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ENVIRONMENTAL INDICATOR RESEARCH: A LITERATURE REVIEW FOR STATE OF THE ENVIRONMENT REPORTING

(DRAFT)

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1. INTRODUCTION

The development of a set of environmental indicators which represents the total array of desirable and available data for state of the environment (SOE) reporting is a long-term goal of Environment Canada's SOE Reporting program. The concept of indicators is well established, but rarely has the literature been reviewed from the standpoint of information needs in SOE reporting. This study was therefore commissioned as an initial stage in the development of an appropriate set of environmental indicators for agencies which will be involved in SOE data collection and analysis.

The review provides a documented assessment of the state of the art of indicator research and application, with a particular focus on North America, Europe and by international organizations. Research documents judged to be most useful are included in the Annotated Bibliography.

1.1 Definitions

There are several different types of measures of environmental quality which may in a general sense be called environmental indicators. These range from specific quantitative measures of the condition of environmental media (e.g. sulphur dioxide in an air sample) to broad indices which combine a mass of data in a single measure of the supposed quality of the environment.

A number of technical terms have been developed to cover this range of environmental quality measures:

Environmental Indicator: "An environmental parameter, theoretical concept, or aggregation of data that provides a surrogate representation of some aspect of environmental quality or condition" (Council on Environmental Quality, 1984).

"A tool to:

1) monitor the state of the...environment and its evolution over time
2) evaluate the performance of projects, programmes and plans;
3) communicate with the public and between decision makers;
4) identify areas for action;
5) help in the development of future planning procedures

(Organization for Economic Cooperation and Development, 1978).

Environmental Index: "A single number derived from two or more indicators" (Ott, 1978).

In some cases an index reduces a very large amount of unrelated data to a single measure of the purported quality of the environment (see Inhaber, no date).

Environmental Quality Profile: "A number of indicators presented at the same time [but not aggregated together in a single number] to give a picture of environmental conditions" (Ott, 1978).

SOE reports are a form of environmental quality profile.

Quality of Life Indicators: "A set of indicators which attempt to encompass a number of relevant factors comprising quality of life" (Washington Environmental Research Center, 1972).

For a detailed discussion of the different approaches for developing indices, see Ott (1978) or Inhaber (1976).

2. THE NATURE OF ENVIRONMENTAL INDICATOR LITERATURE

To aid the development of a comprehensive set of state of the environment indicators for Canada, this review groups the literature into two general categories:

1) Literature about environmental indicator development and application.

2) State of the environment reports, illustrating the use of different indicators in a specific SOE context.

There is a large body of research in the first category. This literature ranges from broad, conceptual reviews to very specific, technical studies. The conceptual studies commonly include discussion of advantages and disadvantages of different approaches to indicator development. The technical literature primarily involves narrowly-focussed studies about one or a few specific indicators. There have been thousands of such studies in the past two decades, commonly dealing with particular plant or animal species as indicators of air or water pollution.

This review concentrates on the SOE literature and the broader scope indicator research, since these provide the conceptual basis for applying the large volume of research data in an SOE reporting context. It is not practical to provide an exhaustive reiew of the technical literature here. Instead, a number of references are provided as examples of the range and types of research being conducted, with particular attention to studies considered most useful for SOE reporting.

3. USE OF INDICATORS IN STATE OF THE ENVIRONMENT REPORTS

The 1986 State of the Environment Report for Canada (Bird and Rapport, 1986) and the statistical compendium Human Activity and the Environment (Statistics Canada, 1986) together comprise one of the most comprehensive and detailed applications of indicators in SOE reporting. The range and types of indicators used in these reports can be seen in the table of contents from the latter (see Appendix 1). Statistics Canada (1986) organizes indicators by five categories: harvesting, extraction and depletion of non-renewable resources, environmental restructuring, generation of waste residuals, and biotic state.

A number of other countries have used the same or very similar indicators to the ones included in the 1986 Canadian reports. Several of the studies reviewed here however include indicators which were not used in the Canadian reports as well as distinctly different approaches to presenting similar data. Appendix 2 lists such indicators with the appropriate references.

The annual U.S. Environmental Quality series is one of the longest-running SOE reporting programs in the world. Its large and comprehensive reports provide many examples of the use of indicators in an SOE context. A review of the entire series would provide a good history of the development of indicators in SOE reporting (see Council on Environmental Quality (1984), pages 439-443, for a synopsis). Appendix 2 includes selected indicators from the series.

In 1981, the Council on Environmental Quality published Environmental Trends, an environmental data compendium which measures changes associated with economic welfare, human health, recreational opportunity, aesthetic appreciation, concern for ecological diversity and stability. The report is intended to help in developing a consensus on the most important measures of environmental quality, by obtaining new environmental data and highlighting information gaps (Council on Environmental Quality, 1981). The Council expects to publish an updated version of Environmental Trends in the spring of 1989 (Council on Environmental Quality, 1989). The report should be an important addition to the SOE literature. Its authors intend it to provide "the best available data on environmental health" (Council on Environmental Quality, 1984).

The State of the World reports of the Worldwatch Institute are a noteworthy departure from the norm of SOE indicators as measures of the condition of environmental media. Their approach is to measure "progress toward a sustainability society" based on a set of environmental sustainability measures applied to socioeconomic activity. Subjects which have been included in the series include nuclear power, urbanization, agriculture, water management, energy efficiency, conserving biologival diversity, recycling, and protecting forests (Brown et al., 1984, 1985 and 1987). While these international reports make limited use of Canadian data, the approach taken in a number of the sustainability indicators could be adapted for use in this country (see Appendix 2).

Liverman et al. (1988) address the sustainable development indicator concept as applied by (Brown et al., 1984, 1985 and 1987). They describe the state of the art and suggest areas for improvement.

The State of the Environment reports of the U.S. Conservation Foundation include a broad range of indicators in a variety of applications. These measures range from discrete indicators of the quality of media such as air, water and wildlife to measures of the environmental impact of socio-economic activity (similar to the sustainability measures used by Brown et al., 1984, 1985 and 1987). The Foundation's reports provide several examples of measures which combine levels of environmental hazards associated with socio-economic activity. A example here is a graph showing a person's expected exposure levels to respirable particles in the course of a typical work day (The Conservation Foundation, 1987).

The report World Resources 1987 of the International Institute for Environment and Development and World Resources Institute includes measures which are a good integration of the use or amount of toxic materials and associated levels of risk. Examples include a table of sources and possible concentrations of selected indoor air pollutants and a table showing ozone concentrations at which certain plants suffer yield losses (International Institute for Environment and Development and World Resources Institute, 1987). These two examples in particular should be adaptable to SOE reporting in Canada (see also Appendix 2).

The OECD Environmental Data Compendium 1987 includes Canadian material in a set of tables presenting a variety of international indicator statistics within three basic categories: the state of the environment, pressures on the environment, and managing the environment. The approach is similar to that of the stress-response system used in the 1986 Canadian SOE report (Bird and Rapport, 1986; Organization for Economic Cooperation and Development, 1987).

Noteworthy indicators used in the OECD report tables include: the composition of municipal waste in selected countries, population living in areas exposed to various levels of daytime road traffic noise, total energy requirements by unit of gross domestic product, and public research and development expenditures for environmental protection. (Organization for Economic Cooperation and Development, 1987). See Appendix 2.

Environment Statistics in Europe and North America, prepared by the Economic Commission for Europe is a two-part SOE report. The first part is a compilation of environmental data for Europe and North America in the areas of: environmental media; generation and treatment of waste residuals; topical issues--including noise, urban air pollution and forest damage; climate; and miscellaneous demographic and economic statistics. The second part is an SOE case study for the Baltic Sea drainage area.

Part 1 includes some informative indicators related to the environmental implications of resource management. Two examples are: a table of the results of waste water treatment in selected countries, comparing the quality of influents and effluents, using figures for BOD, total phosphorus, mercury and PCB's; and a table comparing different countries in the area of intensity of forest harvest. The latter indicator is expressed as a ratio of fellings to net annual increment (a measure of tree growth).

Examples from Part 2, the SOE case study, are: a table on the impact of dredging along the Finnish coast, showing the levels of certain heavy metals at various locations in comparison with a set of "clean" and "polluted" reference areas; and tables showing levels of trace metals and chlorinated compounds in tissues of animals at different trophic levels (United Nations Economic Commission for Europe, 1987).

4. ENVIRONMENTAL INDICATOR LITERATURE

The general literature about approaches and methods of indicator development and application will be described here from four different perspectives:

- requirements of good indicators
- problems and limitations
- the state of the art
- what is needed to improve the art of indicator development

The more specific technical literature will be reviewed from the standpoint of:

- examples of indicator types
- applications for particular indicators
- advantages and disadvantages of different approaches
- areas for further research and development

4.1 Requirements of Good Indicators

The 1984 Environmental Quality report of the U.S. Council on Environmental Quality provides an insightful discussion of the use of indicators in SOE reporting. The report lists desirable characteristics for indicators:

1) They should be easily understood by the layman.

2) They should be grounded in scientific understanding.

3) They should portray ranges of environmental quality that reflect "normal" conditions, a "problem threshold", and a category that portends serious consequences.

4) They should reflect meaningful variation in environmental quality.

5) They should be easy to calculate from a variety of network sources.

6) They should allow for both aggregration of data to display national trends in environmental quality and for disaggregation to show local/regional conditions.

7) They should be acceptable in terms of cost.

Ott (1978) presents the desired characteristics of environmental indicators and indices:

> Ideally, an index or an indicator is a means devised to reduce a large quantity of data down to its simplest form, retaining essential meaning for the questions that are being asked of the data. In short, an index is designed to simplify. In the process of simplification, of course, some information is lost. Hopefully, if the index is designed properly, the lost information will not seriously distort the answer to the question.

He lists 21 characteristics of an ideal water quality index:

1. be developed from a logical scientific rationale or procedure

2. strike a reasonable balance between oversimplification and technical complexity

3. be sensitive to small changes in water quality

4. avoid eclipsing

5. avoid ambiguity

6. avoid nonlinearity in the aggregation process

7. be dimensionless

8. employ a clearly defined range

9. impart an understanding of the significance of the data

10. be relatively easy to apply

11. easily accomodate new variables

12. permit probabalistic interpretations to be made

13. include variables that are widely and routinely measured

14. include toxic substances

15. include variables that have clear effects on aquatic life, recreational use, or both

16. be tested in a number of geographical areas

17. show reasonable agreement with expert opinion

18. show reasonable agreement with biological measures of water quality

19. be compatible with water quality standards

20. include guidance on how to handle missing values

21. clearly document the limitations.

Wessels Boer (1983) suggests some additional qualities of a good indicator in his criteria for biological monitoring programs:

- the use of the results of the monitoring programmes should not excessively depend on irrelevant environmental changes, like local changes of the weather;

- the cost of the measurements and of the monitoring programme as a whole should correspond to the importance of the results;

- the sensitivity of the measurements should correspond to the accuracy required to support policy decisions;

- the results of the monitoring programme should relate to established norms i.e. the results should be evaluated to allow a classification into categories permissible/not permissible or desired/not desired.

Stokes and Piekarz (1987) report the results of a Toronto workshop which addressed selection criteria for indicators which could be used in SOE reporting. The workshop proceedings and case studies included in the publication provide a useful Canadian perspective on the desirable characteristics of indicators.

4.2 Problems and Limitations in Indicator Development and Application

The Council on Environmental Quality (1984) states that although numerous measures of environmental change have been developed by ecologists, many are based on inadequately tested assumptions, and most have relatively poor precision with limited potential for improvement. The council says that much more can be done to increase the usefulness of existing information by more careful selection, display, and annotation of data collected by government agencies. The Council cites difficulties in development and use of environmental indices: lack of consensus on index design and weighting of factors; serious concerns about the limitations of data once they are "hidden" in indices; and the losses of information associated with the mathematics of index calculation.

Ott (1978) describes a key concern about environmental indices: information loss in the simplification process made possible by the index. These who are very familiar with the complexity of environmental measurements tend to view the potential distortion of an index as unacceptable. By contrast, those who are removed from the measurement process are more willing to accept the distortion for the sake of a snapshot picture of environmental quality.

Ott (1978) questions the accuracy of quality of life indicators as described by the Washington Environmental Research Centre (1972), stating that attempts to apply the concept have suffered from a lack of data and methodological problems. He states that comparisons of environmental conditions in different regions is a considerable technical challenge.

Zonneveld (1983) describes limitations of biological indicators, a key concern being the complexity of factors which can determine presence or absence of a particular "indicator" species in a given location.

Coate and Mason (1977) describe two basic problems which have prevented the adoption of a uniform national system of environmental indicators in the U.S.: 1) lack of consistent nationwide environmental data of sufficient quality and 2) the lack of consensus on the most appropriate approach for environmental indices of water quality, air quality, and for other environmental concerns. They state that part of the problem is "a preoccupation with a level of rigor and preciseness that is not needed for either public information purposes or for the bulk of the program evaluation efforts that must be faced."

In describing a national environmental quality index developed for Canada, Inhaber (no date) stresses that "any index can only explain environmental phenomena in a limited way, or try to relate them to aesthetic perception." He goes on to describe a number of problems and limitations of the environmental quality index:

> Many data are not available for every location, or for particular bodies of air, water or land, but still cover the whole country fairly well. Such data are national but not truly comprehensive....it was difficult to use a consistent status level (or standard) for each environmental condition, because of the different ways data are expressed and the wide variety in environmental aspects which were measured....
>
> With no consistent method of reducing data to index form, care should be taken with any value judgement based on the combination of various indices....

The author's concerns about the approach are shared by other researchers who question the validity of reducing environmental quality to a single index number (Mitchell, 1988; Regier 1989).

4.3 State of the Art

In 1975, the Council on Environmental Quality developed the Pollutant Standards Index (PSI) which it describes as "still the only indicator of environmental quality based on solid theory". The PSI includes five pollutants: carbon monoxide, sulfur dioxide, total suspended particulate matter, ozone, and nitrogen dioxide. PSI values are assigned progressive health related descriptors ranging from "good" to "hazardous" (Council on Environmental Quality, 1984).

The Council on Environmental Quality (1984) states that air pollution indices are more advanced than those in any other environmental area. It goes on to say that its "'evolutionary process' of reporting environmental conditions and trends began with the search for indicators, moved to publication of statistics, with increasingly refined selection criteria, broadened to examination of monitoring problems, and culminated in a relatively consistent data series" in its annual SOE reports.

The Council on Environmental Quality (1984) summarizes the state of the art of indicator development:

> Air quality is the only area in which there is a widely accepted, widely used environmental indicator based on an accepted body of theory... [the U.S. Pollutant Standards Index]. Water quality may be the next area in which indicators can be constructed and widely accepted, but technical problems associated with monitoring, data analysis, and extraneous factors, such as water flow levels, are much more difficult to resolve than in the air quality arena. In other areas, such as aesthetics, ground water contamination, wildlife, and quality of life, the difficulties associated with definition, selection of key

parameters, theory, research, measurement, and monitoring are much more severe than those related to either air or water quality.

The Council on Environmental Quality (1984) describes some current examples from the U.S. in environmental monitoring and indicator development:

1) The National Fisheries Survey--a joint effort of the Environmental Protection Agency and the U.S. Fish and Wildlife Service. This is a classification of the health and diversity of fish in streams based on knowledgeable biologists' judgement.

2) Indices of Marine Degradation of the National Oceanic and Atmospheric Administration. These are based on field observations and are expressed in terms of explicit ecological effects. They are designed to be interpreted readily, without reference to additional standards or similar reference values.

3) The National Wetlands Survey of the Fish and Wildlife Service--an analysis of status and trends of wetlands, expressed in terms of acres gained or lost, and categorized by cause of the change.

The Conservation Foundation (1987) cites a number of shortcomings of air pollution indicators:

> Statements about air quality...whether they pertain to individual communities or national averages, rely on stationary monitors in a few locations. Unfortunately, monitors collect data only on a limited number of places, and often the locations of the monitors are not indicative of actual human exposure. Furthermore, data from monitors are usually not weighted to take population concentrations into account....Moreover, tracking progress through the years is complicated by incomplete records, a variety of measurement techniques, and insufficient checking of data quality.
>
> Progress can also be measured by changes in emissions from industries, automobiles, and other sources. But little information is available on actual emisions, and emission estimates are precisely that--estimates. As such, they are only as accurate as the assumptions underlying them, and these assumptions change periodically.

Ott (1978) states that "formal environmental indices" have been primarily restricted to the area of air and water pollution.

Zonneveld (1983) describes the limitations of biological indicators, stating they often lack quantitative data. He advocates combining biological and chemical/physical methods to overcome the shortcomings of a monitoring program based solely on biological measurements.

Hekstra (1983) states that biological or ecological indicators should play an important part in SOE reporting programs but have been virtually ignored in SOE reports produced to date.

Stokes and Piekarz (1987) take a comprehensive look at the opportunities and limitations which current research and information bases provide for SOE reporting in Canada. The Toronto workshop proceedings and appended case studies demonstrate that a considerable amount of indicator work has been done in the areas of chemical and biological monitoring, but the lack of nationwide, long-term data is a significant obstacle.

4.4 What is Needed to Improve the Art of Indicator Development

The Council on Environmental Quality (1984) describes needed improvements in development of indicators:

> ...a more systematic development of theory designed to demonstrate how observed changes in the environment actually affect human health, economic welfare, and ecological integrity....Environmental scientists display an aversion to generalization, especially when it crosses disciplinary lines.... While economists use generalization to explain the complex, environmental scientists use complexity to avoid generalization. Environmental scientists focus on the unique. Much of their research involves the systematic measurement of unique events and situations. When they have enough information on a collection of unique events and situations, they can make generalizations. But they never have enough. This professional perspective stands in the way of development of environmental indicators. Indicators are after all a form of generalization."

The Organization for Economic Cooperation and Development (1978) calls for "comprehensive sets of indicators well integrated in decision making."

Zonneveld (1983) advocates using a combination of species instead of individual ones as environmental indicators. For instance, vegetation types could be combined with other land attributes such as relief and soils. An important advantage of this approach is that local deviations in species' behaviour will be less significant.

Coate and Mason (1977) describe a project based on the rationale that a national system of indicators can best be achieved by aggregating local, state, and regional perceptions of environmental quality. This approach is contrasted with applying rigid analytical techniques to an inadequate data base. Their system uses judgements of environmental experts to classify conditions of various environmental media in the U.S.

5. EXAMPLES OF INDICATORS

5.1 Quality of Life Indicators

The Washington Environmental Research Center (1972) describes the concept of "quality of life" indicators, reviewing the state of the art in the early 1970's. The authors developed an approach to a quality of life index based on 34 social and environmental factors. These are presented in three categories:

- environment--air, water, noise, radiation, solid waste, hazardous substances, aesthetics, land use, natural resources, housing, transportation, utilities, material quality, and communication and media;

- socio-political--education, privacy, safety, personal skills, equality, community, health, choices in life, social relationships, national security, democratic process, and justice; and

- economic--accumulated assets, living costs, income distribution, economic security, economic growth, public spending, discretionary income, and leisure.

The authors suggest that these factors would be expressed as indicators based on the ratio: status of factor/desired level of factor. They state that "this relationship implies that for every factor under consideration we will obtain both a measure of its status and a measure which reflects the desired level for the same phenomena". One difficulty cited for their approach is obtaining "meaningful measures of both the subjective and objective parameters making up the Quality of Life" (Washington Environmental Research Center, 1972).

The Department of Planning and Economic Development (1971) and UNESCO (1978) provide additional examples of the socio-economic and environmental variables which have been used in measures of the quality of life. The latter includes a Hungarian case study about quality of life modelling.

5.2 Environmental Indices

Inhaber (no date) describes a national Canadian environmental quality index developed in the early 1970's. The index was developed from four component indices: air quality, water quality, land quality, and "miscellaneous". These four are made up of "sub-indices", which in some cases include "sub-sub-indices". The author states that:

> We have attempted to show in this Index what we do know or believe, and this knowledge or set of assumptions is implied in each of the sub-indices. For example, in the discussion on air quality, we have some knowledge of the relationship between air pollution and health, and this is implicit in the types of pollutants mentioned and how they are handled mathematically. Similarly, in the section on land environmental quality, we have some idea of the relationship between forest fires and the quality of the forest environment, and this is again implicit in the discussion in that section (Inhaber, no date).

The rationale for the Canadian Environmental Quality Index is described as follows:

> The index was defined as a number, free from units, which ranges from zero, for the best possible environmental condition, to increasing numbers for progressively worse environmental quality. With all data reduced to a unit-free index, several indices may be combined to give an overall picture of environmental quality (Inhaber, no date).

5.2.1 <u>Air Quality Indices</u>

The Federal-Provincial Committee on Air Pollution (1980a) has produced a guideline for an annual air quality index for Canada.

A major component of this index is the use of 98th percentile concentrations. This concept can perhaps best be illustrated by an example: a reported index number of 35 (FAIR) tells us that the air quality during the year was better than or equal to 35 for 98% of the time. The index is based on the National Air Quality Objectives, and assumes that at the defined objective levels, the effects of air pollutants have equal importance for the quality of the air.

The authors list the following attributes of the index:

- it includes the major pollutants;
- it represents the air quality in downtown locations in major cities;
- it relates the effects of air pollutants on the environment to a common scale;
- it is a uniform index and therefore allows downtown locations in different major cities to be compared;
- it is designed so that any other pollutant, or combinations thereof, can be included in the future (Federal-Provincial Committee on Air Pollution, 1980a).

The Federal-Provincial Committee on Air Pollution (1980b) describes a "short-term air quality index" which is based on reporting the worst effect on air quality. As with the annual air quality index described by the Federal-Provincial Committee on Air Pollution (1980a) the short-term air quality index is based on Canada's National Ambient Air Quality Objectives.

The Federal-Provincial Committee on Air Pollution (1980a) points out that one serious misuse of air quality data is to compare cities that do not have similar weather or comparable monitoring systems. A related problem is that the National Air Quality Objectives cannot take into account regional differences.

5.2.2 Water Quality Indices

Couillard and Lefebvre (1985) introduce twenty different versions of a water quality index. Each approach is described from the standpoint of objectives, approach and potential applications.

Schaeffer and Janardan (1977) describe a water quality index they have developed and compare it with three others, based on a set of eleven "desirable and necessary characteristics of an index":

1. Definite range
2. Single-valued, and varies in systematic manner
3. Responsive to changes in data values
4. Statistical properties
5. Includes information about standard
6. Dimensionless

7. Insensitive to the number of parameters employed
8. Insensitive to the number of observations
9. Usable for all selected parameters
10. Allows stations to be combined
11. Insensitive to extreme values.

They give the highest rating to their own index which uses ranked data rather than raw data to produce an index value. The major disadvantage of using raw data is due to the fact that the different factors involved in an index operate on different scales, and there is no convenient way to normalize them.

Steinhart _et al._ (1982) describe an index for the quality of nearshore waters in the Great Lakes. The index, based on nine physical, biological and toxic chemical variables, is suggested as a useful tool to evaluate Great Lakes cleanup efforts.

5.3 Environmental Quality Profiles

Ott (1978) describes an environmental quality profile developed for the Seattle Region of the U.S. Environmental Protection Agency. The profile covers a variety of environmental topics--air pollution, water pollution, radiation, pesticides, solid waste, and noise. It presents state-of-the-environment information in a series of easy-to-understand bar graphs and charts. He states that although many technical details are lacking from the published description of the technique, it is impressive for its comprehensiveness.

The study used two indicators of water quality violations (1) river miles not meeting ambient standards, and (2) severity of the violation of the standards. Two similar indicators were used for air pollution: (1) number of days during which ambient air quality standards were violated and (2) severity of the violation. Indicators for radiation and noise were based on the number of persons exposed, while a pesticide indicator was based on concentrations measured in food, air and water.

Coate and Mason (1977) describe how a similar system could be applied nationwide in the U.S. A notable aspect of their system is its approach to reporting lake water quality. A bar chart shows the percent of swimming beaches meeting water quality or health standards. The system is applicable to the Great Lakes using information available from the International Joint Commission and from local public health agencies. The evaluation scheme for water quality considers water use for swimming, fishing and drinking.

For lakes, other than the Great Lakes, the profile considers the percent of lake surface area for which the highest beneficial use is impaired, with the degree of impairment, and eutrophication of major lakes. The latter is expressed in square miles of lake area.

5.4 Biological Indicators

Zonneveld (1983) describes the broad scope of biological monitoring in relation to the "ten levels of life", any of which can be used as indicators: macro-molecule, organelle, cell, tissue, organ, organism, population, community, ecosystem, biome. The levels most frequently used as indicators are, tissues and organs, organisms and communities.

Hekstra (1983) states: "Even complex variables such as population dynamics, diversity, rarity, trophic structure and stability can serve as indicators." Relevent aspects of population dynamics include clutch size, breeding success, predation pressure, carrying capacity of the environment and other density-dependent factors.

Zonneveld (1983) lists a number of reasons for using biological indicators:

- Often environmental factors can not be measured by a single observation using a chemical or physical method.

This is commonly the case with groundwater, presence of nitrogen in soil and climate properties.

- Physical and chemical methods may be too time-consuming and/or costly.

- Biological indicators can illustrate gradients in environmental conditions.

- By measuring the effects on biotic elements, one often gets a more realistic image than by measuring some 'pretended' agents themselves.

- One important argument for biological indicators can be stated: "one should '<u>ask the patient herself how she is feeling</u>'".

<u>Biological Indicators of Environmental Quality</u> (Thomas <u>et al.</u> 1973) is an annotated bibliography organized under the categories: cell-free systems, cultured cells, tissues and organs, organisms, and communities. While the material is dated, covering research published before 1973, the bibliography shows the variety of biological indicators which might be used for SOE reporting, and documents the state of the art in the early 70's.

Hytteborn (1979) reports results of a conference about Scandinavian research on biological indicators. A primary objective of the conference was to identify biological and ecological measures most suited to environmental monitoring. The conference discussed pros and cons of using plants and animals in monitoring.

Munawar (1980) describes the state of the art of biological surveillance for the Great Lakes, focussing on two major aspects: trophic status and contaminants. Topics covered include needs and objectives, standardization of techniques, use of indicator species, and integration of human health related data into surveillance.

A number of manuals and texts have been written which provide broad coverage of approaches and applications for biological indicators. See Clarke (1986), Food and Agriculture Organization of the United Nations and United Nations Environment Programme (1976), Greeson (1981), Hellawell (1986) and International Union of Biological Sciences (1986).

5.4.1 Plants

The Monitoring and Assessment Research Centre (1986) examines the range of work on plant indicators. The authors provide an overview of the large volume of work which has been done in terrestrial, freshwater and marine environments, for metal pollutants, organic compounds, gaseous pollutants and radionuclides. They express a similar view to that of Zonneveld (1983) in citing advantages of biological monitoring, stating that knowledge of contaminant concentrations, which can be obtained by physio-chemical methods alone, does not necessarily indicate their significance to plant populations and communities. Plant studies can identify contaminants which may be present at very low levels and may show important spatial relationships. Plant species distribution and visible injury to foliage can be related to levels of contamination. These factors can be demonstrated in types of aquatic and terrestrial habitats.

The conference reported by Hytteborn (1979) concluded that mosses and lichens are particularly useful air pollution indicators, and that different vegetation types and life forms should be represented when vegetation is used in monitoring. Mosses and lichens have been widely used to show the distribution of metals and radionuclides as well as pesticide contamination. Changes in lichan species composition have also been related to the degree of contamination (Monitoring and Assessment Research Centre, 1983). Visible injury to foliage of higher plants may reflect atmospheric concentrations of gaseous pollutants and monitoring networks of transplanted sensitive species can provide regional information on contaminant levels.

Case (1980) reports results of a study of the effects of sour gas processing plants on epiphytic lichens in Alberta. His study produced "relative air pollution impact zone maps" based an "Index of Atmospheric Purity" or IAP. The IAP is "an index of the perturbation of the lichen flora away from an idealized state". He states that his approach can "provide a reliable indication of the diversity of lichen communities without having to census the complete spectrum of species".

Douglas and Skorepa (1976) describe a feasibility study which led to the establishment of an air quality monitoring network using lichens as indicators of atmospheric sulfur in the Fort McMurray region of Alberta.

Pipes (1982) presents a set of articles on water quality and health significance of bacterial indicators of pollution. Topics covered include use of bacterial indicators of surface and ground water quality, public health, quality of life, and technical and cost considerations for monitoring programs. A wide range of organisms are discussed.

5.4.1 Animals

Hytteborn (1979) states that animals may be difficult to use as indicators due to the large population size variations which commonly occur in nature. However, due to the phenomenon of bioaccumulation in food chains, animals can provide useful information about the effects of chemical pollution. He maintains that birds can be particularly useful environmental indicators, and that both migration studies and breeding bird surveys investigations have been of value in pollution detection.

Small animals including various insects, beetles, macroarthropods, molluscs and spiders have been used effectively in environmental monitoring. Relative abundance figures can be used to compare different localities with a reference area. By contrast, Hytteborn (1979) suggests that work with larger animals has been limited. He states that methods for the long-term study of mammals should be developed.

The Work Group on Indicators of Ecosystem Quality (1985) reports on the use of lake trout as an indicator of ecosystem quality in the Great Lakes. The authors' objectives were to provide a rationale for any future revisions of the 1978 Great Lakes Water Quality Agreement and to identify ecosystem indicators.

To develop the indicator organism concept, the work group chose the lake trout for detailed research:

> A realistic ecosystem objective for the Upper Great Lakes was deemed to be the attainment and maintenance of a quality oligotrophic environment ....Within this broad objective, the lake trout as a terminal predator would be used as an ecosystem surrogate to detect any marked changes to the biota or environment.
>
> A general set of criteria for biological indicators of ecosystem quality was devised and various organisms were classified against the standard of an ideal indicator organism. Candidate indicator organisms were divided into two categories; essentially those intolerant of most cultural stresses and those tolerant of the same suite of stresses. The intolerant species were exemplified by lake trout and the amphipod *Pontoporeia hoyi* for oligotrophic systems while the walleye and the burrowing mayfly filled this role for mesotrophic systems. Carp and sludgeworms were designated as tolerant organisms for both oligotrophic and mesotrophic systems(Work Group on Indicators of Ecosystem Quality, 1985).

Gilbertson (1987) describes the advantages and disadvantages of four predators, the bald eagle, osprey, mink and otter, as indicators of aquatic environmental quality. He lists the kinds of information required for each species, working from the premise that, if these species are present and maintaining their populations, then aquatic environmental quality is probably satisfactory.

Popham and D'auria (1980) describe an approach to the use of molluscs as a terrestrial pollution indicator in southwestern British Columbia. They used X-ray energy spectroscopy to determine concentrations of a number of heavy metals were measured in the terrestrial gastropod, Arion ater at various distanced from a highway. The data were used in a classification system in which trace metal concentrations in the gastropod are used as measures of environmental quality.

Eaton and Farant (1982) provide an example of the use of a mammal in monitoring heavy metal concentrations in the environment. The authors studied mercury concentrations in polar bears from the western Canadian arctic to determine whether industrial sources were causing elevated mercury levels in the bears.

5.4.3 Communities

Cairns (1974) compares the use of indicator species with measures of community structure as pollution indicators. He favors the latter approach for a number of reasons. He maintains that the absence of a species is less useful as an environmental indicator than the presence of a species. By contrast, the absence of an entire group of species with similar environmental requirements is a much stronger indication that the community has been excluded or eliminated by some form of environmental disturbance. The absence of an individual species is often due simply to the lack of opportunity to colonize a particular location. The author describes a study which linked effects of various types of pollution to changes in the number of species in various groups of aquatic organisms. He states that:

> We know that waste discharges and pollution will change the number of species present and the diversity of the system. The reliability of the results obtained with community structure indices can be calculated. Various methods are available [for measurement] ranging from those requiring highly specialized training...to those requiring an analytical mind but relatively little formal biological training (Cairns, 1974).

Cairns (1974) suggests that a community structure approach to biological indicators can provide better and more refined information about the state of the environment than can study of individual species. Pollution can be caused by a variety of stresses, and a given organism may be tolerant of one type of pollution and sensitive to another. Looking at a group of different organisms should allow the researcher to demonstrate a range of reactions to different stresses. He maintains that in fact, there are very few data to support the use of species as indicators of pollution.

5.5 Chemical Indicators

Applied chemistry is an important component of many environmental monitoring programs, and a wide variety of chemical analyses are used to identify and monitor pollutants in air, water and living matter. In their study of Atmospheric sulfur and iron in Belgium, Hallet et al. (1984) show how researchers can use a few selected chemical indicators to estimate concentrations of a variety of pollutants in the environment.

Pennock (1987) describes an interesting approach to monitoring soil erosion based on changes in the distribution of ^{137}Cesium. This isotope was widely distributed over the earth's surface as a result of nuclear testing in the late 1950's and early 1960's. It adheres strongly to soil particles, and thus could be used in SOE reporting as a chemical indicator of erosion.

Rahn and Lowenthal (1983) describe a seven-element tracer system used to determine the origins of pollution aerosols at Narragansett, Rhode Island. The study identified five regional sources in the northeastern and midwestern U.S.

Many of the references cited in Section 5.4 describe means to apply chemical indicators to analyse environmental stresses affecting living organisms and ecosystems.

Hodson (1987) describes some limitations of chemical and biological monitoring of aquatic ecosystems. Regarding the former, he maintains that, even when water quality objectives are met, the complexity of aquatic ecosystems means that there is no guarantee that aquatic biota are protected from unforseen environmental stresses. With the latter, the time lag between identifying a problem and finding a cause may have disastrous consequences for the ecosystem. He presents a case for biochemical monitoring--the measurement of primary or secondary responses of individual organisms to chemical exposure:

> Since all toxicity at any level of organization must start with a reaction between a chemical and a biological substrate in individual organisms, these responses will provide the most sensitive and earliest indicators of chemical exposure and effect.

5.6 Urban Environmental Indicators

The Organization for Economic Cooperation and Development (1978) describes a set of urban environmental indicators applicable to developed countries. The indicators are adaptable by central and local authorities according to their own specific needs. The report describes both "proposed indicators" and "suggested indicators for further development" in four broad areas: housing, services and employment, ambient environment and nuisances, and social and cultural. The environment and nuisance category includes air and water quality, noise, solid waste disposal, exposure to natural hazards, weather conditions, and land quality and urban landscape.

The Department of Home Affairs and Environment (1983) adapted the OECD urban environmental indicators concept for use in Australia. The publication lists some ninety environmental and socio-economic indicators which were applied to every major metropolitan area in Australia.

Ben-Chieh (1982) describes a set of environmental indicators developed as part of quality of life index applied to 65 large U.S. metropolitan areas. Four major factors are included in the approach: air and water pollution, noise and visual pollution, climate and weather, and residential environment.

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ANNOTATED BIBLIOGRAPHY

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OF ENVIRONMENTAL INDICATOR RESEARCH

1. LITERATURE REVIEWS, CONCEPTUAL STUDIES AND MANUALS ABOUT INDICATOR DEVELOPMENT AND APPLICATION

1) Council on Environmental Quality (1984) Environmental Quality. 15th Annual Report of the Council on Environmental Quality. U.S. Government Printing Office, Washington.

One of an annual series of SOE reports, this edition of Environmental Quality includes a discussion of the development and use of indicators. The state of the art in the U.S. is described and needed improvements are identified.

This is one of the few examples in the literature of an in depth analysis of use of indicators for SOE reporting.

2) Department of Planning and Economic Development (1971) Proceedings of the Conference on Socio-Environmental Indicators. Department of Planning and Economic Development, State of Hawaii, Honolulu.

This is a broad-ranging collection of short papers which emphasize the socio-economic aspects of environmental indicators. Topics covered include urban environmental quality indicators, housing, health and welfare, quality of life indicators, outdoor recreation, and pollution indicators.

3) Liverman, D.M., M.E.Hanson, B.J. Brown and R.W. Merideth (1988) "Global Sustainability: Toward Measurement" Environmental Management, Vol. 12, No. 2, pp. 133-143.

The authors describe the concept of sustainable development indicators, with a critical look at some approaches from the literature. They conclude that work to date has a number of shortcomings. They list desirable characteristics of sustainable development indicators and illustrate an approach to evaluation of potential indicators with examples in the areas of soil erosion, population, quality of life, and energy.

4) Ott, W. (1978) Environmental Indices: Theory and Practice. Ann Arbor Science Publishers, Ann Arbor, Michigan.

This book can serve as a basic reference for any agency wishing to apply indices to analyse environmental data. It describes a number of different types of indicators and indices in suficient detail for the reader to apply them directly, and numerous examples are included.

5) Stokes, P. and D. Piekarz, eds. (1987) Ecological Indicators of the State of the Environment: Report of a Workshop held May 27-29, 1987. Institute for Environmental Studies, University of Toronto.

The workshop was conducted to assist Environment Canada in developing a set of indicators for SOE reporting. Participants included workers in the field from Environment Canada and Statistics Canada as well as other federal employees and academics. Topics covered include: criteria for ecological indicators, chemical and biochemical indicators, and specific applications for forestry, agriculture and fisheries. The publication includes a collection of papers about Canadian case studies on these topics.

6) Strickland, J. and T. Blue (1972) Environmental Indicators for Pesticides. Council on Environmental Quality, Washington, D.C.

The study explored the information base to support development by the U.S. Government of a set of indicators related to pesticide use. The authors conclude that a substantial information base exists, and they list indicators which could be applied.

Measures are suggested for imports, exports, and consumption of pesticides, by type and over time; the amount of pesticides found in food, air, water, soil, wildlife, plants, and the human body, by type and over time; and indirect measures of pesticide utilization as they relate to public health, crop quality and yield, and recreational and aesthetic values.

7) UNESCO (1978) Indicators of Environmental Quality and Quality of Life. Reports and Papers in the Social Sciences, No. 38, UNESCO, Paris.

This publication contains three papers and the final report from a December, 1976 UNESCO "Meeting of Experts on Indicators of the Quality of Life and Environmental Quality". Topics covered in the papers are: indicators of the quality of working life, environmental quality indicators, and the Hungarian experience in developing quality of life models. The quality of working life paper is a literature review and provides a good introduction to the subject. The paper on environmental quality indicators describes a methodological framework for applying socio-economic and environmental indicators. The framework presents a set of indicators in four broad categories: physical environment (including topography, climate, water and air quality); man-made environment (including transportation systems, buildings and landscaping): activity environments (including schools, the workplace and shopping areas); and overall community environment (including goods, services, spiritual institutions and government). The final report provides a good summary of the concepts of environmental quality and quality of life indicators and suggests areas for further study.

The breadth of information which is reviewed and summarized in this publication make it a good reference for any agency which may become involved in SOE reporting.

2. ENVIRONMENTAL INDICES

1) Couillard, D. and Y. Lefebvre (1985) "Analysis of Water Quality Indices". Journal of Environmental Management, Vo. 21, No. 2, pp. 161-179.

This article provides an introduction to twenty different water quality indices. Each index is described form the standpoint of its objectives, approach and potential applications.

2) Federal-Provincial Committee on Air Pollution (1980a) Guidelines for an Annual Air Quality Index. Minister of Supply and Services Canada, Ottawa.

This is a report of the findings of a committee established in 1975 to examine the need for an air quality index in Canada. The committee developed the Annual Air Quality Index which is in use today. The index is based on the National Ambient Air Quality Objectives. The report includes a description of the index, with examples of its application.

3) Federal-Provincial Committee on Air Pollution (1980b) Guidelines for a Short-term Air Quality Index. Minister of Supply and Services Canada, Ottawa.

The publication describes an air quality index which is suitable to inform the public about air quality in local communities. As with the Annual Air Quality Index, the short-term index is based on the National Ambient Air Quality Objectives.

4) House, M. (1987) "Water Quality Indices as Indicators of Ecosystem Change". In: Stokes, P. and D. Piekarz, eds. (1987) Ecological Indicators of the State of the Environment: Report of a Workshop held May 27-29, 1987. Institute for Environmental Studies, University of Toronto.

The author cites a need for a more effective method of communicating information on a range of physio-chemical parameters in terms of their chemical and ecological significance. She states that a number of approaches to this problem have been attempted which range from the use of subjectively applied water quality classifications, to the development of mathematically derived water quality indices. The paper describes the development and use of water quality indices in management of surface water quality. It illustrates the potential value of such an approach as an indicator of ecological change.

5) Inhaber, H. (1976) Environmental Indices. John Wiley & Sons, New York.

This is a broad-ranging primer in which the author describes indices for air, water, land, biota, esthetics and other environmental factors. The book is written for the non-specialist, and provides a good introduction to the subject.

6) Inhaber, H. (no date) A National Environmental Quality Index for Canada. Environment Canada, Ottawa.

This is a detailed description of a comprehensive environmental quality index developed for Canada in the early 1970's. The index is made up of sub-indices for air, water, land, and a miscellaneous category. Each of the sub-indices is developed from further sub-indices.

The author provides background on considerations in the development of environmental indices and describes the methodology for each of the sub-indices used in the overall environmental quality index.

7) Steinhart, C.E., L. Schiero and W.C. Sonzogni (1982) "An Environmental Quality Index for the Great Lakes". Water Resources Bulletin, Vol. 18, No. 6, pp. 1025-1027.

This article describes an index for the quality of nearshore waters in the Great Lakes. The index, based on nine physical, chemical, biological, and toxic chemical variables, is suggested as a useful tool to help managers evaluate the response of the Great Lakes to the multibillion dollar cleanup efforts of the last decade.

3. ENVIRONMENTAL QUALITY PROFILES

1) Coate, L.E. and A.K. Mason (1977) "Toward a National System of Environmental Indicators". Sensing of Environmental Pollutants 4th Joint Conference, New Orleans, Nov. 6-11, 1977.

The authors document the lack of progress in developing nationally applicable environmental indicators in the U.S. To address this lack, they describe an environmental quality profile based on the professional judgements of knowledgeable biologists and other professionals at the local level. The profile covers a range of environmental issues, including lake and river water quality, air quality, radiation, waste disposal and pesticide use.

This is an easy-to-understand approach to describing the state of the environment. Many of the indicators used could be adapted to SOE reporting in Canada.

4. BIOLOGICAL INDICATORS

1) Beeton, A.M. (1966) "Indices of Great Lakes Eutrophication". In: Proceedings of the 9th Conference on Great Lakes Research, 1966. Publication No. 15, Great Lakes Research Division, the University of Michigan, Ann Arbor, Michigan.

The author evaluates a variety of physical, chemical and biological measures as indicators of eutrophication in the Great Lakes. He concludes that increases in nitrogen and phosphorus, changes in species compostion of aquatic communities and abundance of plankton, and dissolved oxygen content of bottom waters are all useful indicators.

2) Cairns, J.R. (1974) "Indicator Species vs. Community Structure". Water Resources Bulletin, V. 10, No.2. p. 338.

The author describes an approach to use of plant and animal communities as environmental indicators, and compares such this method to the use of indicator species. The community approach is considered superior. The scientific justification for indicator species is seriously questioned.

This paper provides good background for indicator development and application, since it challenges much of the conventional wisdom and describes two of the basic approaches for biological indicators.

3) Cairns, J., G.P. Patil and W.E. Waters, eds. (1979) Environmental Biomonitoring, Assessment, Prediction and Management--Certain Case Studies and Related Quantitative Issues. International Co-operative Publishing House, Fairland, Maryland.

This is a collection of papers in four general subject areas: biomonitoring--concepts and methods, environmental assessment and prediction, environmental management, and other management studies and quantative issues. While the publication covers a wide range of topics, certain of the papers relate more particularly to issues in SOE reporting. These include an introduction to the concept of biological monitoring and research reports on aquatic nematodes and ecological diversity indices as water quality indicators.

4) Clarke, R., ed. (1986) The Handbook of Ecological Monitoring. A GEMS/UNEP Publication, Clarendon Press, Oxford.

This comprehensive handbook purports to provide "for the first time a detailed account of the whole system of ecological monitoring under one cover". For planners, it describes the range of techniques that are available to obtain environmental data, the variables that can be analysed, and the precision that can be obtained. It is also intended for technical specialists who may need to design monitoring programs. The diverse subject matter is presented in four major sections: habitat monitoring theory, ground monitoring, aerial monitoring, and remote sensing.

5) Douglas, G.W. and A.C. Skorepa (1976) Monitoring Air Quality with Lichen: a Feasibility Study. Environmental Research Monograph 1976-2, Syncrude Canada Ltd., Edmonton.

The authors report on a 1975 study of the technical and economic feasibility of establishing a biological monitoring grid network using lichens as indicators of atmospheric sulfur in the Fort McMurray region of Alberta. The study concluded that the project was feasible, and a monitoring network was established in 1976.

6) Food and Agriculture Organization of the United Nations and United Nations Environment Programme (1976) Indices for Measuring Responses of Aquatic Ecological Systems to Various Human Influences. A Report of the ACMRR/IABO Working Party on Ecological Indices of Stress to Fishery Resources. FAO, Rome.

This is a feasibility study for a program to apply ecological theory to exploitation and conservation of marine fisheries resources. The proposed program would evaluate potential indicators at the population, community and ecosystem levels.

The publication describes the state of the art and presents an ecological monitoring framework for fisheries.

7) Gilbertson, M. (1987) "Freshwater Avian and Mammalian Predators as Indicators of Aquatic Environmental Quality". In: Stokes, P. and D. Piekarz, eds. (1987) Ecological Indicators of the State of the Environment: Report of a Workshop held May 27-29, 1987. Institute for Environmental Studies, University of Toronto.

This paper describes the advantages and disadvantages of four predators, the bald eagle, osprey, mink and otter, as indicators of aquatic environmental quality. It lists the kinds of information required to make a scientifically defensible case for regulatory action. The authors work from the premise that, if these species are present and maintaining their populations, then aquatic environmental quality is probably satisfactory.

8) Greeson, P.E., ed. (1981) Biota and Biological Parameters as Environmental Indicators. Briefing Papers on Water Quality. Geological Survey Circular 848-b, U.S. Geological Survey, Alexandria, Virginia.

This is a compilation of nontechnical, easy-to-understand papers on biological indicators. Topics covered are: species diversity and its measurement, algal growth potential, estimation of microbial biomass by measurement of adenosine triphosphate, and lake classification.

9) Hekstra, G.P. (1983) "Indicators in Complex Systems". Environmental Monitoring and Assessment. V. 3, Nos. 3/4, 1983.

The author provides a general discussion of the use of biological indicators to determine the nature of interactions among air, water, soil, chemicals and biota. The state of the art is described, with some examples provided for indicators of population dynamics, diversity, rarity and trophic structure. The author questions why SOE reporting has not made greater use of such ecological indicators.

10) Hellawell, J.M. (1986) Biological Indicators of Freshwater Pollution and Environmental Management. Elsevier Science Publishing Co., Inc., New York.

The primary function of this book is to provide background on the development of aquatic indicators. It begins with a very basic introduction to aquatic ecology and proceeds to describe environmental stresses including organic enrichment and pollution of aquatic systems by heavy metals, pesticides and PCB's. Later chapters focus on indicator methods and techniques.

11) Hodson, P. (1987) "Indicators of Ecosystem Health at the Species Level and the Example of Selenium Effects on Fish". In: Stokes, P. and D. Piekarz, eds. (1987) Ecological Indicators of the State of the Environment: Report of a Workshop held May 27-29, 1987. Institute for Environmental Studies, University of Toronto.

The author describes limitations of chemical and biological monitoring of aquatic ecosystems. Regarding the former, he maintains that, even when water quality objectives are met, there is no guarantee that aquatic biota are protected from the effects of unexpected chemicals, mixtures and the interactions between chemical exposure and environmental stress. With the latter, the time lag between identifying a problem and finding a cause may allow a complete destruction of the resource. He presents a case for biochemical monitoring--the measurement of primary or secondary responses of individual organisms to chemical exposure: since all toxicity at any level of organization must start with a reaction between a chemical and a biological substrate in individual organisms, these responses will provide the most sensitive and earliest indicators of chemical exposure and effect.

12) Hytteborn, H. (1978) The use of Ecological Variables in Environmental Monitoring: Proceedings of the First Nordic Oikos Conference, Oct. 2-4, 1978. Uppsala, Sweden.

This is the proceedings from a Scandinavian conference on biological indicators. Papers include specific studies on individual plant and animal indicators as well as reports on group discussions about the state of the art. Subject areas include: aquatic environments, species diversity, and chemically induced changes in organisms.

The report is particularly useful for the overview provided by the group sessions.

13) International Union of Biological Sciences (1986) Biological Monitoring of the State of the Environment: Bioindicators. IUBS Monograph Series, No. 1, IRL Press Limited, Oxford.

This book is a collection of review articles which together provide a broad coverage of methods and approaches to indicators at the cellular, species, community and ecosystem level. The publication should be useful for those engaged in SOE reporting, as it introduces a major subject area and provides a good introduction to the international literature.

14) Khalil, M.F., J. Labbe, A.C. Horth and M. Arnac (1985) "Chlorinated Hydrocarbons: Pollutants or Indicators of Fish Stock Structure". International Journal of Environmental Analytical Chemistry, Vol. 21, pp. 105-114.

This article illustrates the use of pollutants as identifying markers in the study of fish populations. In an attempt to identify the herring stock units present in the St. Lawrence estuary and the Chaleur Bay, the authors measured the degree of contamination by certain organochlorinated compounds, of herrings fished in both locations. The purpose of the study was to establish the presence of many discrete stocks units or of only one homogenous stock brought about by large scale straying of individuals from one group to another.

15) Kimmins, J.P. "Monitoring the Condition of the Canadian Forest Environment: the Relevance of the Concept of 'Ecological Indicators'". In: Stokes, P. and D. Piekarz, eds. (1987) Ecological Indicators of the State of the Environment: Report of a Workshop held May 27-29, 1987. Institute for Environmental Studies, University of Toronto.

This paper reviews some of the sources of spatial variation in the physical environments in which Canadian forests develop, and the types of episodic disturbance that have resulted in today's complex mosaic of forest stands. The author maintains that any attempt to monitor the quality of the Canadian forest environment which fails to account for the inherent spatial and temporal variability of forests is doomed to failure. He describes the type of monitoring tool which could be used to overcome these problems, and provides a brief introduction to one such tool, the computer ecosystem simulation model FORCYTE.

16) Monitoring and Assessment Research Centre (1986) Biological Monitoring of Environmental Contaminants (Plants). MARC, London.

The report is a comprehensive review of the use of plants as indicators in terrestrial, freshwater and marine ecosystems. Subject areas include metal pollutants, organic compounds, gaseous pollutants, and radionuclides.

This study provides a useful background for SOE reporting, because it synthesizes information gathered from the very large number of plant studies which have been done. The authors describe a number of different applications for plant indicators.

17) Munawar, M. (1980) Proceedings of the First Biological Surveillance Symposium, Twenty Second Conference on Great Lakes Research, May 3, 1979, Rochester, New York. Canadian Technical Report of Fisheries and Aquatic Sciences No. 976., Department of Fisheries and Oceans, Burlington, Ontario.

The symposium was organized to assess the state of the art of biological surveillance for the Great Lakes, focussing on two major aspects: trophic status and contaminants. It covered topics including: needs and objectives, standardization of techniques, use of indicator species, and integration of human health-related data into surveillance.

18) Pipes, W.O. (1982) Bacterial Indicators of Pollution. CRC Press, Boca Raton, Florida.

This publication is a broad coverage of a class of biological indicators which has been particularly well developed. Topics covered in individual chapters by different authors include: criteria for indicators, health effects, water quality, cost of monitoring programs, and lifestyle hazards.

19) Popham, J.D. and J.M. D'Auria (1980) "Arion ater (Mollusca: Pulmonata) as an indicator of Terrestrial Environmental Pollution". Water, Air, and Soil Pollution. V. 14 pp. 115-124.

The authors used x-ray energy spectroscopy to study concentrations of heavy metals in a terrestrial amphipod in British Columbia. They have developed, and in their study demonstrate, a classification procedure in which trace metal concentrations in the amphipod are used to assess environmental quality.

20) Scott, M.G. and T.C. Hutchinson (1987) "The use of Lichen Growth Abnormalities as an Early Warning Indicator of Forest Dieback". In: Stokes, P. and D. Piekarz, eds. (1987) Ecological Indicators of the State of the Environment: Report of a Workshop held May 27-29, 1987. Institute for Environmental Studies, University of Toronto.

The authors describe research in progress involving indicator analysis based on 1) transplantation of healthy lichens which have been selected for their potential to develop particular abnormalities when stressed, and 2) study of the occurrence of these abnormalities in natural field populations. The transplantation approach is an alternative to use of presence/absense data in pollution indicator research with lichens.

21) Soule, D.F. and G.S. Kleppel, eds. (1987) Marine Organisms as Indicators. Springer-Verlag New York Inc., New York.

This is a collection of chapters by scientists knowledgeable in particular aspects of the indicator species concept applied tomarine systems. Each chapter relates to a certain marine habitat: planktonic, pelagic, intertidal, reefal and benthic. Scientific disciplines coverd include physical and biological oceanography, marine ecology and environmental science.

22) Thomas, W.A., W.H. Wilcox and G. Goldstein (1973) Biological Indicators of Environmental Quality: A Bibliography of Abstracts. Ann Arbor Science Publishers, Ann Arbor, Michigan.

This bibliography is a bit dated, covering literature published before 1973. However, it is useful as a measure of the range of research on biological indicators, having assembled abstracts on research in areas including; cell-free systems. cultured cells, tissues and organs, organisms, and communities.

23) Wessels Boer, J.G. (1983) "Ecological Indicator Organisms for Environmental Protection Policy": Environmental Monitoring and Assessment. V. 3, Nos. 3/4, 1983.

This paper is a general discussion of the policy support functions of environmental indicators. It can provide useful background to place SOE reporting in a policy context. The author includes a list of criteria which biological monitoring programs should meet.

24) Zonneveld, I.S. (1983) "Principles of Bio-indication". Environmental Monitoring and Assessment. V. 3, Nos. 3/4, 1983.

This publication is a good introduction to the concept of biological indicators. The author describes the range of types of biological indicators (from macro-molecules to the biosphere) and describes a number of common applications. He describes requirements of good indicators and presents an argument in favor of using biological indicators as opposed to strict reliance on physico-chemical measures.

5. CHEMICAL INDICATORS

1) Hallet, J.P., C. Ronneau and J. Cara (1984) "Sulfur and Iron as Indicators of Pollution Status in a Rural Atmosphere". Atmospheric Environment, Vol. 18, No. 10, pp. 2191-2196.

This article reports on air quality monitoring studies in a semi-rural area of Belgium, using sulfur and iron as indicator pollutants. The authors state that, because atmospheric concentrations of many elements are linked to concentrations of sulfur and iron, the amounts of these two elements in air samples can be used to estimate concentrations of a range of pollutants.

2) Pennock, D. (1987) "Redistribution of ^{137}Cs as an Example of a Chemical Indicator of Environmental Stress". In: Stokes, P. and D. Piekarz, eds. (1987) Ecological Indicators of the State of the Environment: Report of a Workshop held May 27-29, 1987. Institute for Environmental Studies, University of Toronto.

This paper examines the theoretical, methodological and analytical basis of the use of cesium isotope concentrations as a chemical indicator of soil erosion. Cesium was distributed widely and uniformly over the earth's surface as a result of atmospheric nuclear weapons testing in the late 1950's and early 1960's. The isotope became bound to particles of surface soil, with minimal uptake by plants and animals. Thus the author maintains that changes in distribution of the isotope indicates erosion rates of soil within a given study area. He proceeds to describe advantages and disadvantages of applying this indicator approach in Canadian SOE reporting.

3) Rahn, K.A. and D.H. Lowenthal (1983) "The Promise of Elemental Tracers as Indicators of Source Areas of Pollution Aerosol in the Eastern United States". In: University of Rhode Island, University of Missouri, et al. (1983) 17th Trace Substances in Environmental Health Conference.

The authors describe a seven-element tracer system used to apportion pollution aerosols at Narragansett, Rhode Island, into contributions from five regional sources in the northeastern and midwestern U.S.

6. URBAN ENVIRONMENTAL INDICATORS

1) Ben-Chieh, L. (1982) "Environmental Quality Indicators for Large Metropolitan Areas: A Factor Analysis". Journal of Environmental Management, Vol. 14, No. 2, pp. 127-138.

The author describes a set of environmental quality indicators developed as part of a quality of life index applied to 65 large U.S. metropolitan areas. Using data on manmade and natural environmental conditions, four major factors--air and water pollution, noise and visual pollution, climate and weather, and residential environment--were deduced from 15 composite variables. The difficulty of constructing a single index of overall environmental quality is described.

2) Department of Home Affairs and Environment (1983) Australian Urban Environmental Indicators. Australian Government Publishing Service, Canberra.

This report provides a wide range of information on aspects of the quality of life in Australia's major metropolitan and non-metropolitan urban areas. A series of indicators were developed to cover the initial information requirements of many different possible users. The indicators permit comparisons among urban areas and the monitoring of trends in particular aspects of the urban environment. The authors drew on the work of the OECD as well as other sources to develop ninety quality measures in the areas of: demographic components, physical environment, the urban economy, housing, and the social environment.

3) Organization for Economic Cooperation and Development (1978) Urban Environmental Indicators. OECD, Paris.

The publication reports results of a meeting organized to examine the range of experience of various cities in the development and use of urban environmental indicators, as well as a set of indicators developed by the OECD Working Group on Environmental Indicators. The measures described fall in four categories: housing; services and employment; and ambient environment and nuisances. The report lists both proposed indicators and topic areas suggested for further work.

This material is particularly useful background for municipal SOE reports.

APPENDIX I

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HUMAN ACTIVITY AND THE ENVIRONMENT

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APPENDIX II

INDICATORS WHICH HAVE BEEN USED IN NON-CANADIAN SOE REPORTS AND WHICH COULD BE APPLIED IN ENVIRONMENT CANADA'S SOE PROGRAM

INTRODUCTION

This Appendix lists environmental indicators which may not have been considered for the federal State of the Environment Reporting Program, but which may in fact have merit for the program.

From: Brown, L.R., E. Wolf and L. Starke (1984) <u>State of the World 1984</u>. A Worldwatch Institute Report on Progress Toward a Sustainable Society. W.W. Norton & Company, New York and London.

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1. Fuel efficiency in new automobiles

2. Cropping systems and soil erosion

3. Effect of topsoil loss on corn and wheat yields

4. Increase in fertilizer needs for corn as soil erodes

5. Reduction in yields of key crops as soil erodes

6. Siltation rates in selected reservoirs

7. Per capita consumption of wood products

8. Ratios of use to recycling for paper, aluminum, steel and beverage containers

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From: Brown, L.R., E. Wolf and L. Starke (1985) <u>State of the World 1985</u>. A Worldwatch Institute Report on Progress Toward a Sustainable Society. W.W. Norton & Company, New York and London.

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1. Annual household water use and potential savings with simple conservation measures

2. Efficiency of grain conversion to meat by various animals

3. Estimated accelleration of mammal extinctions

4. Number of samples of major crops held in gene banks

5. Efficiency of typical household appliances versus best 1983/84 models

6. Energy consumption and carbon dioxide and sulfur emissions in 1984, with alternative projections for 2000 and 2025

7. Cost of burying a ton of trash in landfill, with projections to 1990

8. Efficiency improvements in residential space heating 1970-82

From: Brown, L.R., E. Wolf and L. Starke (1987) State of the World 1987. A Worldwatch Institute Report on Progress Toward a Sustainable Society. W.W. Norton & Company, New York and London.

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1. Projected reductions in annual grain output as unsustainable use of land and water is phased out

2. Water supplies under present and postulated climate

3. Projected dates for a doubling of carbon dioxide over preindustrial levels given different rates of growth in fossil fuel emissions

4. Eficiency of energy use, selected countries, 1983 (megajoules per dollar of GNP)

5. Carbon emissions intensity of economic output (carbon per $1000 of GNP

From: Council on Environmental Quality (1984) Environmental Quality. 15th Annual Report of the Council on Environmental Quality. U.S. Government Printing Office, Washington.

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1. Pollution abatement expenditures by selected industries

2. Pesticide production by type

3. River miles meeting the fishable/swimmable goal of the Clean Water Act

4. Lake acres meeting the fishable/swimmable goal of the Clean Water Act

5. Comparison of estimates of global inputs of petroleum to ocean waters, 1974-1984 in millions of metric tons per year

6. Costs and benefits of lead phasedown

7. Incremental cancer risk to most exposed individual from incineration releases

8. Sheet and rill erosion by major land use

9. Average annual sheet, rill, and wind erosion on cropland

10. Scale and levels of concern for the Index of Fish and Shellfish Diseases

11. Index of Marine Degradation

12. Proposed indices of coastal degradation

From: International Institute for Environment and Development and World Resources Institute (1987) World Resources 1987. Basic Books, Inc., New York.

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1. Protected areas classified by biogeographical realm and province

2. Recovery of selected materials (aluminum, copper, iron and steel, lead, tin, zinc, paper, and glass

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From: Organization for Economic Cooperation and Development (1987) OECD Environmental Data Compendium 1987. OECD, Paris.

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1. Cumulative production and release into the atmosphere of CFC-11 and CFC-12

2. Waste recycling activities, recovery rates

3. Population exposure to transport noise

4. Population living in areas exposed to various levels of daytime road traffic noise

5. Estimated cumulative volumes of radioactive wastes from nuclear power plants

6. Public research and development expenditures for environmental protection

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From: The Conservation Foundation (1987) State of the Environment: A View toward the Nineties. A Report from the Conservation Foundation, Washington.

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1. Number of areas not ataining air pollution standards, by pollutant

2. Commuter exposure to carbon monoxide in Washington, D.C., Winter, 1982-83

3. Worker exposure to carbon monoxide in Washington, D.C., Winter, 1982-83

4. Estimated degree of damage to foliage in West Germany, by species, 1984

5. Visibility in national parks and the western states, summer, 1985

6. Major sources of groundwater contamination

7. Selected pesticides in human adipose tissue, 1970-83

8. Dietary intake of metals

9. Generation of hazardous waste per capita

10. Area and annual average erosion of selected land-use classes

11. U.S. Cropland treated with soil conservation practices, by erosion potential category

12. Percent of total cropland treated with conservation tillage

13. Resources used in U.S. agricultural production, 1964-85

14. Estimated expenditures for hazardous waste management, 1983 and 1990

15. A day in the life of...--one person's exposure to respirable particles, October 16, 1979

From: United Nations Economic Commission for Europe (1987) Environment Statistics in Europe and North America: An Experimental Compendium. United Nations, New York.

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1. Results of waste-water treatment (quality of influents/quality of effluents)

2. Harvesting intensity of forest (percent)

3. Trace metals in animals of different trophic levels, by area

4. Chlorinated compounds in animal tissue of diferent trophic levels, by area