (STRESS) framework.[1]

In the early 1990s, Statistics Canada developed the Population-Environment-Process framework (PEP) primarily to organize environmental-economic statistics presented in the *Human Activity and the Environment* statistical compendium. PEP put more importance on population and its impact on the environment compared to the STRESS framework. The overall model introduced the concept of stocks and flows between the population, the economy and the environment.

The Pressure-State-Response (PSR) framework is an adaptation of the STRESS framework and is still in use today internationally (UNEP and OECD). A derivative of the PSR framework is the Driving Force-Pressure-State-Response (DPSIR)

[1] The United Nations Statistical office published the Framework for the Development of Environmental Statistics (FDES) in 1984 based on the stress-response framework.

framework adopted by the European Environment Agency (EEA). DPSIR includes two additional, intermediary, categories to provide more details on the interactions between the pressures on the environment and the corresponding societal response to those pressures. Both PSR and DPSIR-based systems are also still used as frameworks for analysis by some government policy areas in Canada.

The frameworks briefly described above all share similar approaches and structures. For example, each framework attempts to organize and link human activities to their impact on the environment. Each one also includes the state of the environment at a particular point in time and society's response to its negative impact on the environment.

These frameworks also share common weaknesses. It is often difficult to distinguish human and natural stressors on the environment, and even more challenging to link a particular stressor to a specific response. In a multi-component system framework, it may be impossible to establish cause and effect. In the natural world, each process and state influences and is influenced, making it difficult to separate out the pressure, the state and the response. Public policy and decision makers may also have difficulty interpreting the results from a multi-component framework that can result in misclassifications and improper conclusions being drawn from the results.[2]

The PSR-type frameworks also tend to focus on the harmful aspects of the human-ecosystem relationship and do not distinguish between beneficial and harmful stressors and impacts. For example, a flooded agricultural field may have harmful economic consequences for the farmer, but may also replenish the nutrients in the soil while a forest fire will destroy habitat and property, but may in fact be a prime source of regeneration and renewal. However, human activities can also be beneficial to an ecosystem and ecosystems, contribute to human well-being and are the foundation of our economic system. Such relationships are not well captured in a PSR system.[3]

2.2 Natural capital

The natural capital approach is a means for identifying and quantifying natural resources and associated ecosystem goods and services.[4] The approach follows the notion of capital which refers to a stock of resources used to produce goods and services. The service derived from a capital stock can be used independently, or in

[2] A.R. Berger and R.A. Hodge, *Natural Change in the Environment: A Challenge to the Pressure-State-Response Concept*, 1977.
[3] Ibid.
[4] International Institute for Sustainable Development, *The Natural Capital Approach: A Concept Paper*, March 2008, Winnipeg, http://www.iisd.org/pdf/2008/natural_capital_approach.pdf, accessed October 25, 2009.

conjunction with services from other capital stocks to produce a flow of services that can transform materials used in the production of other goods.

Natural capital consists of the stock of natural resources, the land and the ecosystems upon which the economy, and in some instances life itself, depends. Natural capital is an essential factor in economic and social development. Businesses and individuals rely on this natural capital to provide the raw materials that are basic materials from which goods, buildings and infrastructure are built. They also rely upon it to provide the energy that is needed to heat and light buildings and power vehicles and equipment. Natural capital provides other essential environmental services ranging from protection against UV solar radiation to the assimilation of pollutants.
Like all forms of capital, however, it is limited in supply and is subject to depletion and degradation as a result of human use.

There has been significant progress in the adoption and implementation of the natural capital approach, particularly in the valuation of a country's natural resource assets and in tracking material and energy flows throughout the economy. The concept of natural capital is recognized in the System of Integrated Environment and Economic Accounts (SEEA 2003) and is described as the "capital approach to sustainable development."[5] Within the SEEA, economic accounting principles are used to provide a measurement framework for natural capital.

The main challenge, however, in the implementation of an environmental accounting framework based on natural capital lies in the availability and quality of the environmental datasets required to carry out the statistical measurement and estimation. For example, difficulties in obtaining some basic environmental statistics needed to complete the measurement of an environmental accounting framework has been a common challenge faced by analysts working in this area.

2.3 Ecosystems and ecosystem services

Ecosystems are collections of living organisms, decaying organic matter and the inanimate (or abiotic) environment (soil, rocks, water, gases) within which the organisms live. Ecosystems are 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.

The underlying principle behind the ecosystems approach is the move away from an emphasis on individual elements that comprise an ecosystem to a perspective that is

[5] United Nations Statistics Division, Handbook of National Accounting: Integrated Environmental and Economic Accounting, 2003, http://unstats.un.org/unsd/envaccounting/seea.asp, accessed October 26, 2009

more comprehensive - a holistic approach.[6] Further elaboration of the rationale behind this integrated approach is provided in the Millenium Ecosystem Assessment document by way of an analogy to the economic framework: "...decision-makers would not make a decision about financial policy in a country without examining the condition of the economic system, since information on the economy of a single sector such as manufacturing would be insufficient. The same applies to ecosystems: decisions can be improved by considering the interactions among the parts of the system..."[7]

The ecosystems framework has gained support in many science-based departments in Canada. For example, a collaborative project undertaken by a number of federal agencies in cooperation with provincial and territorial governments, established a common ecological framework for Canada, with the focus on three priority levels of stratification, namely ecozones, ecoregions, and ecodistricts.[8] Fisheries and Oceans Canada's *New Ecosystem Science Framework* articulated the approach in support of integrated management of diverse human activities in aquatic ecosystems such as fishing, aquaculture, transportation, oil and gas exploration, etc.[9]

One of the biggest challenges in the ecosystems approach is in ensuring effective implementation. It requires a significant move away from traditional systems, processes and business models. More importantly, it necessitates improved interaction and coordination among data suppliers, clients and stakeholders. Given the cross-cutting nature of many environmental issues, increased level of cooperation would also be required across government departments and agencies.

2.4 Other frameworks and approaches

There are a number of other approaches often used by various agencies and departments to organize and report statistical information. Such approaches have also been referred to as "frameworks." In many instances, these are not really frameworks but common methods or practices for analysing and presenting the available information relevant to a particular topic. Examples include:

- issues framework: focuses on specific environmental issues or controversies;

[6] Environment Canada, Agriculture and Agri-Food Canada, *A National Ecological Framework for Canada*, 1999, Ottawa, http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html, accessed October 25, 2009.

[7] Millenium Ecosystem Assessment, *Ecosystems and Human Well-being: A Framework for Assessment*, 2005, http://www.millenniumassessment.org/en/Framework.aspx, accessed October 25, 2009.

[8] Environment Canada, Agriculture and Agri-Food Canada, *A National Ecological Framework for Canada*, 1999, Ottawa, http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html, accessed October 25, 2009.

[9] Fisheries and Oceans Canada, *A New Ecosystem Science Framework in Support of Integrated Management*, 2007, Ottawa, http://www.dfo-mpo.gc.ca/science/Publications/ecosystem/index-eng.htm, accessed October 25, 2009.

- resource sector framework : focuses on the conditions and trends found in the resource sectors (forestry, mining, energy and agriculture);
- environmental media framework: describes the condition or state of environmental media such as air, water, land, flora and fauna.[10]

3 Environmental statistics and quality standards for official statistics

3.1 Elements 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 these elements to identify their main strengths as well as deficiencies.

Statistics Canada is not the only source of environmental statistics. There are many collectors of environmental data. In fact, 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.[11]

- **Relevance –** Good statistics shed light on issues that are important to users.

- **Accuracy** – Good statistics reflect as closely as possible the actual values of the variables they are intended to measure. They reflect the full universe of phenomena relevant to the measurement of a given variable. They also capture all required variables in order to shed light on a given issue.

- **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.

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[10] University of Toronto, Department of Geography and Program in Planning, Local SOE and SOC Reporting in Canada, http://faculty.geog.utoronto.ca/MacLaren/soesoc/Website/Definitions.htm, accessed August 7, 2009.

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

- **Interpretability** – Good statistics are based on professionally-accepted methods that are transparent to anyone using them. Transparency is essential if independent verification of soundness is to be possible. Availability of metadata and supplementary information necessary to interpret and appropriately utilize the statistical information are also key attributes 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 artefacts. 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.

3.2 Environmental statistics and quality standards

Do existing environmental statistics measure up to quality standards for official statistics?

Given that environmental datasets are oftentimes collected for purposes other than statistical monitoring, it is not surprising to find that lack of **methodological rigour** tends to be a common problem, especially in sample design. For example, the sampling design of freshwater quality monitoring networks in Canada is not representative of the whole country because they have not originally been intended as mechanisms for statistical data collection.

The **accuracy** of environmental data may be compromised by a variety of factors, including methodology, reporting error and scientific uncertainty. Currently published national forest statistics, for example, are less accurate than they might be because they have been derived from provincial statistics that are not all collected at the same time or in the same way. The national forest inventory for 2001 (CanFI) 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 huge 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*[12] on

[12] Environment Canada, National Inventory Report, http://www.ec.gc.ca/pdb/ghg/ghg_home_e.cfm, accessed October 1, 2009.

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[13] and Health Canada, presents indicators that are two years old at the time of publication.

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 quite cumbersome to access. Not only must users know where to go to access a particular set of statistics, but they must accustom themselves with numerous dissemination channels.

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 important 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.

Industrial facilities are important sources of toxic pollutant emissions, but not the only ones. Households, governments and other 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.

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

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

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.[14]

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 relatively 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. The greenhouse gas inventory uses another industrial grouping in which five manufacturing industries are uniquely identified. Having these diverse groupings and classifications makes it quite a challenge for data users to properly align and analyze environmental information, sometimes even from data collected and produced within the same department.

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. Inherent differences in the overall purpose, scope and in underlying data sources are some of the key reasons.

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,

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[14] Fisheries and Oceans Canada, *Framework for Statistical Integration of Fisheries Information, Draft Requirements Analysis Report (draft)*, 2007.

"Canada's economic statistics in the 1920s offered little real insight into [the economy's] workings."[15] In 1931, the head of the statistical bureau, Robert Coats, admitted that "statistics [on national wealth] are suggestive and indicative rather than strictly accurate…".[16] 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.

4 Proposed approach towards developing a framework based on ecosystems

4.1 Rationale

Just as the variables associated with economic production and income, so too must those associated with the highest environmental objective need to be defined in the environmental statistics framework. The discussion in Section 2 illustrates past experiences and current approaches, their strengths and weaknesses. What value does this framework add over other frameworks?

First, the proposed approach is founded on the rationale that the ecosystems approach is multi-dimensional. It recognizes the complex relationships and linkages among various parts of the structure as information needs are systematically analyzed.

Second, unlike the ecosystems framework described in Section 2 which has been supported mainly by science sectors in policy department, this new framework aims to bridge the gap between science and socio-economic/policy analysis. A primary objective here, for instance, is to provide a means of transforming scientific and research data into official statistics that are relevant for socio-economic research and policy analysis.

Third, the proposed framework brings to the forefront the role of statistical quality in ensuring reliable information for use by decision makers and the general public. Transforming scientific data to official statistics would require (1) comprehensive evaluation of environmental datasets in terms of statistical quality elements; (2) identification of important gaps (missing information; low quality datasets, etc.); and (3) priority setting and resource allocation. Improved quality of basic environmental statistics would also complement related efforts such as efforts to improve the valuation measures for natural resources and other natural capital.

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

[16] 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.*

And fourth, the national statistical agency's involvement through this framework will also establish and strengthen the dissemination mechanisms, i.e., regular reporting of environmental statistics and integrated environmental datasets.

4.2 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 "measuring and monitoring 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 focused around environmental quality. Indeed, Canada's most important environmental law, the *Canadian Environment Protection Act*, cites this objective directly in its preamble:[17]

> "…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. Note, however, that given the complexity of environmental issues, it is important to recognize the crosswalks and linkages with other frameworks (Section 4.5).

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

4.3 Specifying the target variables

Key target variables are the most important variables that need to be taken into account 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 objective of nearly all economic statistical efforts.

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 measuring and monitoring environmental quality be defined here.

One could envision "ecosystems" in the proposed environmental statistics framework as the equivalent of the "elements of the economic production" in the SNA. The discussion in the previous sections suggests strongly that ecosystems would be appropriate target variables. 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. Thus, the somewhat abstract high-level objective can be thought of in more rigorous terms as the need to measure and monitor the quality of ecosystems.

The proposed set of key target variables is illustrated below (Table 1).[18] 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.

Table 1 High-level Objective: Measuring and Monitoring Environmental Quality

High-level objective	Measure and monitor environmental quality	
Key target variables	Marine ecosystems	Terrestrial ecosystems

Marine and terrestrial ecosystems could be further broken down into their respective biomes:

Table 2 Key Target Variable: Marine Ecosystems

High-level objective and key target variable	Measure and monitor marine ecosystems	
Biomes	Open Ocean	Coastal (estuaries, seagrass/algae beds, coral reefs, shelf)

[18] Nature, Volume 387, "The value of the world's ecosystem services and natural capital," May 1997.

Table 3 Key Target Variable: Terrestrial Ecosystems

High-level objective and key target variable	Measure and monitor terrestrial ecosystems								
Biomes	Forest	Grass / rangeland	Wetlands	Lakes / rivers	Desert	Tundra	Ice / Rock	Cropland	Urban

Human activities are, arguably, the most significant drivers to changes in these target variables. In numerous instances, such changes have resulted in the environmental issues and problems that must be dealt with today. Over the years, for example, land-use change has altered many terrestrial and even marine ecosystems (Tables 2 and 3). Statistical monitoring of such changes requires information that would address a wide range of inter-related questions and issues, including: conversion of cropland to settled and/or urban areas; conversion of wetlands, grass/rangelands to cropland; increased use of the forest for commercial activities; and impacts on lakes and rivers.

The objective here is not to make all the information fit into the boxes listed in the preceding tables. Rather, they should be used as reference to guide the analysis of statistical requirements.

4.4 Identifying sub-component variables

Ecosystems are highly dynamic, not static. They undergo constant change from season to season and year to year. *Sub-component variables* relate to the dynamic processes that bring about ecosystem change. These include the interactions between living organisms (animals, plants, micro-organisms) and components of the physical environment (soil, water, air, nutrients).

In this context, stock or state variables alone are insufficient. Flows between ecosystems and the human sphere, for example, are equally important. In many parts of the world today, human-induced flows of matter and energy are the dominant forces determining ecosystem quality. The relevant stocks and flows sub-components will ultimately be the variables to be measured and monitored in the statistical system.

Ecosystem quality is a complex, evolving topic. Oftentimes, statistical requirements are analysed from the perspective of individual policy or research activities and focus only on sub-components that are closely linked to those activities. Such approaches have resulted in overlaps and duplication of efforts in some areas while leaving significant gaps in others. Although elaborating a complete list of sub-components is nearly impossible, it is possible to follow an integrated approach to identifying the relevant sub-component variables for a given issue.

Table 4 extends the illustration in the previous section by using a specific example of an environmental issue. Water quality is a high priority environmental issue both in Canada and around the world. In the context of the high-level objective proposed in Table 1, one could envision "measuring and monitoring the sustainability of water resources" as the high-level objective related to water quality.

Changes in marine and terrestrial ecosystems could either improve or intensify water quality issues, and vice versa. What stock and flow variables are required to track these changes, in support of the high-level objective (measuring and monitoring the sustainability of water resources)? Table 4 lists some examples of stock and flow data that could be used to track overall water quality in Canada. These diverse sets of data illustrate the complex and multi-dimensional aspects of a given environmental issue.

Among the examples in Table 4, nutrient and chemical loadings in water bodies and other water sources could be viewed as those sub-component variables that directly relate to the issue of water quality. However, the proposed framework also aims to be explicit about other inter-related sub-components. These could include information on activities by various sectors of the economy and accompanying pollutant releases; changes to species mix; and the state of wetlands, coral reefs, estuaries, etc.

Table 4 Examples of sub-component variables

Environmental issue: Water Quality		
High-level objective	Measure and monitor environmental quality *Sustainability of water resources*	
Key target variables	Marine ecosystems	Terrestrial ecosystems
Some examples of sub-component variables (stocks and flow data)	• maritime economic activities • non-market activities in oceans and coastal/tidal areas • coral reef cover, density, conditions, etc. • species mix • nutrient and chemical loadings in ocean and coastal/tidal waters • pollutant releases and effluents • pollution abatement, control, prevention activities • invasive alien species; species at risk	• economic activities • non-market activities • nutrient and chemical loadings in lakes, rivers, other freshwater sources • pollutant releases and effluents • wetland cover and condition • pollution abatement, control, prevention activities • species mix • invasive alien species • species at risk

4.5 Crosswalks and linkages

Understanding ecosystem dynamics and 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.

The environmental statistics framework cannot exist in a vacuum. Part of its value added is in enabling the links to existing frameworks that address other high-level policy objectives and strategic outcomes: strong economic growth; innovative and knowledge-based economy; Canada's safety and security; prosperity through global commerce, etc.[19]

In Table 4, there are other examples of sub-component variables that are relevant to water quality issues but do not directly relate to the high-level objective of measuring and monitoring environmental quality. The development and deployment of environmental technologies is one example. It could be argued that the main objective for these activities is to increase innovation, improve the competitiveness of Canadian businesses and promote economic growth. Positive impacts on environmental quality could be viewed as an auxiliary outcome. A similar line of reasoning could be used in the case of adaptation activities, i.e., adjusting or living with the impacts of environmental issues. These activities are undertaken primarily to protect the safety and security of Canadians.

Recognizing the distinctions outlined above has important implications for the way in which measurement should be carried out within the environmental statistics framework. The idea is not to simply design one structure around all possible dimensions and datasets without evaluating the relationships between the components, thereby, rendering the framework meaningless. The idea is to layout all relevant components, to identify inter-relationships and systematically delineate the scope of environmental framework activities, and to decide where accountabilities will reside.

5 From concepts to measurement

5.1 Operationalizing the proposed framework

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.

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[19] Treasury Board of Canada, "Whole-of-Government Framework," http://www.tbs-sct.gc.ca/ppg-cpr/framework-cadre-eng.aspx?Rt=1039, accessed October 19, 2009.

Ideally, all data for the sub-component variables would be collected, estimated, weighted and aggregated 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 reliable 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, the utility of the proposed framework is in facilitating the transformation of scientific and research data into official statistics via a logical approach and structure for classifying and organizing complex environmental information. By populating various parts of the framework with the relevant high quality datasets, policy makers could, themselves, analyse the tradeoffs and make decisions based on the statistics and indicators presented.

5.2 Using the framework to assess gaps and identify priorities

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.

In Section 4, it was noted that data on nutrient and chemical loadings in water bodies and other water sources would most directly inform the high-level objective of measuring and monitoring water quality in Canada. The localized nature of stocks, flows and their impacts suggest the importance of spatially-detailed measurement in environmental statistics.[20] This is in addition to the sectoral and temporal evaluation of existing datasets, i.e., availability of information by various economic sectors and comparability of datasets overtime.

Following the discussion in Section 4, the framework approach could be used to identify data sources, assess gaps and prioritize statistical activities as they relate to stocks and flows of nutrient and chemical loadings in water bodies and other water sources. More specifically, how do the existing datasets measure up to the elements of statistical quality? To illustrate, Table 5 presents a summary of findings from a similar exercise conducted by Statistics Canada during the development of the

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

freshwater quality indicator.[21] Undoubtedly, the table only covers a relatively small portion of the wide range of statistical requirements to fully meet the high-level objective. However, a similar approach could be undertaken to evaluate other sub-component variables identified in the framework. 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.

Table 5 Key findings from preliminary assessment of environmental datasets: development of freshwater quality indicator

Environmental issue: Water Quality	
High-level objective	Measure and monitor environmental quality *Sustainability of water resources*
Key target variables	Terrestrial ecosystems
	Sub-component variables: nutrient and chemical loadings in lakes, rivers, other freshwater sources Data sources: Canada's freshwater quality monitoring programs Basic environmental datasets: ambient concentrations of substances in the aquatic environment, including nutrients, metals, organic compounds and other parameters, from which the water quality index is calculated
Relevance	• datasets were found to be the most detailed sets of information available and therefore were highly relevant to the development of a national freshwater quality indicator.
Accuracy	• issue of methodological soundness: current collection of monitoring networks was not designed to be representative of Canada's hydrological network; they respond to specific federal and provincial monitoring program needs • reliability: each monitoring program follows standardized methods for sample collection in the field to ensure reliability and quality assurance of collected data
Timeliness	• sampling frequencies differ among networks according to program needs, resource constraints and accessibility of monitoring sites
Accessibility	• freshwater quality monitoring programs are managed by federal departments, provincial departments or under federal-provincial agreements; there was no central repository of all required information.
Interpretability	• datasets come in various formats and structure; variability in the quality of available metadata
Coherence	• each program monitors a different array of parameters designed to suit the program's objectives and resource constraints

[21] Statistics Canada, Freshwater Quality Indicator, http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5128&lang=en&db=imdb&adm=8&dis=2, accessed October 21, 2009.

The figure below illustrates how the assessment in Table 5 links to the example presented in the Section 4. One can envision a similar exercise being conducted for the other sub-component variables identified in this framework.

Environmental issue: Water Quality		
High-level objective	Measure and monitor environmental quality *Sustainability of water resources*	
Key target variables	Marine ecosystems	Terrestrial ecosystems
Some examples of sub-component variables (stocks and flow data)	• maritime economic activities • non-market activities in oceans and coastal/tidal areas • coral reef cover, density, conditions, etc. • species mix • nutrient and chemical loadings in ocean and coastal/tidal waters • pollutant releases and effluents • pollution abatement, control, prevention activities • invasive alien species • species at risk	• economic activities • non-market activities • nutrient and chemical loadings in lakes, rivers, other freshwater sources • pollutant releases and effluents • wetland cover and condition • pollution abatement, control, prevention activities • species mix • invasive alien species • species at risk

Freshwater Quality Indicator: Assessment of existing datasets: ambient concentration of substances in aquatic environment including nutrients (Table 5).

6 Linking the framework to policy

Working through the example of a policy issue (water quality) in the previous sections demonstrates a practical application of the proposed framework. It presents a structure for organizing the information. More importantly, it emphasizes the logic behind the approach.

This section discusses how the framework could be used for the statistical measurement and monitoring of another 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. The framework provides a concrete reference point. The broad categories could then be defined based on this reference point:

- 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 Table 6 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. This illustration also provides some insights on the interpretability of the organized information.

Table 6 Linking the framework to policy: climate change illustration

Environmental issue: Climate Change		
High-level objective	Measure and monitor environmental quality	
Key target variables	Marine ecosystems	Terrestrial ecosystems
Some examples of sub-component variables (stocks and flows)	• greenhouse gas emissions (driver) • glacier mass balance (impact) • permafrost (impact) • coastal monitoring (impact) • sea level rise (impact) • water yield (impact) • species mix (impact) • clean fuels, renewable and alternative energy (mitigation) • fuel switching (mitigation) • navigation routes (adaptation) • water ways and water systems (adaptation) • seawall restructuring (adaptation)	• land-use change (driver) • greenhouse gas emissions (driver) • snow cover (impact) • water yield (impact) • leaf cover, vegetation greenness (impact) • land cover (impact) • lake/river ice seasonality (impact) • average temperatures, rainfall (impact) • species mix (impact) • reforestation, aforestation (mitigation) • clean fuels, renewable and alternative energy (mitigation) • fuel switching (mitigation) • dwelling structures in Northern communities (adaptation) • water treatment systems (adaptation) • irrigation systems (adaptation) • agricultural cycles (adaptation)

Do the sub-component variables support the high-level objective? In the case of climate change, the stocks and flow variables related to drivers and biophysical impacts fit the overall objective of measuring and monitoring environmental quality. Looking at adaptation, however, the sub-component variables do not necessarily address the same high level objective. Many of these variables pertain instead to actions that support related but different high-level objectives, i.e., strengthening the safety and security of Canadians and ensuring Canada's competitiveness and economic growth. The objective of enhancing resilience to a changing climate is quite distinct from monitoring environmental quality. The main point here is that ability to make such a distinction increases the utility of the framework in assigning accountabilities and identifying priorities especially in light of the cross-cutting policy context.

7 Conclusion

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. It has also resulted in duplication of efforts among environmental data collectors and providers in certain areas while leaving significant data gaps in other areas. 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, this is a long-term undertaking, and 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 coherence and 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.