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# Application of holistic thermodynamic indicators

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**Abstract**

The paper proposes to use eco-exergy, specific eco-exergy = eco-exergy/biomass and ecological buffer capacities as ecological indicators for ecosystem development and health. After definitions of these three concepts, it is shown that the attributes for ecosystem development proposed by von Bertalanffy and E.P. Odum and six descriptors of ecosystem health proposed by Costanza are covered by three types of ecosystem growth forms: growth of biomass, network and information. As it has been shown that eco-exergy increases with all three growth forms, eco-exergy seems a good candidate for a holistic indicator of ecosystem development and health. By supplementing eco-exergy with specific eco-exergy and buffer capacity, we obtain also direct indication of the level of information, respectively, the resistance of the ecosystem to perturbations.

*Keywords:* Exergy; Specific exergy; Growth; Buffer capacity; Holistic indicators; Information; Resistance

## 1. Introduction

This paper proposes application of three thermodynamic indicators: eco-exergy, specific exergy and buffer capacity. After the indicators are introduced and defined in the next section, von Bertalanffy's and E.P. Odum's description of ecosystem development and Costanza's six indicators defining ecosystem health will be shown to be covered by three growth forms. It has been shown in the literature that all three growth forms coincide with increasing exergy, but the main arguments for this accordance between exergy and growth will be repeated her together with a presentation of the characteristics of eco-exergy and specific exergy as indicators, and which aspects of ecosystem health that these two thermodynamic holistic indicators are covering. An overview of the case studies where these indicators have been used as ecological indicators for the assessment of ecosystem health will be presented, followed by the conclusions that are resulting from the theoretical discussions presented in this paper.

## 2. Eco-exergy, specifc eco-exergy and buffer capacity

Exergy is defined as the amount of work a system can perform when it is brought into equilibrium with its environment. Exergy can be considered the amount of energy that can be utilised for doing work, opposite the heat released at the temperature of the environment

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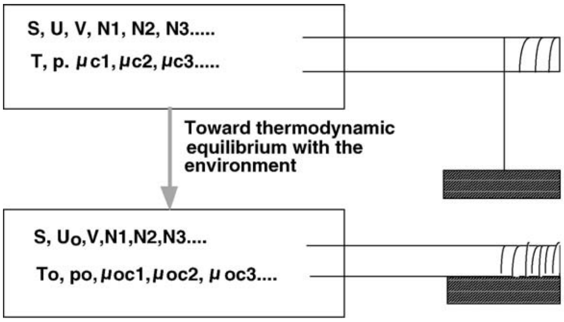

Fig. 1. Definition of exergy.

that cannot be utilise to do work. The definition is shown in Fig. 1 taken from Jørgensen (2002). When we want to find the work capacity of an ecosystem, we are interested in the chemical energy of the biomass and the complicated biochemical components. Minor differences in pressure and temperature are uninteresting. For ecological use, we have, therefore, defined another exergy, named eco-exergy that is defined in Fig. 2 (Jørgensen, 1982, 2002). As seen the eco-exergy content is, therefore, the chemical energy embodied in the biomass and the complex biochemical constituents. Eco-exergy measures according to the definition the distance from thermodynamic equilibrium and can be found as the chemical energy difference between the system and the thermodynamic equilibrium:

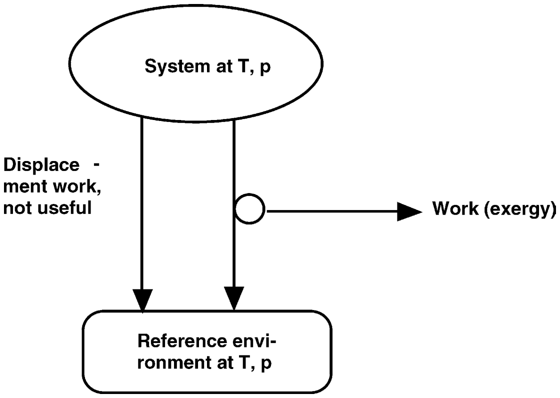

Fig. 2. The exergy content of the system is calculated in the text for the system relatively to a reference environment of the same system at the same temperature and pressure, but as an inorganic soup with no life, biological structure, information or organic molecules.

$$\text{Eco-ex} = RT\sum_{i=0}^{i=n} ci \ln \frac{ci}{cio} \tag{1}$$

To illustrate the application of this equation, let us calculate the formation constant for a high molecular organic compounds. We use:

$$-\Delta G = RT \ln K. \tag{2}$$

$-\Delta G = -18.7$ kJ/g × 104,400 g/mole = 1952 MJ/mole = 8.2 J/mole × 300 ln K, which implies that $\ln K = -793{,}496$ or $K$ is about $10^{-344998}$.

Eco-exergy for organisms is found as eco-exergy

$$= \sum \beta i \times ci, \tag{3}$$

where $\beta$ is a weighting factor = $RT \ln ci/cio$, considering that the concentration at thermodynamic equilibrium can be found as the probability to form the organism at these conditions, i.e. what is the probability to form the right sequence of the amino acids in the enzymes that determine the life processes. Or how much information does an organism contain? The genome size is known for some organisms from the gene mapping project and for other organisms we can find the $\beta$-values by comparison of many different measures of the complexity of the organisms (Jørgensen et al., 2005). Table 1 summarises the genome size and the repetition genes which are not directly necessary for the determination of the amino acid sequence, and therefore do not count in our calculations of the $\beta$-value.

Prigogine (1947, 1980) has discussed how systems can move away from thermodynamic equilibrium in spite of the Second Law of Thermodynamics, which is formulate by the use of eco-exergy as follows: the eco-exergy of a closed system will decrease until the system reaches thermodynamic equilibrium. But ecosystems are open systems, and can therefore receive energy (and working capacity = exergy) from outside, which explains that the system can gain exergy. A certain amount of eco-exergy is used in the system (eco-exergy decreases as indicated in the Second Law of Thermodynamics) for maintenance; but if the input of eco-exergy for instance from the solar radiation is bigger than the amount of eco-exergy used for maintenance, the stored eco-exergy can