Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

From Exergy to Economy: a transdiciplinary approach to sustainability of ecosystems: a synthesis

Da Exergia para a Economia: abordagem transdisciplinar para a sustentabilidade dos ecossistemas: uma síntese

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Abstract

Exergy is the amount of energy that produce genes and infornmation. To be away from the thermodynamic equilibrium, find in detritus, the exergy of an ecosystem, represents the accumulation of information. Higher exergy levels,means higher buffer capacity and a measure of ecosystem health. The ability of an ecosystem to resist perturbation represents a high exergy level, and results in stability. To be away from the thermodynamic equilibrium, means more growth capacity of an ecosystem, more stability, increased information, increased network. Growth of physical strucrture growth of complexity of network, growth of information results in stability and less entropy. More stability means more and diverse ecosystems services and as a result better economical performance of the ecosystems. Therefore exergy and economy are conected througouth ecosystem stability and buffer capacity. Therefore it pays for the economy to preserve ecosystem structure and function.

Keywords: exergy, stability, buffer capacity, resilience, ecosystem services, economy.

Resumo

Exergia é a energia que produz gens e portanto informação. O afastamento do equilíbrio termodinâmico, representa no ecossistema o acumulo de informação. Níveis elevados de exergia representam maior capacidade de resiliência e estabilidade e melhor saúde do ecossistema. A estabilidade dos ecossistemas para resistir a perturbações está relacionada a uma maior biodiversidade maior número de redes e consistente comportamento de retorno próximo ás condições iniciais. Ao se afastar do equilíbrio termodinâmico (o qual ocorre ao nível dos detritos) com maior energia utilizada para o crescimento, aumento das conexões, e maior crescimento físico e estrutura de redes, maior biodiversidade, acentua-se a estabilidade do ecossistema. E maior estabilidade significa uma capacidade de fornecer para o bem estar humano um grande e variado conjunto de serviços ecossistêmicos que deverá impulsionar e estimular a economia regional e local. Assim a relação entre EXERGIA e ECONOMIA fica muito evidente e torna-se consistente. É portanto fundamental preservar a função e estrutura dos ecossistemas o que é extremamente positivo em termos econômicos.

Palavras-chave: exergia, estabilidade, capacidade tampão, resiliência, serviços ecossistêmicos, economia.

1. Introduction

The theories of ecosystem stability states that ecosystems that are more complex in structure and function are more stable . Several observations of real ecosystems supports this theory. The concept of ecosystem stability has several meanings expressing resilience resistance, persistence . Jorgensen and Svirezhev 2004, defined exergy as the capacity of the ecosystem to move away from thermodynamic equilibrium, this being represented by detritus that has no genes.

Exergy was expressed by Jorgensen (1992) with the following formula (Equation 1):

$$EX = RT_0 \sum_{i=1}^{n} \xi \beta_i c_i \tag{1}$$

where R = Gas constant ;T_0 = temperature of the ecosystem; n = number of non repetitive genes in genome; Bi = is the weighing factor for each organism; ci = biomass of components corresponding in grams. The weighing fator is designed as energy inclusion in the system in relation to detritus.

The total exergy of a ecosystem can be calculated altough a complete exergy cannot be exactly determined due to

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Received: July 21, 2025 – Accepted: September 24, 2025
Editor: Takako Matsumura Tundisi

the impossibility to measure all the components of the ecosystem especially at the biological level.

2. Ecosystem Stability and Complexity

The maintenance of a ecosystem complexity from the thermodynamic point of view, requires a supply of exergy. This is represented by a increase in biomass, a more complex network and more information. As the system moves away from the thermodynamic equilibrium, it can be shown that the trophic chain selects the branch that gives the highest exergy. Ecosystems consume energy and as exergy flows trough the system is fundamental to keep the system function and its complexity. As pointed out by Jorgensen (1992), ecosystems manifest growth as progresses in time:

Growth of physical and biological infrastructure
Growth of complexity of network
Growth of information
More feedback loops
Progressive interaction of components.
More interaction of processes and components.

Constanza et al. (1992), defines ecosystem integrity as a summation of the following atributes:

Homeostasis, absence os disease, diversity and complexity, stability and resilience; equilibrium beteween ecosystem components. This integrity reflects the functional and structural characteristics of ecosystems.

3. Ecosystem Integrity, Stability and Ecosystems Services

The growth of an ecosystem occurs by increasing the infrastructure, (biomass),increase of networks, (more cycling), and increase of information as a result of a input in exergy.

Costanza et al. (1997), defined the value of ecosystems services and natural capital. Millenium Ecosystem Assessment (2003) has identified four major categories of ecosystem services that are related directly to human well being and economy: ***provisioning services, cultural, regulating and supply services***. Biodiversity is fundamental to many ecosystem services (Millenium Ecosystem Assessment, 2003) providing stability and resilience vital for human well being and economic development. Biodiversity has a stabilizing and a buffering function, providing multiples sources of ecosystem services (Davies, 1996; Chambers, 1997; Carney, 1998).

The ***regulatory function*** of ecosystems is another important service including the purification of the air, fresh water, reducing flood and drought, stabilizing regional and local climate. These regulatory services are fundamental for human well being and quality of life.

Cultural ecosystem services influences aesthetic values, scenic landscapes, river and lakes, improving recreation, culture and education at regional and local levels (Periotto and Tundisi, 2013).

The challenge is to maintain and conserve ecosytem stability, in order to improve the enhancement of human well being, develop economy and reduce poverty.

The links between ecosystem services and its stability, population, poverty and well being have a complex relationship.However several authors pointed out that there is a direct relationship between conservation of processes and structures at ecosystem level and economy Baskin (1997). Many case studies have demonstrated this (Fath and Patten, 1998; Jorgensen and Muller, 2000; Daily and Ellison, 2002; Tundisi, 2025). A example of the ecosystem services and its recovery of the Parana River Basin is given:

The Parana River Basin in South America has a area of 2.6x10^6km^{2}and a population of approximately 100 million inhabitants (Metcalfe and Castro, 2020). The basin has great ecological economic and cultural importance for the region and worldwide. The basin is a great reserve of freshwater and biodiversity. The freshwater is used for hydroelectric supply (46 large dams constructed in the upper basin), agricultural irrigation,water suply to cities, navigation (Tietê River waterway) and fisheries.

Despite the impacts of dam construction and deterioration of water quality (Tundisi and Matsumura-Tundisi, 2020) the basin still has a important stock of natural biodiversity. Provisioning services are given by this biodiversity and even by the introduced species of fish. Therefore the four main services proposed by Constanza et al (1997 that is provisioning, regulating, cultural and suply are relatively well provided by this basin. Metcalfe and Castro (2020) presented and discussed the projects for the management of the water resources in order to recover, diversify and improve the services of the basin with focus on water quality recovery, pollution abatment, biodiversity restauration and watersheds conservation. Meeting the targets for clean water and sanitation (ODS 6) implementing integrated water resources management at all levels, restoring forests, wetlands,aquifers, rivers and lakes will improve substantially ecosystem services, reduce entropy and use more exergy to promote ecosystem stability and improving the economy at the basin level in all countries that share the basin.

4. Conclusions: Exergy, Ecosystem Services and Economy

In the ecosystem theory discussed by Jorgensen and Svirezhev (2004), exergy is the central issue. Other approaches to ecosystem theories exist and all are consistent with the ecological theory presented by Jorgensen and Svirezhev (2004). These authors stated "When a system receives a troughflow of exergy this system after covering the maintenance of energy, uses the exergy to move away from the thermodynamic equilibrium selecting the option which most moves away from the thermodynamic equilibrium" (SIC).

To move away from the thermodynamic equilibrium means increase of networks, efficient feedback loops and stability and capacity of resilience. It pays off in terms of economic development when the ecosystem moves away from the themodynamic equilibrium because this enhances the promotion of more diverse and qualified ecosystem services. More ecological services means a diversification of economy of a given ecosystem being this a river a lake, a forest, a wetland or a reservoir . The measurement of the exergy of a ecosystem therefore, is a consistent indicator of economic development based on ecological services (Daily and Ellison, 2002).

Several observations of the enhancement of local or regional economy related to ecological services and ecosystem stability are described in recent publications (Suarez-Oroszco and Ramanathan, 2025; Tundisi, 2025).

The pathways of exergy, ecosystems conservation of structure and function, entropy and their relationship with economy include a transdisciplinary approach and several observations and measurements of long term at ecosystem level (Tundisi, 2017). And this approach promotes Ecological Science to another level of undestanding stimulating a better interaction of theory with reality.

Data Availability Statement

Suporting data for this paper is found in Costanza et al. (1997), Jorgensen (1992), Jorgensen and Svirezhev (2004). These references are cited in the paper.

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