Ecological Indicators 60 (2016) 329–334

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Ecological vulnerability indicators

Mary Antonette Beroya-Eitner*

Global Change Ecology im Elitenetzwerk Bayern, GEO II, Universität Bayreuth, Universitätsstraße 30, 95440 Bayreuth, Germany

ARTICLE INFO

Article history:
Received 21 November 2014
Received in revised form 30 June 2015
Accepted 1 July 2015

Keywords:
Ecological vulnerability
Ecosystem vulnerability
Environmental vulnerability
Vulnerability indicators

ABSTRACT

Indicators provide easy and quick information on the status or condition of an object of interest and are therefore widely used in policy-making. In recent years, policy interest in vulnerability research has increased and a growing number of studies have been aimed at developing vulnerability indicators. Some of these studies have been done within the social–ecological system (SES) framework, taking into account both social vulnerability and ecological vulnerability. A particular challenged faced, however, is with regard to the incorporation of indicators to capture the latter, especially as the concept of vulnerability as applied in ecology is relatively new and not yet well-explored. This paper expounds on this problem by answering the following questions: (1) How are the concept of vulnerability and thereby ecological vulnerability currently understood? (2) What are the challenges in the development and use of ecological vulnerability indicators? (3) What are the current efforts to overcome these challenges? One insight gathered is that due to the complexity, nonlinearity, and multiplicity of dynamics of natural systems, development of sufficiently general indicators of ecological vulnerability may not be realizable. Rather, ecological vulnerability assessment and the development of indicators thereof, whether done independent of the human system or within the SES, should be conducted at smaller scales and must be context-specific.

1. Introduction

Indicators are designed for quick and easy information about something of interest. They are usually surrogates that allow isolation of key aspects of a system from an overwhelming array of signals (National Research Council, 2000a), simplifying and synthesizing complex state-of-affairs. Thus, in vulnerability research, particularly within the context of disaster risk and climate change, indicators are increasingly being recognized as key tools in understanding better the underlying processes, determining the robustness of response strategies over time and providing insights as to where more targeted research or policy interventions are necessary, among others (Abson et al., 2012; Adger et al., 2004).

In recent years, efforts have been made to develop vulnerability indicators within the social–ecological system (SES) framework (e.g., Abson et al., 2012; Brooks et al., 2005; Damm, 2010; Mamauag et al., 2013) following recognition that social and natural systems are integrally coupled and should therefore be both considered for a more holistic approach to vulnerability assessment (e.g., Adger, 2006; Eakin and Luers, 2006; Folke et al., 2002; Kasperson et al., 2005; National Research Council, 2000b; Parris and Kates, 2003; Turner et al., 2003; White et al., 2001). A particular challenge in this task, however, apart from the general challenges involved in the generation of indicators, is the incorporation of indicators that can capture ecological vulnerability. As compared to social vulnerability, ecological vulnerability is a lesser explored and understood topic. Inevitably therefore, the latter is usually treated with lesser depth in many of these recent works on SES vulnerability, a manifestation of which is the disproportionately much fewer ecological indicators than social indicators considered. Furthermore, these ecological indicators are usually limited to some measure of exposure or state of (e.g., % forest land) and/or a couple of geophysical variables (e.g., coefficient of variation in rainfall), which arguably are insufficient measures of ecological vulnerability.

In this paper, the above problem is further expounded by answering the following questions: (1) How are the concept of vulnerability and thereby ecological vulnerability currently understood? (2) What are the challenges in the development and use of ecological vulnerability indicators? (3) What are the current efforts to overcome these challenges? This review is part of the author's research on the development of flood vulnerability index for delta SES.

* Present address: United Nations University, Institute for the Advanced Study of Sustainability (UNU-IAS), 5-53-70 Jingumae, Shibuya-ku, Tokyo 150-8925, Japan. Tel.: +81 03 5467 1212.
E-mail address: eitner@unu.edu
URL: http://www.unu.edu.

http://dx.doi.org/10.1016/j.ecolind.2015.07.001
1470-160X/

Ecological vulnerability is here used interchangeably with ecosystem vulnerability and environmental vulnerability, as is often so in literature. Strictly speaking, however, the terms ecology, ecosystem and environment mean differently, however subtle the difference though may be: The term "environment" generally refers to the *external* conditions surrounding an organism, including both biotic factors and abiotic factors, while an "ecosystem" is a natural system that *includes that organism* as well as all the other plants, animals and microorganisms in an area *functioning together* with all the abiotic components of the environment (Christopherson, 1997). Ecology, on the other hand, is the scientific study of these interactions between organisms and their natural environment (Haeckel, 1866), and so can also be viewed as the study of ecosystem (Odum, 1971). It also concerns itself with the distribution and abundance of organisms (Andrewartha and Birch, 1954).

2. Vulnerability

The concept of vulnerability has decades of history in social science and is now increasingly used in ecology. Investigation of the historical trend in publications about vulnerability through a general search in the Web of Science shows that there are more than 190,000 published articles on the topic (Topic search term: Vulnerability; Search Limit: Article) until the first quarter of 2014. Published articles on social vulnerability and economic vulnerability (Topic search term: "social vulnerability" OR "economic vulnerability") together number 1003 and date back to almost 50 years. In contrast, there are only a total of 342 published articles on ecological vulnerability, ecosystem vulnerability and environmental vulnerability (Topic search term: "ecological vulnerability" OR "ecosystem vulnerability" OR "environmental vulnerability"), mostly in the last 15 years (315 out of the 342 articles were from the year 2000 onwards). The last 20 years saw an increasing trend in the number of publications in all fields. A supplementary search in SCOPUS for the same time period on Document Type "Article", reveals similar trend: about 196,000 articles on "vulnerability" when searched in all fields, reduced to about 53,000 articles when the search is limited to "Article Title, Abstract and Keywords"; 919 articles on "social vulnerability" OR "economic vulnerability"; and 319 articles on "ecological vulnerability" OR "ecosystem vulnerability" OR "environmental vulnerability".

But what actually is vulnerability? Despite its intuitive meaning, the operational definition of the term has actually neither been clear nor consistent. In fact, it has many definitions. Thywissen (2006), for example, lists 35. On top of these multiple definitions, Hinkel (2011) notes that there is also an array of terms that either express similar ideas (e.g., risk, sensitivity and fragility) or inversely similar ideas (e.g. resilience, adaptability, adaptive capacity and stability), all of which somehow overlap in their meanings. However, on the most general level, vulnerability may be taken to mean the potential for loss or harm (Cutter, 1996; Hinkel, 2011; Wolf et al., 2013). According to Barnett et al. (2008), the definition of Turner et al. (2003) which refers to vulnerability as "the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or a stress/stressor", is consistent with how social researchers working on hazards or environmental change define the term. They also note that although there is no widely agreed upon method to conduct vulnerability assessment, most assessments entail considering one or more of exposure to risks, susceptibility to damage, capacity to recover, and net outcomes.

In recent years, policy interest in vulnerability research has increased and explicit demands have been put on the scientific community to develop vulnerability indicators to guide significant and informed policy choices. However, due to the complex array of issues, scales, and processes that determine vulnerability, attempts to express it in the form of a few indicators or a single index have been problematic (Barnett et al., 2008). Barnett et al. (2008) and Hinkel (2011) provide thorough discussion of the key conceptual and methodological problems associated with these indicators and indices. Nevertheless, because of their ability to provide succinct and easy-to-understand information that are useful to policy makers, vulnerability indicators have become increasingly important in recent years and the number of studies involving their development continues to rise.

As already mentioned, some of these recent studies on vulnerability indicator development have been contextualized within the framework of SES, which Gallopin (1991) defines as "a system that includes societal (human) and ecological (biophysical) subsystems in mutual interactions". In contrast to the dualistic view of human-nature relationship that dominated the 17th and 18th century thinking, SES reflects the idea that human and nature are integral to each other and hence any distinction between social and natural systems is arbitrary (Adger, 2006; Berkes et al., 2001; Folke, 2006). Gallopin (2006) argues that understanding and anticipating the behavior of the social and ecological components of the SES usually requires the simultaneous taking into account of both components. In other words, a SES is non-decomposable and therefore should be investigated in its totality since many of its important traits emerge from the dynamic interplay between these components. While this is true, however, elemental to the understanding of these between-components dynamics is a rigorous understanding of the dynamics within each component. Thus, understanding SES vulnerability requires comprehending both the social vulnerability and ecological vulnerability of the system under consideration, separately and then jointly, in interaction with each other. This paper focuses on the latter vulnerability (i.e., where the bio-geophysical system is the main responder to stress or perturbation), and more specifically on the indicators to assess it.

3. Ecological vulnerability and indicators

Although indicators have been longer and more popularly used in economic and social policy-making, environmental and ecological indicators have also been around for some three decades now. The early 1990s saw them gained importance in many countries and in international fora (OECD, 2008), which consequently led to the development of a number of such indicators by national/international agencies, among them the Ecological Indicators for the Nation (National Research Council, 2000a), ecological indicators to assess the State of the Nation's Ecosystem (US) (H. John Heinz III Center for Science, Economics, and the Environment, 2002); Environmental Pressure Indicators for the EU (European Communities and Eurostat, 2001), Environmental Sustainability Index (Esty et al., 2005) and its successor, the Environmental Performance Index (Emerson et al., 2012), and OECD's Key Environmental Indicators (OECD, 2008). However, in the context of vulnerability analysis, especially within the themes of disaster risk and climate change, the search for reliable ecological indicators is only just beginning.

There are many challenges to such a search, however. First, the concept of vulnerability as applied in ecology is relatively new and yet to be fully expounded. It is worth noting that one of the earliest uses of the term "vulnerability" in ecology is in ecotoxicology, where Van Straalen (1994) identified three components in his conceptual model of vulnerable ecological receptors: external exposure, intrinsic sensitivity and capacity to recover. Second, the lack of conceptual agreement on the term vulnerability itself naturally translates to confusion on what ecological vulnerability means and what factors determine it. Reporting on the conclusions