ELSEVIER

Environmental Impact Assessment Review
20 (2000) 125–133

Environmental Impact Assessment Review

www.elsevier.com/locate/eiar

Quantitative methods

Quantifying the transient response of ecological-economic systems to perturbations

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Accepted 1 April 1999

Abstract

Ecologists and economists are increasingly in agreement that ecological and economic systems are linked and that these actually should be viewed as one system. Perhaps because this recognition has been very recent, neither ecologists nor economists have studied the short-term behavior of jointly determined ecological-economic systems that are subject to perturbations stemming from natural events and the continuance of economic activities. Consequently, the purpose of this paper is to construct a metric that can be used to quantify the transient response of ecological-economic systems to perturbations. This metric is a non-asymptotic measure of an ecological-economic system's resilience.

Keywords: Ecological-economic system

1. Introduction

Generally speaking, natural systems are subject to two kinds of perturbations. The first kind of perturbation stems from the occurrence of natural events such as droughts and hurricanes. The second kind of perturbation arises from the conduct of economic activities such as fishing and grazing. *Inter alia*, a recognition of the vulnerability of natural systems to these two kinds of perturbations, has led ecologists and economists to conclude that ecological and economic systems actually should be viewed as one system.

With this conclusion, a whole host of questions pertaining to the effective

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0195-9255/00/$ – see front matter
PII: S0195-9255(99)00020-7

management of ecological-economic systems becomes salient. In particular, it is now important to know how such systems respond to perturbations. In the ecology literature, the response of ecosystems to perturbations traditionally has been measured by the concept of resilience. Resilience is measured by first constructing a matrix that gives the strength of the interactions between the various species at their equilibrium population densities. The maximal eigenvalue of this matrix then is defined to be the resilience of the ecosystem. Put differently, this notion of resilience measures the rapidity with which a stable ecosystem returns to its original state following a perturbation.[1]

Although this method for computing resilience has been used widely in the ecology literature, it is important to note that resilience, measured in terms of the maximal eigenvalue of the matrix of interaction effects, is an *asymptotic* property. In other words, this notion of resilience provides information about the rate of decay of perturbations as time approaches infinity. The short-term, transient behavior of an ecosystem is completely ignored. However, from a management perspective, the relevant issue is the behavior of an ecological-economic system following a perturbation. For most ecological-economic systems, it is *transient* behavior that is generally of interest. As Batabyal has noted [1,3], knowing how a given ecological-economic system responds to perturbations in the long run, i.e., as time approaches infinity, would not be very helpful, because most policy-makers set policy—and are interested in the effects of policy—over much shorter timer horizons. In addition to this, Neubert and Caswell [14] have argued persuasively that ecosystems cannot be managed effectively without understanding their transient behavior. In particular, these authors formally have demonstrated that "even in stable, resilient [ecosystems], transient behavior can be dramatic, long lasting, and counterintuitive" [14, p. 654].

Given the significance of transient behavior for the effective management of ecological-economic systems, one can question our current level of knowledge regarding the measurement of this kind of short-term behavior. Unfortunately, as best as we can tell, this knowledge level is very low. In particular, the economics literature appears to have ignored this issue completely. This is, as Dasgupta has noted [6, p. 390], a rather sorry state of affairs. Even the vast ecology literature on resilience seems to have focused on resilience as an asymptotic property.[2] Recognizing the limitations of this asymptotic approach, a small group of ecologists [5,7,8] recently have used methods that are not based on eigenvalue analysis to quantify the transient behavior of ecosystems following perturbations. However, a

[1] At the very outset, it is important to note that two notions of resilience are prevalent in the ecology literature. The notion that we have just mentioned is the one that has been popularized by Pimm [17,18]. The other notion of resilience refers to "the amount of disturbance that can be sustained [by an ecosystem] before a change in system control or structure occurs" [11, p. 50]. This latter notion of resilience was first proposed by Holling in 1973 [10].

[2] For a more detailed corroboration of this claim, see Neubert and Caswell [14] and the papers cited therein.