A possibilistic approach to diverse-stressor aquatic ecological risk estimation

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Abstract

A possibilistic approach to assess the risk of co-occurring stressors in an aquatic ecosystem based on the use of fuzzy sets is illustrated at the hand of a hypothetical case study. There are two aspects of importance: a fuzzy stressor response relationship where the response may have reference to a lower level end-point, and a rule-based inference model relating the occurrence of low-level stressors to a high-level ecological goal such as sustainability. The stressor-response is expressed as a conditional possibility. The possibility and necessity measures of the disjunctive composition of the stressor-response with the possibility distribution of the stressors yield an estimate of the ecological risk. Such a possibilistic approach may well serve as a screening procedure in multiple stressor resource management when only qualitative risk assessments are needed.

Introduction

The South African National Water Act places a premium on water supply for basic human needs and for the sustainable development and use of the aquatic ecosystem. This is reflected in the reserve. The ecological component of the reserve has been defined as that level of quantity and quality necessary to ensure the sustainable development of the water resource (NWA, 1998). The ecological reserve is a water resource management instrument for aquatic ecosystem protection to ensure sustainability in the use and development of the water resource. As a practical management measure, the capacity of the water resource to maintain its sustainability can be discretised into different management classes (MacKay, 1998) corresponding to different levels of risk that the resource may lose its sustainability.

Risk is used here in the sense of the likelihood that a specific undesired event would occur. This likelihood may be expressed in terms of either probability or possibility. In probabilistic risk assessment, it is assumed that this event is crisply defined, i.e. it is possible to decide whether the event has occurred or not. However, the nature and epistemology of the event would determine how likelihood is expressed. Possibility theory offers the option of addressing fuzzy events where the event is perhaps epistemologically vague.

A point of departure in this paper is the recognition that in assessing the risk of the aquatic ecosystem losing its sustainability:

- there are several stressors (such as chemical substances, flow reduction and habitat degradation) that may be present simultaneously and that may result in responses such as loss of sustainability (although the mechanics of these impacts may differ), and
- unambiguous quantitative and possibly even quantitative site specific data may often be lacking.

An argument will be presented for the application of a fuzzy approach to aquatic ecological risk. Two types of ecological risk may be defined depending on how the likelihood measure is expressed: a risk based on a possibility measure (referred to as "ecological concern") and a risk based on a necessity measure (related to the possibility measure and referred to as "ecological dread"). These are illustrated by a hypothetical application to water resource classification.

Rationale for a fuzzy approach

The term "sustainability" is not defined in the NWA. For the purpose of discussion, it is assumed that ecological sustainability refers to the ability of a system to maintain an acceptable level integrity subject to anthropgenic stress. Concepts such as sustainability and integrity may be spatially and temporally scale-dependent and the knowledge of the mechanisms underpinning these phenomena is vague (Costanza et al., 1993, De Leo and Levin, 1997). Variability is both a normal and sometimes a necessary ecosystem characteristic to certain ecosystem processes. "Therefore, in managing ecosystems, the goal should not be to eliminate all forms of disturbance, but rather to maintain processes within limits or ranges of variation that may be considered natural, historic or acceptable" (De Leo and Levin, 1997).

Not only must natural variability be accounted for in the management process, but also uncertainty and, in some cases, vagueness. Definitions of ecosystem integrity varies; e.g. "the maintenance of the community structure and function characteristic of a particular locale or deemed satisfactory to society" (Cairns, 1977) or "the capability of supporting and maintaining a balanced, integrative, adaptive, community of organisms having species composition, diversity, and functional organization comparable to that of natural habitats of the region" (Karr and Dudley, 1981). Terms such as "deemed satisfactory"; "balanced", "comparable" and "natural" in these definitions are, without further qualification, essentially vague and subjective. This means that in terms of the risk assessment under the NWA, the end-point is vague.

In addition, the system boundaries, the response to stressors and the stressors themselves may only be known qualitatively. The functional entities that best reflect the goals of ecosystem management may only be vaguely identifiable. Consequently, in dealing with ecological risk in the context of protective ecosystem management, it would be advantageous to use a paradigm that is

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