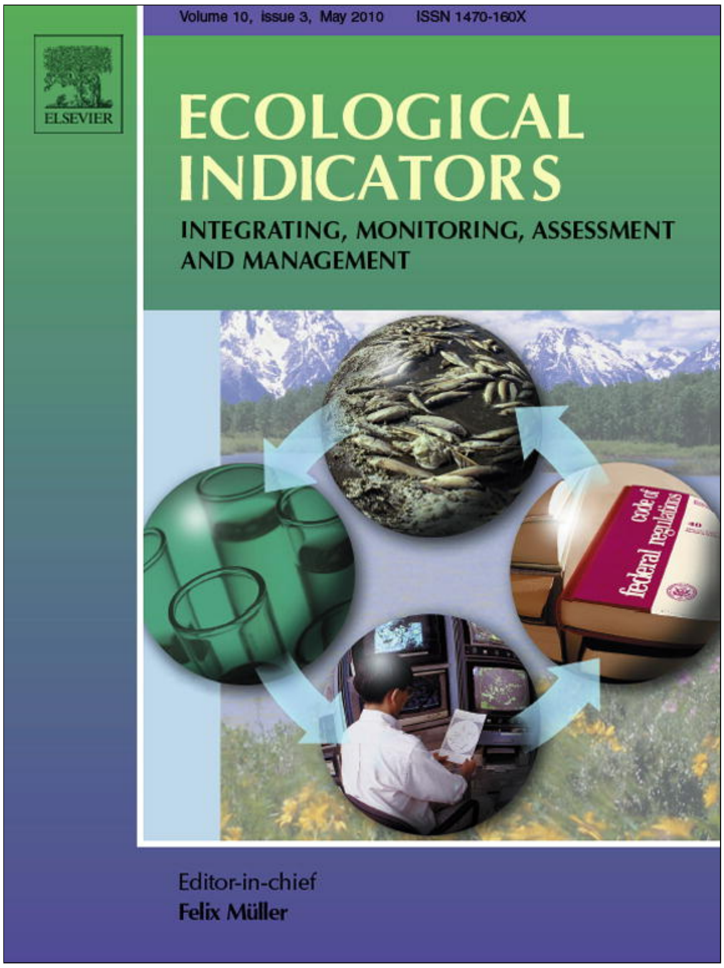
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What are indicators? On the definition of indicators in ecology and environmental planning

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ABSTRACT

The term ''indicator'' is frequently used at the interface between science and policy. Although there is a great demand for clear definitions of technical terms in science and policy, the meaning of indicator is still ambiguous. In this contribution, we analyze different meanings of the term in ecology and environmental planning, suggest a general definition, and make recommendations for its appropriate use. We determined that the ways in which indicator is defined differ greatly, and some definitions are mutually exclusive. We arrived at the conclusion that a broad definition of the term is feasible. We recommend distinguishing between indicators as ecological components, i.e., ecological units, structures, or processes and as measures, i.e., properties of a phenomenon, body, or substance to which a magnitude can be assigned, and between descriptive and normative indicators. This clarification prevents the term ''indicator'' from becoming a meaningless buzzword, improves communication among stakeholders, and assures the testability of theories that include indicators. To avoid problems based on different understandings of the term and to maintain integrity in its use, we advise always providing a definition of the indicator term.

1. Introduction

The importance of defining technical terms is widely accepted in science. A failure to define technical terms unambiguously leads to two main problems (Hempel, 1952, 1966; Murphy and Noon, 1991; Hull et al., 2003). First, theories that rely on a specific term without defining it cannot be readily tested. Second, communication is difficult; agreements based on certain terms are illusory if different stakeholders have a different comprehension of the term's meaning. Thus Murphy and Noon (1991) call for providing clear definitions for crucial terminology in legislation, standards, and guidelines.

Several publications have struggled to clarify ambiguous terms in conservation biology and environmental planning (e.g., Johnson et al., 1997 with an overview of environmental terms). The ambiguous terms include biodiversity (Delong, 1996); potential natural vegetation (Härdtle, 1995); weeds (Randall, 1997); introduction, naturalization, and invasion (Richardson et al., 2000); naturalness (Kowarik, 1999; McIsaac and Brün, 1999); and biotic homogenization (Olden and Rooney, 2006). Even definitions of fundamental, long-existing concepts such as species, community, ecosystem, and environment have been analyzed (e.g., Mason and Langenheim, 1957; Mayden, 1997; Jax, 2006, 2007).

The term ''indicator'' is used often and defined nearly as often in ecology and environmental planning. Although it is often used ambiguously and in different contexts, so far a systematic overview of existing definitions of the term is missing. Moreover, none of the available definitions cover the complete breadth of the term.

In this contribution, we first examine existing definitions of indicator in the domains of ecology and environmental planning. We highlight the pivotal elements of existing definitions. Subsequently, we discuss which of those elements are really necessary for defining the term. Finally, with this discussion in mind, we present a general definition of an indicator and propose specific modifications of the definition for different indicator concepts.

2. Definitional analysis of the term ''indicator''

In the following, different definitions of indicators in ecology and environmental planning and the contexts of their application are analyzed. We use the indicator term here as a synonym for ''*indicans*'', i.e., a measure or component from which conclusions on the phenomenon of interest (the *indicandum*) can be inferred. *Indication* here is the reflection of an indicandum by an indicator. We examine the broad classes to which indicator terms are frequently assigned and discuss whether indicators are used in a

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descriptive or normative sense, how indicators and indicanda are specified, and how they correspond to one another. Finally, we investigate the need for accuracy in the correlation between indicator and indicandum, the validity of indicators, and their normative foundation.

For our analysis we screened published articles through theoretical sampling. In grounded theory, theoretical sampling is defined as "sampling on the basis of the emerging concepts, with the aim to explore the dimensional range or varied conditions along which the properties of concepts vary" (Strauss and Corbin, 1998, p. 73). Theoretical sampling allows for the continuous comparison of variations in a concept during analysis (Patton, 2001), leading to elucidation of the meaning. Thus, analyzing, theory-building, and sampling go hand in hand. Theoretical saturation is the point when no new variation in a concept emerges. At this point, the analysis reaches closure.

2.1. The genus proximum in the definition of the indicator term

According to the doctrine of classical logic, the *definiens* consists of two parts (Hempel, 1952; Copi, 1986): the *genus proximum* and the *differentia specifica* (genus–differentia definition). The *genus proximum* is a broad class to which the term to be defined belongs. The *differentia specifica* is a distinguishing feature that separates it from other members of the same class. As a first step it is important to specify the *genus proximum* to which the term indicator belongs.

Indicators are often referred to as parameters, measures, or measurement endpoints (Ferris and Humphrey, 1999; Burger, 2006); measuring entities (Gordon et al., 2005); or variables (Hughes and Madden, 2003). In these cases, an indicator is a quantity, i.e., a property of a phenomenon, body, or substance to which a magnitude can be assigned (ISO/IEC, 2007), e.g., diameter and age class of trees in forests, population size of species, or content of soil organic matter. In the following, we refer to the genus of this kind of indicator as "measures."

In contrast, it is often certain ecological components (sensu Noss, 1990) that are suggested to be the genus for indicators (e.g., the definitions of Carignan and Villard, 2002 or Fränzle, 2006 in Table 1). Components are objects or phenomena themselves (e.g., a species or a process such as fire regime) and not measurable quantities (e.g., species number, mean interval between fire events). Species are often denoted as indicators (Patton, 1987; McGeoch, 1998, Table 1). For example, birds (Gregory et al., 2005), spheciform wasps or mites serve as indicators for biodiversity (Gayubo et al., 2005; Gulvik, 2007), and nematodes serve as soil health indicators (Yeates, 2003). Certain structures (e.g., snags, woody debris; Rempel et al., 2004) or processes (seed dispersal, herbivory; EPA-SAB, 2002) are also used as indicators.

Sometimes these ecological components are referred to using the metaphors "instrument" (Dziock et al., 2006), "gauge" (Meffe and Carroll, 1994), or "device" (Fränzle, 2006), suggesting that an indicator is regarded as corresponding to a measuring instrument. According to the *International Vocabulary of Metrology* (ISO/IEC, 2007), a measuring instrument comprises different components that are necessary for measurement, e.g., a sensor and a displaying device. If species are denoted as indicators, they can be understood as sensors that are affected by the phenomenon or substance of interest (e.g., damage to tobacco leaves as an indicator of the ozone concentration in the air). This is analogous to the sensors that make up a part of the measurement instrument, such as the rotor of a turbine flow meter, the float of a level-measuring instrument or the mercury column of a thermometer. Therefore, in most cases understanding indicators as sensors is more appropriate than as measuring instruments.

Rarely, indicators are referred to as parameter values or concrete measured or calculated results (Messer et al., 1991; Shear et al., 2003, Table 1), for example critical loads of atmospheric sulphur or nitrogen deposition can serve as an indicator for detrimental effects on ecosystems (e.g., acidification of soils). In contrast to indicators as *measures* (e.g., nitrogen deposition), indicators as *measurements* have a specific value (e.g., 1.5 kg N ha^{-1} yr^{-1}).

The use of measures or ecosystem components as indicators is widespread in ecology and environmental planning. In contrast, the use of parameter values or measurements as indicators is quite uncommon. Therefore, we will further address only measures and components as the genus for the indicator term.

2.2. Descriptive and normative indicators

Concepts that address indication as a measurement use indicators at a descriptive level and aim to reflect attributes of indicanda (Zehlius-Eckert, 1998), describe the state of a system (Walz, 2000), or analyze environmental changes (McGeoch, 1998). However, indicators are not only used to describe environmental states or changes but also to evaluate them and to set objectives (Rempel et al., 2004; Dziock et al., 2006). Table 1 shows an overview of definitions of indicators covering a broad range of descriptive, normative, and hybrid indicator concepts.

Rempel et al. (2004) use normative indicators to stipulate the future condition of habitats (prescriptive indicators) and to test whether a desired environmental condition was ultimately achieved (evaluative indicators). Prescriptive indicators are often developed in conjunction with evaluative indicators. Prescriptive indicators relate to attributes that are directly affected by management (e.g., fire regime, fragmentation). Evaluative indicators serve for evaluating the conservation status of an area or for verifying the efficiency of management. Thus the presence or population size of a species that reacts sensitively to changes in environmental conditions is often used as an evaluative indicator, while the changes themselves serve as prescriptive indicators. For example, Rempel et al. (2004) suggest snags and downed woody debris as prescriptive indicators in forest management. As an indicator to evaluate the success of forest management, they propose the presence of the Red-backed vole (*Clethrionymus rutilus*) or the Barred owl (*Strix varia*), which indicate that the required structures exceed a certain minimum threshold.

Both indicators as measures and as components can be used descriptively and normatively (see definitions in Table 1). Species that are used as prescriptive indicators are often called focal species (Lambeck, 1997) or umbrella species (Roberge and Angelstam, 2004).

Some authors use a hybrid indicator concept, i.e., they use indicators both in a descriptive and in a normative sense. This is not problematic as long as the descriptive and normative uses are clearly distinguished (e.g., Patton, 1987; Scholles, 2008, see Table 1). But there are also cases where descriptive and normative indicator concepts are intermingled in an ambiguous way (Noss, 1990; Messer et al., 1991; Alfsen and Sæbø, 1993, see Table 1).

2.3. Direct or indirect measurement?

Landres et al. (1988) argue that a measurement directly quantifies the attribute of interest and an indication only does so indirectly (cf. Mitchell et al., 1995; Carignan and Villard, 2002). It is not clear though, how a direct representation should be distinguished from an indirect one. And measurement theory concedes that measurement itself can be indirect (Finkelstein, 1975; Fraser, 1980; International Electrotechnical Commission 1992; ISO/IEC, 2007). An indirect measurement may be a function of a combination of direct measurements; for example, the measurement of density can be derived from the measurement of volume

Table 1
Examples of definitions and attributes of the indicator term that exemplify its different uses in ecology and environmental planning.

	Definition	Comment
Indicators as descriptive measures		
Walz (2000)	"An indicator is a variable that describes the state of a system" (Walz, 2000, p. 613).	This definition clearly addresses indicators at a descriptive level as Walz (2000) explicitly points out that states are described by indicators.
Zehlius-Eckert (1998)	"Indicator: attribute of an object, of which the parameter values show a high correlation to parameter values of another attribute (indicandum) of the same or another object. The parameter values of both attributes must be qualitatively or quantitatively correlated as closely and distinctly as possible. Therefore it is advantageous if the causal implications on which the correlation is based are preferably direct and monocausal" (Zehlius-Eckert, 1998, p. 10, our translation).	Zehlius-Eckert (1998) maintains that there must be a high correlation between indicator and indicandum. This requirement is much more rigorous than in other definitions where indicators serve to "describe" (Walz, 2000), "reflect" (Shear et al., 2003), or "represent" (Rempel et al., 2004) an issue of concern. Moreover Zehlius-Eckert advocates that there be a direct causal relationship between indicator and indicandum.
Indicators as normative measures		
Burger (2006)	"Indicator: Index or measurement endpoint to evaluate health of a system (economic, physical, biological, human)" (Burger, 2006, p. 27).	Of the definitions given here this is the one that refers most unambiguously to an evaluative use of indicators. By including indices in the conception, Burger (2006) includes complex measures as indicators.
Riley (2001)	"It is essential to define here exactly what an indicator is. Is an indicator—a variable or a parameter or a measurement or an estimate or an estimator or a threshold? (...) An indicator is ... a function of variables. It provides an indication, i.e., an entity that can be used as an argument of a function used to take a decision." (Riley, 2001, p. 126).	As indicators are a function of variables, an indicator can be a complex parameter. This is the only definition in which the nature of the *genus proximum* is explicitly discussed.
Indicators as hybrid measures		
Alfsen and Sæbø (1993)	"An environmental indicator is usually defined as a number indicating the state and development of the environment or conditions affecting the environment. (...) The indicator is meant to give information in excess of what is directly measured or observed, i.e., the parameter value or statistical information. Thus, an indicator is seldom presented as a single datum, but it should be put in some context from which it is possible to infer what is indicated" (Alfsen and Sæbø, 1993, p. 416).	According to Alfsen and Sæbø (1993) indicators can be used descriptively for a scientific purpose or normatively for a political purpose. For them an indicator must be placed in a context that allows an interpretation of indicator values. They use the evaluation of air quality as an example of a context (Alfsen and Sæbø, 1993). It is quite remarkable that Alfsen and Sæbø (1993) do not point explicitly to the relation between an indicator and an indicandum. Rather, the crucial characteristic of an indicator is that it is possible to interpret or evaluate its value.
Ferris and Humphrey (1999)	"An indicator may be defined as a characteristic which, when measured repeatedly, demonstrates ecological trends, and a measure of current state or quality of an area" (Ferris and Humphrey, 1999, p. 313f).	Ferris and Humphrey (1999) explicitly point out that indicators are used to assess not only states and trends, but also quality. Quality in this context is a highly value-laden term (cf. Kraft, 1981).
Mitchell et al. (1995)	"Indicators are alternative measures that are used to identify the status of a concern when for technical or financial reasons the concern cannot be measured directly. We need indicators because they enable us to gain an understanding of the complex systems around us. They do this by: (1) synthesizing masses of data; (2) showing the current position, in relation to desirable states; (3) demonstrating progress towards goals and objectives; and (4) communicating current status to users (scientists, policy makers or the public) so that effective management decisions can be taken that lead us towards objectives. (...) There are two types of 'indicator': simple indicators expressed in units (e.g. rainfall, in mm) and indices which combine single indicators in an index that is expressed as a dimensionless number (e.g. the FT100 share–price index)" (Mitchell et al., 1995, p. 105).	Here, indicators are understood as indirect measures for issues of concern. They can be either simple or complex. The indicandum is understood as a complex system.
Noss (1990)	"Indicators are measurable surrogates for environmental end points such as biodiversity that are assumed to be of value to the public" (Noss, 1990, p. 357). "Selection of indicators depends on formulating specific questions relevant to management or policy that are to be answered through the monitoring process" (Noss, 1990, p. 358).	This definition is quite ambiguous with respect to the descriptive and normative functions of indicators. On the one hand Noss (1990) puts an emphasis on the measurement of indicators and, through this, of environmental end points. On the other hand he points out that those end points have to be of value to the public. In this way the definition excludes many indicators in natural science that serve to assess end points for value-free scientific interest.

Table 1 (*Continued*)

	Definition	Comment
Indicators as parameter values, measurements or measurement results in hybrid concepts		
Messer et al. (1991)	"Response indicators are biological measurements that quantify the condition of ecosystems and integrate the effects of man-induced stresses acting alone or together, episodically or chronically over time (...). Exposure indicators include physical, chemical, and biological measurements that can be related to pollutant exposure, habitat degradation, or other causes of poor condition (...). Stress indicators include economic, social, and engineering data, and other measures that can be used to determine the most probable sources of pollutant exposure or poor habitat condition" (Messer et al., 1991, p. 70).	Messer et al. (1991) refer to concrete measurements as indicators. Most important in this indicator concept is the way it distinguishes among a causal chain of stresses, exposure to those stresses, and the results of the exposure. Thus Messer et al. (1991) establish a wide range of applications for indicators. Value-related aspects of this definition include the fact that it limits the objects of indication to certain positive or negative issues and the use of value-laden terms ("stressor," "degradation," "pollutant," cf. Kraft, 1981).
EEA (2003)	"An indicator is an observed value representative of a phenomenon of study. In general, indicators quantify information by aggregating different and multiple data" (EEA, 2003, p. 5).	By describing an indicator as representative of a phenomenon of study, the correlation between indicator and indicandum remains only vaguely specified. Indicators are understood as complex values.
Rempel et al. (2004)	"Indicators are measurements representing specific issues or concerns. If they do not specifically represent an issue, they are simply measurements, and of no concern to a monitoring program" (Rempel et al., 2004, p. 83). "Prescriptive indicators are used in harvest planning to stipulate the future condition of the forest" (Rempel et al., 2004, p. 84). "Evaluative indicators test whether the future forest condition achieved the ultimate objective" (Rempel et al., 2004, p. 84).	Similarly to Alfsen and Sæbø (1993) and Mitchell et al. (1995), Rempel et al. (2004) maintain that indicators have to reflect certain concerns, which distinguishes them from other measurements. They make clear that indicators can be used in a normative context and divide normative indicators into prescriptive and evaluative indicators. The use of indicators for setting goals for certain sites or as yardsticks for a general evaluation suggests that the denomination of indicators as measurements is made unintentionally.
Shear et al. (2003)	"An indicator is a parameter or value that reflects the condition of an environmental (or human health) component, usually with significance that extends beyond the measurement or value itself. Used alone or in combination, indicators provide the means to assess progress toward one or more objectives ..." (Shear et al., 2003, p. 122).	This indicator concept includes both parameters and values. This is contrary to the opinion of Riley (2001) who explicitly excludes values from the indicator concept.
Indicators as descriptive components		
Carignan and Villard (2002)	"... an indicator is an element, process, or property of the ecosystem that for some reason (logistical, budgetary, technological) cannot be measured in a more direct way" (Carignan and Villard, 2002, p. 46).	Carignan and Villard (2002) explicitly define indicators both as measures (properties) and components (elements and processes). They state that indicators cannot be measured in a more direct way. This is an unusual view as, generally, only indicanda can be measured indirectly. Hence the authors seem to apply the term "indicator" to the indicandum rather than to the indicans.
Fränzle (2006)	"In a general ecological sense, bioindicators are organelles, organisms or groups of organisms suited to determine qualitatively or quantitatively the state of the environment, in the narrower sense of the term the designation frequently refers to the organismic indication of anthropogenic environmental stressors" (Fränzle, 2006, p. 130).	Fränzle (2006) refers to bioindicators as a subgroup of indicators. He gives a general and narrow definition of bioindicators that is somewhat contradictory as the first part refers to the indication of environmental states and the latter part to the indication of stressors.
McGeoch (1998)	"A loose, all-encompassing definition of a biological indicator would therefore be a species or group of species that readily reflects the abiotic or biotic state of an environment; represents the impact of environmental change on habitat, community or ecosystem; or is indicative of the diversity of a subset of taxa, or of wholesale diversity, within an area" (McGeoch, 1998, p. 185).	This definition opens up a wide field of application for indicators (assessment of environmental states, changes or biodiversity).
Indicators as hybrid components		
Scholles (2008)	"An indicator in the language of natural science is an organism, a substance, or an object that provides evidence of a parameter that cannot be measured directly or only with prohibitive effort (...). In environmental planning, in addition to simple indicators, there are also indicators that serve as surrogates for a wide range of individual components and – as a complex indicator or index – deliver an immediate assessment result (...). In environmental planning, the indicator term is used more universally in the context of goal systems. On the lowest level of a hierarchy of goals, indicators are used to measure the fulfilment of goals" (Scholles, 2008, p. 318f, our translation).	Similar to Patton (1987), Scholles (2008) clearly distinguishes between scientific and policy indicators. In this definition, scientific indicators are used to derive an indirect measurement for the parameter of interest and policy indicators are used for evaluating the fulfillment of goals. The use of "to measure" in a normative context in this definition is ambiguously phrased. Indicators in this definition are components, specified as organisms, substances or objects. Moreover, indicators can be simple or complex.

Table 1 (*Continued*)

	Definition	Comment
Patton (1987)	"To indicate is to make known with a high degree of certainty. In biology an indicator is an organism so intimately associated with particular environmental conditions that its presence indicates the existence of those conditions. A major difference between the use of indicators in scientific literature and in federal regulations is that 'management' appears as a modifier in the regulations [National Forest Management Act], thereby creating a term describing conditions that have not been tested" (Patton, 1987, p. 33). "A management indicator ... is used to set goals and direction, but unlike ecological indicators, need not indicate a direct cause-and-effect relationship. The assumption is, however, that some relationship exists between prescribed management activities and MIS [Management Indicator Species]" (Patton, 1987, p. 33).	Patton (1987) clearly distinguishes between indicators in biological science and management indicators. A main feature of a biological indicator is its close association with particular environmental conditions. This is not necessary for management indicators, which serve to set goals and direction.

We differentiate among three kinds of *genus proximum* used in the definition, namely measures (e.g., species richness), components (e.g., a certain taxon), and values and measurement results (e.g., a vegetation cover of 50% in the understory). Furthermore we distinguish between descriptive and normative indicator concepts. Hybrid indicator concepts are those that can be used both descriptively and normatively. In these concepts, authors can either separate the descriptive from the normative level or intermingle these levels in an ambiguous way.

and of mass (cf. Adams, 1966; ISO/IEC, 2007). Finally, in his classic definition of measurement, Stevens (1946) states that measurement is the assignment of numbers to objects or events according to a rule; this is also valid for indications. Adams (1966, p. 142) equates measurement and indication: "The proper question to ask of a procedure of measurement for measuring some quantity (say weight) is not 'Is it a true measure of the quantity or not?' but 'How good an indicator is it of the phenomena it is supposed to give information about?'." Thus it is also clear that the trueness of representation is not an adequate criterion for discriminating between indication and measurement. To conclude, the directness with which indicanda are represented lies along a spectrum. Measurements can be both direct and indirect. We did not find any consistent criteria for distinguishing direct from indirect representation. Therefore directness does not seem suitable for defining what constitutes an indicator.

2.4. Specification of the indicator

2.4.1. Complexity of the indicator: simple or complex indicator (index)?

It is often claimed that indicators capture complex ecological interrelations (Walz, 2000; EPA-SAB, 2002). Indices, which integrate complex conditions in one parameter, are used as indicators (e.g., saprobic index, Kolkwitz and Marsson, 1908, 1909; index of biotic integrity, Karr, 1991; and maturity index, Ruf, 1998). Girardin et al. (1999) subsume both "simple indicators" and "composite indicators" under the term "indicator" (see also the definition of Mitchell et al., 1995, Table 1). At least for composite indicators, not only the indicandum but also the indicator itself is not directly measurable.

Turnhout et al. (2007) define indicator as a nested concept, able to represent any level of complexity. This is also evident in the use of the indicator term in language: invertebrates are indicators of soil quality (Stork and Eggleton, 1992) and soil quality is an indicator of sustainable land management (Herrick, 2000). There are indicators for biodiversity (Noss, 1990) und biodiversity itself can serve as an indicator of soil health (Pankhurst, 1997).

2.4.2. Applications along the chain of cause and effect

Indicators can refer to actions that cause environmental changes, to the exposure of an environmental component to stress, to environmental states or effects caused by certain impacts, or to societal responses to environmental changes (Messer et al., 1991; EPA-SAB, 2002; Braband et al., 2003; OECD, 2003; Burger, 2006). Most notably, the OECD (2003) developed a pressure-state-response (PSR) model to structure its work on environmental policies and reporting. The European Environment Agency (EEA, 2003) extended this model to a driving force-pressure-state-impact-response (DPSIR) model by adding (1) driving-force indicators that describe the social, demographic, and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption, and production patterns and (2) impact indicators describing changes in environmental conditions.

Pressure and stress indicators are used to describe pressures that human activities exert on the environment. They refer to the cause of an environmental change or condition (e.g., emission of harmful substances, the release of nonindigenous or genetically modified organisms, road network density, proportion of intensive crop agriculture). Exposure indicators are characteristics of the environment measured to estimate the co-occurrence or contact between an environmental specimen and stressors over a defined time period (EPA-SAB, 2002), e.g., the concentrations of contaminants in tissues or levels of road noise. They relate to the exposure to conditions or processes that an indicator species or other environmental components can be subjected to without damage (e.g., in its physiological functions or population size).

State-, effects-, and results-oriented indicators relate to environmental conditions and integrated effects of anthropogenically induced stresses. The use of these indicators relies on the sensitive reaction of natural resources to impact factors, for example, damage to trees due to acid rain, the presence or absence of species that are particularly sensitive to pollutants, species composition in habitats, or the proportion of threatened or extinct species as a share of total species.

Response indicators show the extent to which society responds to environmental concerns (OECD, 2003). They relate, for example, to the mitigation of negative effects or preservation of natural resources, e.g., number of protected areas in a country. Note that the meaning of response indicators according to Messer et al. (1991) – who use the term as synonymous with effects indicators (see Table 1) – is different from the more widespread use of the term according to the OECD (2003).

Indicators can be both the impacts on natural resources and the causes of those impacts (Cairns et al., 1993; Dale and Beyeler, 2001; Niemi and McDonald, 2004). For instance, indicators can be used to assess the condition of the environment based on structural features of habitats or to diagnose the presence of a pollutant. Hence, indication can run in two different directions: effect indicators can be used to gain information about stresses, and environmental effects can be concluded from pressure indicators. The most elaborate system accounting for the breadth of indicators is the DPSIR model by the EEA (2003). It includes indicators for driving forces, the resulting environmental pressures, on the state of the environment and the impacts resulting from changes in environmental quality and on the societal responses to these changes in the environment.

All definitions of indicators considered reveal that a generally shared viewpoint on what indicators specify does not seem to exist. Indicators can represent any level of complexity, and they can be applied at any point along a causal chain from an initial human action to responses to impacts on environmental resources.

2.5. Complexity of the indicandum

Indicanda can be simple or complex. Complex indicanda are multidimensional, i.e., they include different fields for which information is needed and may integrate different information over a large area and a long period of time. In contrast, simple indicanda are one-dimensional and reflect singular, short-term conditions.

2.5.1. One-dimensional or multidimensional indicanda

Indicanda can be one-dimensional or multidimensional. For example chlorotic effects on the bean *Phaseolus vulgaris* indicate a one-dimensional indicandum, i.e., the presence of a certain amount of NO_2 (Fränzle, 2006), whereas sustainability is a multidimensional indicandum that comprises environmental compatibility, social acceptability, justice, and sound economic development.

Often it seems that the suggested indicandum is more complex than what is actually indicated. For example, species richness of a certain taxon is often chosen as an indicator for overall biodiversity, but mostly it is only the correlation between different taxonomical groups that is tested (e.g., Sánchez-Fernández et al., 2006; Pearman and Weber, 2007) and not the correlation between species richness of a taxon and other dimensions of biodiversity such as certain ecological processes and structures at different levels of ecological organization. A land use may be considered sustainable if it is economically sound, socially acceptable, and environmentally compatible. But if earthworms are chosen as indicator taxa for sustainability (Paoletti, 1999a), the relation to economy or social acceptability remains unclear.

2.5.2. Integration of information over space and time

Sometimes, indicator species are expected to provide information over long periods and thus integrate environmental changes and fluctuations (Zonneveld, 1983; Dziock et al., 2006). Moreover indicator organisms can combine different environmental influences at once, for example, emission levels of different harmful substances (e.g., Fränzle, 2006) or various human impacts on current site conditions expressed in terms of a hemeroby indicator (Kowarik, 1990). For detecting ecosystem change, Karr (1991) is of the opinion that an ideal index (which is composed of several indicators) would be sensitive to all stresses placed on biological systems by human society while also having limited sensitivity to natural variation in physical and biological environments.

Integration of ecological information over long periods and at larger scales does not, however, seem to be a general definitional attribute for indicator species. For many purposes, indicator organisms that react sensitively to singular and acute environmental conditions (sensitive species or sentinels) are required (McGeoch, 1998; Noss, 1999; Fränzle, 2006). To identify a stressor it is particularly important that the indicator species reacts specifically to a certain influence but is insensitive to others. Zehlius-Eckert (1998) therefore argues that it is advantageous if the ecological interrelations between indicator and indicandum are direct and monocausal to ensure a close correlation between their parameter values. To conclude, there are different viewpoints on the topic of whether an indicator represents single, well-demarcated environmental factors or a complex of different environmental conditions. In the latter case, indicators again serve to reduce complexity.

2.6. Accuracy, validity, and legitimacy of indicators

Indicators can relate in different ways to indicanda. Indicators may be parts of the indicandum or not. In the first case, the indicandum is generally a construct that consists of many features of which one is selected to depict the entire construct. Examples include species richness as an indicator of biodiversity or diameter and age-class distributions of trees for the assessment of the impact of silviculture (Noss, 1999). In contrast, the presence of speckle necroses on *Nicotiana tabacum* leaves as an indicator for ozone concentration in the air (Fränzle, 2006) is not a component of the indicandum.

Several authors argue that indicators must be closely correlated with an indicandum (e.g., Kias and Trachsler, 1985; McCarty and Munkittrick, 1996; Zehlius-Eckert, 1998; Dziock et al., 2006). Kias and Trachsler (1985) are of the opinion that a parameter is an indicator only if it is clearly related to an indicandum as the assessment endpoint. Relatedly, Zehlius-Eckert (1998, p. 10) defines an indicator as an attribute of an object with values strongly correlated to the values of another attribute of the same or another object.

The correlation between indicator and indicandum values can be checked by comparing the results of an indication with the results of an accepted scientific measurement of the indicandum. For example, Ellenberg's indicator values for nitrogen can be compared to physical measurements of soil nitrogen (e.g., measurement in a dilution of KCl or $CaCl_2$) (Wamelink et al., 2002; Diekmann, 2003) or soil humidity values can be correlated with the groundwater level, precipitation, or water capacity of the soil (Kowarik and Seidling, 1989).

For conceptual constructs such as sustainability or biodiversity, standardized measurement methods do not exist. In this case, the validity of the indicators operationalizing these constructs must be checked. Construct validity in this context means that a construct is adequately reflected in its operationalization (Cronbach and Meehl, 1955; Addiscott et al., 1995). For descriptive indicators, an empirical correlation between indicator and indicandum seems to be a necessary defining criterion, although a perfect level of accuracy in the correlation does not need to be achieved. As an analogy, no one would suggest that a measurement of weight is not a measurement if the scale it is taken with fluctuates slightly.

McCarty et al. (2002) endorse the idea that there should be a causal link between indicator values and indicandum values and not only a statistical correlation. In this way, the indicator can give information about the cause and location of an environmental stress. But as the indicator concept is not restricted to the indication of causes of environmental stress (see below), a causal link between indicator and indicandum values does not seem a feasible defining criterion for indicators.

Alfsen and Sæbø (1993) do not call for a rigorous correlation between indicator and indicandum in their definition of indicators. Instead, they maintain that an indicator is meant to give information beyond that which is directly measured or observed. With this, they simply mean that the data obtained with the aid of indicators should be put in some context that allows for its interpretation. For example, to indicate air pollution, the indicator SO_2 concentration can be supplemented with information on places of emissions or a recommended threshold level to interpret the indicator value.

To call for a correlation between indicator and indicandum only makes sense on a descriptive level. For evaluative and prescriptive indicators, the correlation between indicator and indicandum only has a subordinate function. In many cases, an indicandum in a descriptive sense does not exist at all, for example when an indicator species itself is the target of management actions (e.g., Thompson, 2006) and does not serve instrumentally for the conservation of other species or habitats. This applies for example to "special interest species" (threatened or endangered species, game species, charismatic species), which are listed as indicators by Dale and Beyeler (2001). Thus, in an evaluative context, indication primarily means that an indicator reflects a value or an improvement or deterioration. On a prescriptive level, indication simply means a specification of objectives and, thus, in environmental planning, the clarification of conservation goals and of the prevention of environmental damages. In fact, indicators of sustainability are mainly chosen based on their relation to environmental goals and policy relevance (cf. Lang, 2003; Bell and Morse, 2008).

In lieu of a correlation between indicator and indicandum, the legitimation of indicators gains importance in a normative context (Hagan and Whitman, 2006; Mace and Baillie, 2007). Majone (1982) maintains that the scientific and conceptual basis for environmental goals and standards is so precarious, the empirical evidence so ambiguous, that most decisions first and foremost have to be evaluated and legitimated in terms of procedural rationality.

3. Attributes of indicators used for a definition—a proposal

From the previous analysis, we can draw the following conclusions. Indication at a descriptive level is comparable to measurement. To designate indication as an indirect measurement does not seem feasible. The *genus proximum* of the definiens for the indicator term can be a measure or a component of environmentally relevant objects or phenomena. Indicators can be applied in descriptive, evaluative, and prescriptive contexts. A correlation between an indicator and indicandum should be established for descriptive indicators, but is not necessary for normative indicators. Indicators can be used to assess effects on natural resources. And vice versa, indicators related to effects can be used to indicate causes.

The indicator term is sometimes narrowly, sometimes broadly defined. The definitions considered here do not have a common core. In fact, some are mutually exclusive, for example, those definitions that conceive of indicators as measures and those that conceive of them as components. If all definitions are considered complementarily, the indicator concept is extremely broad. Broad in this context means that the set of objects represented by the extension of a given term is very large (Essler, 1982). If indicators are both measures and components, if they can be descriptive, evaluative, or prescriptive, and if they are used to assess states and trends, an all-encompassing definition of indicator results:

> An indicator in ecology and environmental planning is a component or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals. Environmentally relevant phenomena are pressures, states, and responses as defined by the OECD (2003).

This definition delineates a "conceptual cluster" (Jax, 2006) of indicators with different meanings in ecological science and environmental policy. There is no fundamental objection to such a broad definition of a term. In biology, many broadly defined terms are highly useful (e.g., the terms "plant" or "taxon"). But the question arises of how to assess the adequacy of a concept's definition. According to Carnap (1950), fruitfulness is a crucial requirement for an adequate explicatum for a given explicandum. An explicatum is fruitful if it is useful for the formulation of many universal statements. Fruitfulness determines the relevance of a concept in a field of application: to what extent does the term provide for structuring and summarizing a variety of relevant phenomena? For example, in biology the scientific term "fish" (cold-blooded vertebrates with gills that spend their lives in water) is more fruitful than the prescientific term, which included dolphins and whales, because the scientific term indicates more biological properties in common than the prescientific term. Hence the use of the term with a narrower meaning is reasonable in biology as otherwise many universal statements on fish would have to be restricted as they are not valid for whales and dolphins. From an economic perspective, however, it would not make sense to exclude whaling from professional fishery.

The criterion of fruitfulness can also be applied to the concept of indicators. The fruitfulness of the broad definition for indicators given above is restricted, as universal statements and the use of the indicator term in theories are often not possible. As shown above, statements on indicators as measures are not valid for indicators as components whose attributes will be measured. For example, indicators are often required to be habitat specialists and sensitive to change (e.g., Pearson, 1994; Ferris and Humphrey, 1999), but those requirements only hold for species as indicators. At the same time, the demand for a high correlation between an indicator and other parameters (e.g., Lindenmayer, 1999; Duelli and Obrist, 2003) only makes sense if indicators are measures. The concept of a precise correlation between indicator and indicandum is not applicable to prescriptive indicators in environmental planning. The question of the complexity of an indicator mainly relates to measures, as different parameters can be integrated into a single measure. Indicators as components are mainly used to measure effects on those components. Indicators as measures however can relate to pressures (e.g., road network density), effects (e.g., number of threatened species in a country), or human responses to effects (e.g., protected areas as share of national territory). The term indicator thus denotes concepts that should be clearly distinguished, both during conceptualization and in the choice of terms, to achieve fruitfulness.

To keep the indicator concept fruitful, we advise at minimum clarifying whether an indicator is a measure or an ecosystem component and whether the indicator is applied in a descriptive or a normative context. The combination of the particular specifications of indicator attributes leads to four types of indicators: descriptive measures, normative measures, ecological components by means of which certain endpoints of interest can be assessed and ecological components by means of which environmental states or changes are evaluated or by means of which goals for states or changes are set (see Table 2).

A separation of descriptive and normative indicators is essential from the perspective of the philosophy of science (cf. Turnhout et al., 2007). Goals and values cannot be deduced directly from descriptions (e.g., Hudson, 1969; von der Pfordten, 1993), a fact that is emphasized repeatedly in the literature of environmental ethics (e.g., Shrader-Frechette, 1995). Hence, we advise always specifying the definition of indicators and propose clearly distinguishing ecological indicators in science from policy indicators used for decision-making processes. Further, to avoid misunderstanding, we recommend that this distinction be expressed with the use of different terms (e.g. "ecological indicators" vs. "environmental policy indicators").

Only descriptive indicators require a correlation between indicator and indicandum. For evaluative and prescriptive indicators, this correlation is not relevant. However, there is a need for a normative foundation for the correlation between a normative value and a descriptive indicator value (value functions). In many cases the common assumption that there is a linear correlation between indicator values and normative values does

Table 2
Relevance of the criteria that different indicator concepts should address.

Indicator concept	Correlation between indicator and indicandum	Normative legitimation	Possible complexity of the indicator	Application point of the indicator
1. Ecological indicator	Required	Irrelevant	Simple or complex	Pressure, state or response
2. Environmental policy indicator	Negligible	Required	Simple or complex	Pressure, state or response
3. Ecological indicator component	Irrelevant, but relevant for the measured attribute of the component	Irrelevant	Irrelevant	State of an ecological component (organism, structure, process)
4. Indicator component for environmental policy	Irrelevant	Required	Irrelevant	State of an ecological component (organism, structure, process)

In the left column we present four different indicator concepts (ecological indicators = indicators as descriptive measures, environmental policy indicators = normative measures, ecological indicator components = components used to measure environmental attributes, and indicator components for environmental policy = components used for evaluation and goal setting in environmental policy). We analyze whether correlation between indicator and indicandum, normative legitimation, and complexity of the indicator are relevant and at which point the indicator is applied. Complexity refers to the number of environmental conditions that are integrated in one indicator. Application points can be pressures from human activities exerted on the environment, exposure to a stress or an impact (e.g., accumulation of a contaminant in soil or levels of road noise), the state of biotic and abiotic conservation resources and effects on these resources, and responses of society towards environmental concerns.

not hold. O'Keeffe et al. (1987) give examples of well-founded value functions. They assume for example a linear correlation between sewage effluent and the severity of resulting consequences, but in cases where the importance of an attribute is contained in its presence or absence, normative values are assumed to converge towards an upper limit (e.g., endemic species, for which the authors assume that a difference between one and two species is less important than the difference between zero and one species). Smyth et al. (2007) examined the acceptance towards different values of ecological indicators. In a survey, stakeholders of the Lake Champlain Basin were asked to evaluate values of eight different ecological indicators on an ordinal scale from −3 to +3. In most cases the resulting correlation between indicator values and acceptance values was non-linear.

Beyond the clarification of indicators as ecosystem components or measures and of their use in a descriptive or normative context, we suggest a broad concept for indicators. An indicator as a measure can be a single or a composite indicator; it can be applied as a pressure, state or response indicator; and both states and changes can be indicated. The meaning of the indicator term should always be narrowed down based on the purpose of the study. When applying indicators, the underlying indicator concept should always be clarified.

For distinguishing between measures and components, we suggest using simply "indicator" for measures, and "indicator components" or, more specifically, "indicator species," "indicator organisms," "indicative structures," etc. for the respective components. Descriptive indicators should be referred to as "ecological indicators", evaluative und prescriptive indicators should be designated as indicators for environmental policy. Species used as normative indicators can be called "focal species" (Lambeck, 1997; Caro, 2000; Zacharias and Roff, 2001; Padoa-Schioppa et al., 2006), "umbrella species" (Andelman and Fagan, 2000; Fleishman et al., 2000; Roberge and Angelstam, 2004), and sometimes "target species" (Rosenthal, 2003; Koper and Schmiegelow, 2006; Kiehl and Pfadenhauer, 2007).

The intermingling of descriptive and normative concepts in the use of indicators is rife in conservation literature. There are many articles that make use of indicators for soil quality, sustainability, ecosystem health, or biodiversity value (Paoletti, 1999b; Shear et al., 2003; Hietala-Koivu et al., 2004), while leaving the normative justification for the selection of the respective indicators mostly unclear. This implies that normative values can be measured objectively, which is certainly not true. Thus, implicit values are insinuated to the reader, a situation which has to be avoided (Sagoff, 1985; von der Pfordten, 1993). To distinguish empirical science from normative settings or even personal viewpoints with doubtful acceptability, it is very helpful to separate descriptive from normative indicators.

If the indicandum itself is an unclear concept, further problems will result. Langor and Spence (2006, p. 345) describe "sustainability" as a "presently undefined balance among economical, ecological, and sociological goals" but they nevertheless use sustainability as an indicandum. This is an example where the operationalization of a term precedes its conceptualization (for a critical discussion of this topic, see Loughlin, 2002). But how can one judge if adequate indicators have been chosen, if it is not really clear what should be indicated? In cases where the indicandum is unclear, the selection of indicators will necessarily be somewhat arbitrary. Therefore a clarification of the indicandum is mandatory.

4. Opportunities and hazards in the conception of indicators

Indicators are used both in the analytical context of natural science and as a basis for decision-making. Therefore they are so-called boundary objects. Star and Griesemer (1989, p. 393) define a boundary object as "an analytical concept of those scientific objects which both inhabit several intersecting social worlds ... *and* satisfy the informational requirements of each of them."

Boundary objects thus can equally serve the different interests of scientists and decision makers. The term is recognizable and translates concepts from one field into another and in this manner enables communication. However, boundary objects are plastic enough to adapt to local needs. Thus, the indicator term often has a different meaning in scientific and political contexts.

In addition to plasticity, the indicator term exhibits some other interesting features (Pörksen, 1988). It is not possible to reduce different indicator definitions to a common attribute that is shared by all definitions. Indicators cover a huge field of application and thus claim a diffuse and nearly meaningless universality. Pörksen (1988) describes such a phenomenon as having a reciprocal proportionality of extension and meaning. The greater the extension, the emptier the meaning and vice versa.

The word indicator has a scientific aura, but there is no overall accepted precise definition of this term that is free from a halo of associations. The connotation of indicator is positive and conveys expert knowledge. Its mere sound is fascinating. Its function of bridging science and policy and of representing expertise dominates while the content retreats. The bridging of different disciplines is facilitated by the fact that the word indicator is easily combined with other words. There are bioindicators, environmental indicators, ecological indicators, and indicators of sustainability.

The vagueness of the word indicator brings some problems. Terms identified as buzzwords are too useful in the construction of tautologies. Those who are responsible for applying indicators in empirical science or for monitoring or evaluating biodiversity of certain parts of the landscape are forced to interpret the indicator term first, as there is no clear standard definition. As there are many indicator concepts, the risk of misinterpretation of policy guidelines is high. By using the term indicator without clarifying it, policy makers shirk their responsibility to enable appropriate implementation of the guidelines they create (Loughlin, 2002).

5. Conclusions

We can draw the following conclusions from our analysis.

- Presently, the indicator term is a profoundly ambiguous term that has different meanings in different contexts.
- We suggest defining the indicator term clearly, but in a broad context. An all-encompassing definition of indicators is given as follows: "An indicator in ecology and environmental planning is a component or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals. Environmentally relevant phenomena are pressures, states, and responses as defined by the OECD (2003)".
- The indicator concept used in studies should be based on this definition and clarified depending on the specific issue.
- It is essential to distinguish indicators based on the following attributes: descriptive indicators versus normative indicators and indicators as measures of ecological attributes versus indicators as ecological components. These distinctions should be made explicit through the use of a coherent terminology (e.g., ecological indicators vs. environmental policy indicators, indicators conceived as indicator measures vs. indicator components).
- To enhance transparency, an intermingling between descriptive and normative levels should be avoided. If a correlation between an indicator and an indicandum is established, this should be done first at a descriptive level. Afterwards, the relation of indicators to goals and values can be determined.
- The indicator term plays an important role as a boundary object at the interface between science and policy. To avoid problems due to different understandings of the indicator term, we advise always giving a definition of the indicator term. Otherwise the indicator term degenerates into a mere buzzword or "plastic word" (Pörksen, 1988).

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