Indicators in Environmental Health: Identifying and Selecting Common Sets

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ABSTRACT

In association with the proposed goals of the conference, this paper is presented to support the conference discussions on environmental health indicators by providing background on indicators for environmental health and their identification, selection, organization and use. This paper discusses the purpose of indicator use, frameworks used to organize indicators and the common types of indicators in use in monitoring programs today. It proposes a process for the identification and selection of indicators within the different environments, stressing the importance of clear goal definition and scientific and use-based criteria selection to support decisions. Finally, the paper suggests methods by which to organize and limit the number of indicators retained within a program, and the development of a potential "core" of indicators common to many environments and geographical scales.

RÉSUMÉ

En lien avec les objectifs de la conférence, l'article alimente les discussions sur les indicateurs de l'hygiène de l'environnement en présentant le cadre de tels indicateurs et de leur choix, leur organisation et leur utilisation. Les auteurs analysent le but du recours aux indicateurs, les cadres servant à leur organisation et les types courants d'indicateurs qui sont utilisés de nos jours dans les programmes de surveillance. Ils suggèrent une méthode de détermination et de choix des indicateurs dans divers milieux, en insistant sur l'importance de définir précisément les objectifs ainsi que les critères scientifiques et ceux qui sont fondés sur l'utilisation et qui servent à justifier les décisions. Enfin, l'article propose des méthodes pour organiser les indicateurs retenus dans le cadre d'un programme et en limiter le nombre et pour définir un groupe potentiel d'indicateurs communs à nombre de milieux et d'échelles géographiques.

Why monitor and develop surveillance systems?

Monitoring and surveillance are important aspects of public health practice. They involve the collection and analysis of routine measurements aimed at detecting changes in the environment, the health status of populations, or both. Further, they can involve continuous or periodic measurement of the effect of an intervention on the health status of the population, the environment, or both. Finally, they can provide overseeing of activities to ensure that things are going according to plan.[1] Surveillance is a key task in many governmental organizations charged with ensuring the health and well-being of the population and/or environment (see Eylenbosch and Noah[2]). These activities are particularly important in ecosystems, such as the Great Lakes, where the link between society and environment (or human health and ecosystem health) is particularly acute. These ecosystems are a source of potential hazards as well as a fundamental condition for human well-being (see Cole et al.[3]) and thus their monitoring and surveillance are critical.

Valuing measurement and monitoring

Monitoring and surveillance are purposeful human activities, closely related to the goals and values of the societies in which they are embedded. They are measurement devices that inform on what society deems important enough to monitor. Yet measurement is only one way of conceptualizing and categorizing phenomena of interest (see Fortin,[4] City of Toronto,[5] Hancock et al.,[6]). As Alonso and Starr[7] note, for such things as official statistics, measurements reflect presuppositions and theories about the nature of society being shaped by social, political and economic interests. Thus, data from monitoring are only meaningful when they are interpreted.[8] As Allen and Hoekstra[9] note, measurement has to wait for a definition – normatively and scientifically derived – of what is to be quantified. It is important therefore to ensure that monitoring systems are broad-based, including local studies, qualitative findings and community stories. It is important to note that monitoring is meant to provide information to think about and conceptualize an issue, to chart progress toward desired change, to provide a basis for empowerment and to identify the needs and capacities of, for example, the

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Great Lakes populations. It represents a larger body of information than simply the data it provides and thus some consideration for a variety of forms of information must be considered where appropriate (e.g., inclusion of community stories allows people to speak in their own words and use their experiences as the basis for action). Yet, counting is societally important. As Stone[10] points out, what is measured is political in that it is based on decisions about categorizing, inclusion-exclusion criteria; it implicitly creates norms; it is used to tell 'stories'; it makes the complex apparently simple and precisely defined; and it creates political communities. Furthermore, numbers have tremendous salience in western culture and monitored, quantified data are usually given precedence over all other (see Porter[11]; Eyles[12]).

All monitoring is thus important and its specificity must come from the value it provides in moving towards desired changes. And while it is increasingly recognized that evidence often plays a small part in decision-making, we concur with Innes[13] that monitoring will be valued in policy decisions if it is theoretically sound and meshed in publicly understood concepts (e.g., stories to support surveillance outputs); is developed and overseen by people representing a variety of interests and processes; utilizes a careful process to ensure public exposure and policy attention (i.e., the timeliness and relevance of the system); and institutionalizes data collection to protect it from special interests.

INDICATORS AND THEIR USE

Monitoring through indicators

With increasing knowledge and understanding of various forms of environmental degradation and pollution and their impacts on human health, there has been increased emphasis on government initiatives to manage and, where possible, minimize these impacts. Subsequently, more attention has been given to tracking processes such as benchmarking and status reporting (i.e., State of the Environment) to provide information for evidence-based decision making. As this task is daunting, measurements that are indicative of the relationships and impacts of concern and of specific interest to individuals are chosen as "indicators" of the status of these relationships and their outcomes. Indicators provide clues to matters of larger significance or make perceptible a trend of phenomenon not immediately detectable and thus their significance extends beyond what is measured. For environment and health, the International Joint Commission[14] outlines five such examples of common uses for environmental indicators. They are:

- Compliance Indicator: assessment of current condition of environment;
- Change Indicator: to document trends or changes;
- Early Warning Indicator: to anticipate hazardous conditions before impacts occur;
- Diagnostic Indicator: to identify causative agents to specify appropriate action;
- Relational Indicator: to identify interdependence between indicators.

Briggs et al.[15] state that environmental health indicators are *"an expression of the link between environment and health, targeted at an issue of specific policy or management concern and presented in a form which facilitates interpretation for effective decision making"*. Despite the numerous definitions in the literature, common characteristics exist among them. Indicators summarize some aspect of a relationship within a phenomenon in a way that can support specific program goals. They are indicative of something based on previous knowledge, experience, or understanding of the relationship between the indicator and the phenomenon studied. Thus, by definition, indicators reflect the conceptual bias of the model on which they are based.[16] Despite these confounding factors, they can provide information in an accessible, and understandable way. However, as Innes[13] states, *"more is required to inform policy than simply producing academically certified data and handing it to policy makers"*.

Framework Components

<table>
<tr><td></td><td colspan="3">Pressure</td><td colspan="2">State</td><td>Response</td></tr>
<tr><td>Issue</td><td>Indirect Determinant</td><td colspan="2">Direct Determinant</td><td colspan="2">Health Status</td><td>Response</td></tr>
<tr><td>Driving Force</td><td>Pressure</td><td>State</td><td colspan="2">Exposure</td><td>Effects</td><td>Actions</td></tr>
<tr><td></td><td>Pressure</td><td colspan="2">External Dose</td><td colspan="2">Internal Dose
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Death</td><td>Actions</td></tr>
<tr><td>Condition</td><td colspan="5">Stress</td><td>Response</td></tr>
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Figure 1. Examples of Frameworks for Indicator Organization.
Sources: OECD,[17] von Schirnding,[18] Environment Canada, WHO[42]

Frameworks of understanding systems

To be useful, the models and biases underlying indicators must be defined. One of the most recognized of these models or "frameworks" is that of the "pressure – state – response" model put forth by the OECD.[17] This model is based on the understanding that certain pressures on a system (e.g., release of toxic substances in the environment) cause certain forms of stress on components within the system (e.g., pollution of organism tissues or compartments of air, soil or water), influencing their status (e.g., levels of substances in organisms, or environmental compartments) which then elicits various forms of response (e.g., organism mortality). From this basic model, a number of others with varying levels of specificity have been derived (Figure 1). Whether the interest of a monitoring program is to look in greater detail at the factors leading to the pressure on the system (what von Schirnding[18] calls "driving forces"), at the states or responses within the system (e.g., external dose, internal dose and effect at the organism, cellular or molecular level), or at actions taken to combat negative impacts (e.g., government emission control legislation), is determined by its goals and ultimate purpose (see Kjellstrom and Corvalan[19]).

Different types of indicators exist to help monitor pressures, responses, and actions. Traditional indicators of individual health have included measurements of morbidity and mortality as they are "objective" representations of the status of a population. In a simplified sense, objective measures are based on counts of behaviour and conditions associated with a particular situation.[20] However, often there is interest and value in investigating subjective measures, such as self-reported notions of health and well-being, as they can indicate deteriorations or improvements in well-being encompassing a number of often hard to measure factors. In a simplified sense, subjective indicators are based on reports people make about their feelings, attitudes and evaluations.[20] Many criticize subjective measurements for their obvious potential interpersonal variability, however Andrews[21] argues that well-constructed subjective measures can show high levels of validity and reliability, and Hancock et al.[6] argue that subjective indices are good for an index of change, but that the confounders to any data must be investigated and identified.

In addition to the objectivity of indicators, one must consider whether the phenomenon of interest is being investigated from a positive or negative perspective. Traditional measures of health, such as rates of disease and life expectancy, are more indices of illness and death than health or well-being and are considered to be negative measures of health. This presence/absence of disease approach is also common in toxicology and epidemiology research on human exposure, health consequences, and outcomes and is used analogously in ecosystem health.[16] Positive aspects can be identified, but are often associated with well-being and are often difficult to measure succinctly. Four ways in which health has been defined positively are:

1. That which enables people to achieve maximum personal potential;[22]
2. Ability to adapt to new or changing circumstances;[23]
3. A state of complete physical and social well-being and not merely absence of disease or infirmity;[24]
4. State of optimum capacity of individual for effective performance of tasks and duties for which they have been socialized.[25]

Just as health is complex, so is the concept of environment. "Environment" and "ecosystem" are multi-faceted and potentially complex entities unto themselves and it must be clearly identified what exactly the focus of these concepts is if a set of indicators is to be successful in achieving the desired focus (for a discussion and definitions of these terms, see Cunningham and Saigo,[26] Haskell et al.,[27] Woodley[28]; for a discussion of the concepts and definitions of health, see Aggleton,[29] Eyles et al.,[16] Cole et al.,[30] Hancock et al.[6]).

Indicators can measure aspects of health or environment, for example, at different scales (e.g., individual, local, regional, national or global). However, consideration must be given to the level at which an indicator is grouped when interpreting the data and making decisions based on this information. Often indicators built upon aggregated data (e.g., a specific indicator for health status at the municipal level) may hide inequalities at smaller scales included in the aggregate information (e.g., significant differences between groups of individuals in the municipality). For example, Canada boasts one of the highest life expectancy rates in the world, but this hides high mortality rates in some Aboriginal communities. Vogel[31] suggests when dealing with communities and individuals, it is better where possible to deal with individual-based data rather than aggregated data, as interpretations at one level of grouping can influence the validity of data at another. For these reasons, consideration must be given to building aggregates from individuals where possible, to ensure sensitivity at the individual level. Again, the level of aggregation required among indicators relates to the goals and objectives of the monitoring and surveillance program and should be considered in indicator identification, selection, or development.

INDICATOR IDENTIFICATION AND SELECTION

Criteria for indicator selection: Selecting the "right" ones

The possible array of indicators for environment and health remains overwhelming. What is necessary to keep in mind is the purpose of indicator selection and the fact that any such selection will appear, for other purposes, incomplete. It will also be temporary, reflecting our state of knowledge and ability to act at any one time. We present here some of the criteria used to select indicators from the many that exist for monitoring purposes within a surveillance program. Each program will have its own set of criteria, but some are common and should be included in most, if not all cases. We concur with the review and organization of criteria present in the literature by Eyles et al.[16] in which these criteria are separated into two basic forms: scientific-based and use-based.

Scientific Criteria

Scientific criteria are generic to the issue of scientific quality and include:

1. Data availability and suitability: is it already collected? what was the original intent?
2. Indicator validity, which includes:
   - Face validity: is it a reasonable measure?
   - Construct validity: does it describe what it claims to?
   - Predictive validity: does it correctly predict a situation?
   - Convergent validity: do many measures collected or structured in different ways move similarly?
   - Content validity: what is the fit between the indicator and the object being observed?
   - Theoretical and empirical validity: is it an important health determinant or dimension?
3. Indicator representativeness: the indicator's appropriateness to represent a specific dimension.
4. Reliability: measured by consistency over a number of repetitions.
5. Ability to disaggregate: those indicators that are able to be broken down into other variables telling us much more than the single measure it represents.

Those criteria presented here are the most commonly identified and what we consider to be representative of a reasonable degree of indicator scientific quality. This list includes those criteria covered by others (e.g., Eyles et al.,[16] Eylenbosch and Noah,[2] Hancock et al.,[6] von Schirnding[18]) although slightly rephrased.

Use-based Criteria

The development and selection of use-based criteria depend on the goals of the indicator application or surveillance program within which they are used. Use-based criteria present in the literature vary from the general (e.g., are they feasible to collect?) to the very specific (e.g., what is the valency of the indicator (potential to carry political and social punch)). As Eyles et al.[16] state, as much clarity as possible is required in the relationship between the indicator and the purpose for which it is used. Some of the commonly reported use-based criteria include:

1. Feasibility (are they already collected, and if not, how feasible is it to collect new information);
2. Resonance with audiences (importance of the indicator measurement to those affected);
3. Gameability (the ability of the indicator to be manipulated for those with something to gain);
4. Manageability (a manageable number is needed to attain specified goals yet not be too large to comprehend and manage mentally);
5. Balance (a balance among all phenomena of interest should be represented);
6. Catalyst for action (those that act as a catalyst to action of one form or another).

There exist variations to these in the literature. Some lists include such things as indicator sensitivity, understandability by the press and policy-makers, cost-effectiveness, minimal environmental impact to collect, audience interpretability, population applicability, etc. (Hancock et al.,[6] USEPA,[32] IJC[14]). Regardless of the specific criteria developed and used, a close relationship between the criteria and the goals set for the use of the indicators is paramount. The criteria selected reflect these goals and help retain indicators to meet them (for an example of a composite of these scientific and use-based criteria, see Rump[33]).

In applying these criteria, we should note that applying the use-based ones may well appear to compromise the scientific ones. But if a particular phenomenon requires special surveys or studies to be carried out at several points in time, then its scientific salience must be set against practical issues such as cost, timeliness, interpretability.

TABLE I
Procedures Used to Combine Indicators

Statistical Methods	Conceptual Methods	Ad Hoc Methods
1. Correlation analysis	1. Expert judgement	1. Indiscriminate selection (e.g., selection of all available data in a content area)
2. Regression analysis	2. Theory	2. Opinion (public)
3. Factor analysis (of various kinds)	3. Logical analysis (e.g., cluster analysis)	3. Addition and equal weighting
	4. Linguistic analysis	

Source: Amended from Rossi and Gilmartin (1980), as in Eyles[20]

Criteria for combining indicators into composites

In addition to selection through the use of specific scientific or use-based criteria, the number of indicators retained can be decreased, in some instances, by developing composite indicators. Composite indicators can group similar data (e.g., concentration of total airborne metal pollutants as compared to concentration of airborne Pb), or through calculation create a "new" indicator (e.g., Quality of Life calculations). These composites carry with them new meaning and represent more than the individual indicators used to create them. Often they are created exactly for that intent, as they carry more "weight" in decision-making processes than their individual components (e.g., QoL or Human Development Index) and are interpreted as being more "meaningful" in comparison across jurisdictions, boundaries, etc. (e.g., air quality index). Eyles[20] reviews procedures used to combine indicators into composites or indices in his review of social indicators (Table I). In any case, caution should be taken in compiling and retaining information in composites without specific reasoning as data compiled as composites are more complex to verify and disaggregate.[18]

Limits to information processing

With an increasing interest to construct, identify and agree upon common indicators that might be utilized throughout many jurisdictions or political boundaries and covering a range of concerns, some consideration for the appropriate number of indicators to use to study any one phenomenon is required. Ideally, the minimum number to be used would be the minimum number needed to meet any targets or established program goals.[2] As this is difficult if not impossible to determine, some consideration for the limits to human comprehension or cognizance is useful. From psychological studies, Miller[34] identified a limit of 7 ± 2 as the "magic" number for humans, a limit of our processing abilities. Hancock et al.[6] argue that conceptual systems are too simple and small (e.g., less than 6), but too many indicators (greater than 30) makes it difficult to manage. Therefore it is suggested that a small number of categories with a small number of indicators in each be retained and then a core selected as a balance from all of the categories. Among those selected, a balance of positive and negative, subjective and objective indicators should be included.

Sentinel events and stories

The need to reduce indicators is particularly pertinent for health indicators with an environmental linkage because of the diverse and complex subject matter, ranging potentially from radon and cancer to fear of contaminant burden and psychosocial health. One practical way of reducing this number is through using sentinel health events (see Rothwell et al.,[35] Mullan and Murthy,[36] Seligman and Frazier[37]). Such events serve as a warning signal, pointing to cases of disease or illness that seem out of the ordinary and that can be potentially linked to an external factor. In this way, such events can be used to assess the stability or change in health levels of a population.[1] In Seligman and Frazier's words,[37, p.16] a sentinel health event is then "a case of unnecessary disability, or untimely death whose occurrence is a warning signal…". It is of course possible to identify sentinel events for environmental integrity or stress, e.g., the disappearance of particular species (see Rothwell et al.[35] for potential indicators of sentinel events for environmental chemical exposures).

By definition, sentinel health events are concerned with death and disease states. If a definition of health is broadened to the

TABLE II
Criteria for 'Assessing' Sentinel 'Stories'

Criteria	Definition	Assumptions	Strategies/Practices to Satisfy Criteria
Credibility	• Authentic representation of experience	• Multiple realities • Causes not distinguishable from effects • Empathetic researcher • Researcher as instrument • Emphasis of the research endeavour	• Purposeful sampling • Disciplined subjectivity/bracketing • Prolonged engagement • Persistent observation • Triangulation • Peer debriefing • Negative case analysis • Referential adequacy • Member checking
Transferability	• Fit within contexts outside the study situation	• Time and context-bound experiences • Not responsibility of 'sending' researcher • Provision of information for 'receiving' researcher	• Purposeful sampling • Thick description
Dependability	• Minimization of idiosyncrasies in interpretation • Variability tracked to identifiable sources	• Researcher as instrument • Consistency in interpretation (same phenomena always matched with the same constructs) • Multiple realities • Idiosyncrasy of behaviour and context	• Low-inference descriptors, mechanically recorded data • Multiple researchers • Participant researchers • Peer examination • Triangulation, inquiry audit
Confirmability	• Extent to which biases, motivations, interests or perspectives of the inquirer influence interpretations	• Biases, motivations, interests or perspectives of the inquirer can influence interpretation • Focus on investigator and interpretations	• Audit trail products • Thick description of the audit process • Autobiography • Journal/notebook

Source: Lincoln and Guba,[38] Baxter and Eyles[39]

illness experience and its positive aspects in human potential and well-being, such indicators may be supplemented with 'sentinel stories' which can illustrate both the adverse effects of the environment for health and the role it plays in enhancing well-being. We suggest the application of qualitative research criteria (see Lincoln and Guba,[38] Baxter and Eyles[39]), especially those of credibility, transferability, dependability, and confirmability (see Table II), all of which ensure the scientific adequacy and trustworthiness of the stories (see Eyles et al.[40] for a description of sentinel story assessment).

CHOOSING A CORE SET

A common process for consensus and influence

Given all of the above, is it possible to choose a core set of indicators? A two-staged process for indicator identification and selection was used by Gosselin et al.[41] in their "Indicators for Sustainable Society". Indicators were first selected based on a variety of criteria including both scientific and use-based criteria tailor-made for the purposes of measuring aspects of sustainability within societies. A stakeholder-based scoring system was used to reduce the final number of indicators retained based on the criteria and their balance among phenomena of interest within the program.

It remains to be decided whether such a process is acceptable for establishing indicators for other ecosystem and large bioregions. At the very least, discussion and agreement on both the process of establishing indicators and the process of establishment itself are required. With respect to the process, those involved must agree on the 'terms of engagement', i.e., who may speak with respect to indicators for specific environments; will those be discussed before core indicators for the whole ecosystem; how will consensus be achieved; etc.

With respect to establishing indicators themselves, it is important to discuss issues such as the scale of applicability (e.g., local, regional, national), the types of comparison that the indicators will illuminate (e.g., geographic comparisons, temporal comparisons, combinations of these). In some ways, these issues attend to goals. Thus, in conclusion, we recommend that the following issues be addressed in the order presented below to begin any identification and selection of indicators for monitoring and surveillance:

- Goals of the indicators;
- Conceptual model used for indicator identification and selection;
- Criteria (scientific and practical) to select indicators with the balance between the types fully discussed;
- Indicator selection – first, for each environment, select 7 ± 2 indicators, and then for the ecosystem as a whole, select 7 ± 2, in light of the choices made with respect to the most important criteria;
- Identification of sentinel events and stories – first for each environment, site or a sentinel indicator/event/story; then for the ecosystem as a whole, select 3 ± 2 sentinel indicators/events/stories.

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