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EXERGY : PRELIMINARY RESULTS OF AN EXPERIMENTAL LABORATORY VERIFICATION OF ITS APPLICABILITY IN APPLIED ECOLOGY

Silow, Eugene A. and In-Hye Oh
Division of Life Science, Paichai University

엑서지 : 응용생태학에서의 exergy의 적용가능성 실증

유진 질로브, 오인혜
(배재대학교 생명과학부)

Summary

The results of laboratory experiments with microcosms containing *Daphnia magna and Chlorella vulgaris* demonstrated decrease of the structural exergy of artificial communities after the addition of model toxicants phenol and cobalt chloride. Structural exergy changes were more expressed than changes of components biomasses and total biomass of the community. It once more points to the possibility of the use of structural exergy as ecosystem health reflecting parameter.

물벼룩(*Daphnia magna*)과 클로렐라(*Chlorella vulgaris*)가 포함된 microcosm에서 독성오염물질인 페놀과 코발트를 첨가함에 따라 구조적 exergy가 감소되었다. microcosm의 구성 생물들의 생물량이나 군집 전체의 생물량보다 구조적 exergy가 훨씬 크게 변화되었다. 이것은 구조적 exergy 가 생태계의 안정성을 평가하는 지표가 될 수 있음을 나타내는 것이다.

I. Introduction

The evidence of the necessity to have measurable parameter reflecting the state of the ecosystem, and allowing to estimate the severity of its anthropogenous damage is clear now (Costanza & Jørgensen, 2002). Many authors have proposed various ecosystem goal functions to be used as such ecosystem health indices: ascendancy, enmergy, energy flow maximization, entropy minimization *etc*(Jørgensen, 1997). Among them one, namely exergy, is shown to have such advantages as good theoretical basis in thermodynamics, close relation to information theory, rather high correlation with others goal functions and relative easiness of computation (Jørgensen & Bendoricchio, 2001).

***Exergy** is defined as the distance between present state of the system and the state of it in thermodynamic equilibrium with the environment, measured in the units of energy.* It demonstrates the amount of work performed to create given system from its primary components (in the case of ecological systems - from inorganic chemical compounds). *Exergy related to the total biomass **(structural or normalized exergy)** measures the possibility of ecosystem to accept and utilize external fluxes of energy.* It reflects the degree of ecosystem development or complexity and has such advantages in comparison with the total exergy as independence from the total biomass of the ecosystem and possibility to serve as indicator, demonstrating the level of evolutionary development of organisms the ecosystem consists of.

The main features of the changes of exergy of ecological systems under the external perturbations were studied in the computational experiments with water bodies and flows mathematical models, describing processes of eutrophication and toxification (Patten & Jørgensen, 1995; Silow, 1999; Ray *et al.*, 2001; Jørgensen, 2001).

During studies of natural waterbodies and water streams, Salomonsen (1992) showed the relation of exergy to the trophic status of water body. Previously we have demonstrated the reverse correlation of structural exergy in some Korean reservoirs with the degree of their watershed basin urbanization (Oh and Silow, 2002) and sufficient decrease of exergy in the region of the Lake Baikal suffering from the Baikalsk Pulp & Paper Combine wastewater discharge input comparing with the pure region (Silow, 2001).

Exergy was also applied to estimate the ecosystem changes under various external influences, mainly chemical intoxication. Some works based on recalculation of results received by other authors were published (Silow, 1997, 1998; Xu *et al.*, 2001). Calculation of exergy changes for mesocosms experiments at the Lake Baikal showed additions of non-toxic organic compounds, nutrients, phenol compounds, oil products, sulfate in low concentrations do not affect structural exergy and the changes in ecosystem structure were reversible. The additions of heavy metal ions and high concentrations of phenol compounds, oil products, and sulphate caused decrease of structural exergy and irreversible degradation of ecosystem structure (Silow, 1999).

The recent work is dedicated to the study of behaviour of exergy and structural exergy in physical models of aquatic ecosystems - microcosms.

II. Methods

Microcosms we used contained two trophic levels, producers and consumers (green alga *Chlorella vulgaris* and cladoceran *Daphnia magna,* respectively). Each microcosm was an 1 L cylinder, containing 10 mature daphnia specimens and algae in concentration about 0.5 g l^{-1}. Microcosms were exposed at constant temperature (20 oC) at 8 hours of darkness, 16 hours of light regime. The exposition was 7 days in each experiment. Direct count of daphnia and algae concentration was fulfilled daily. Exergy was calculated according to S. E. Jørgensen and G. Bendoricchio (2001) and structural exergy was determined as relation of total exergy to total biomass:

$$Ex / RT = \sum_{i=1}^{N} c_i f_i ,$$

$$Ex_{Str} = (\sum_{i=1}^{N} c_i f_i) * (\sum_{i=1}^{N} c_i)^{-1} ,$$

where

Ex the total exergy of community,

R gas constant,

T absolute temperature, K,

N number of components,

c_i concentration of component *i*,

f_i conversion factor for component *i*

We have used two model toxicants phenol, as representative of organic non-conservative degradable toxicants (starting concentrations 1 ~ 25 mg l^{-1}), and Cobalt Chloride ($CoCl_2$), as representative of non-organic conservative non-degradable toxicants (starting concentrations 0.05 ~ 0.5 mgCo l^{-1}).

III. Results and Discussion

Results obtained (some are presented in Fig. 1, Fig.2) demonstrate structural exergy decrease in microcosm experiments proportionally to a value of the added toxicant concentration, while other parameters (biomass of components, total biomass of community and total exergy) fluctuated.

It is necessary to point on the fact that, according to our previous results, when added substances where very toxic or non-metabolised, e.g. Kepone (pesticide), cadmium ions, mercury ions, inorganic acids, or the substances were introduced in high concentrations (copper ions, bifenthrin (pesticide), chlorinated organic compounds, benzene, oil) the decrease of structural exergy was observed. Often it indicated the sufficient degradation of ecosystem, elimination of its component or even entire trophic levels. Sometimes it was observed when the toxicant was added in sub-lethal concentrations, e.g. low concentrations of mercury inhibited the crustacean zooplankton development rate and the growth of fishes (Silow, 1998).

Similar results were obtained in our previous mesocosms experiments at the lake Baikal. There decrease of structural exergy was observed, while total exergy and community biomass could oscillate or fluctuate not directly connected with the the dose of toxicant added (Silow, 1999b).

As it was stressed above, Jørgensen (2001) connects the value of normalised or structural exergy with the possibility of ecosystem to accept and utilize external fluxes of energy. The addition of toxicant can be accepted as external flux of energy and information (in this case - destructive). The remaining of structural exergy at the level, equal to initial or control, demonstrates the stability of ecosystem and its ability to withstand this external influence. The decrease of it shows degradation of ecosystem and its disability to support its structure at given level of external influence. These conclusions are in good accordance with results of mathematical modelling experiments (Silow, 1999a) and calculations based on the results of the field observations (Silow, 2001, Oh & Silow, 2002).

Of course, our results are preliminary and are far from being an ultimate truth, but they may be accepted as fact. Taking into account the data presented here and discussed above, we now can recommend to use such goal function as structural exergy in environmental monitoring as holistic and quantitative parameter, reflecting the ecosystem state and reversibility of anthropogenic changes. Certainly, the additional investigations are necessary.

IV. Acknowledgements

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Figure legends

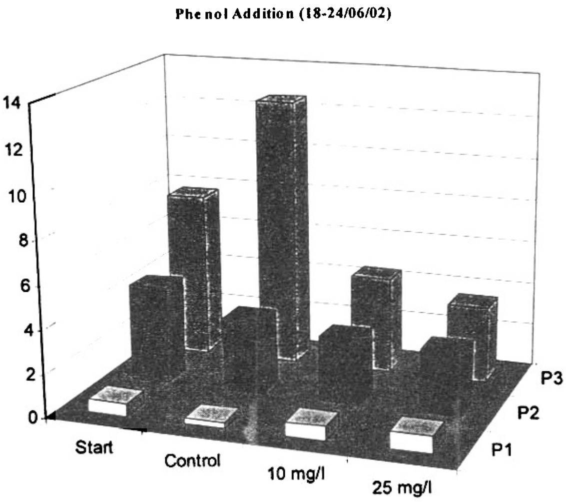

Fig. 1. Changes of total biomass P1 (g l^{-1}), exergy P2 (humus equivalent mg l^{-1}), and structural exergy P3 after phenol addition.

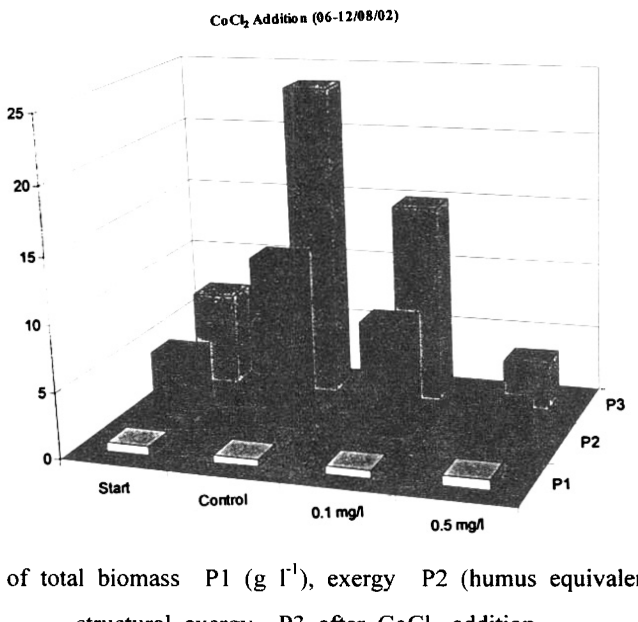

Fig. 2. Changes of total biomass P1 (g l^{-1}), exergy P2 (humus equivalent mg l^{-1}), and structural exergy P3 after $CoCl_2$ addition.