Derivation and Analysis of an Ecosystem Production Function with Structural Dynamics

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In this paper we derivate and analyse an ecological production function that allows for changes in the carrying capacity of an ecosystem due to changes in its total biomass. This ecological production function is based on the model of Cohen (1995) [1], originally devised for human population dynamics, where population growth allows the population to expand its carrying capacity, and adapted to ecosystem dynamics in Rodrigues et al. (2002) [3].

The ecosystem is described using two state variables - biomass and ecosystem carrying capacity - with the assumption that they have autocatalytic dynamics. A rise in biomass produces a rise in ecosystem carrying capacity (for positive feedbacks), which creates a greater potential for biomass to grow. The historically attained degree of self-organization promotes further self-organization [2].

If a new unit of biomass alters the ecosystem carrying capacity, this is because some sort of structural change has occurred. Accordingly, we assume that the ecosystem carrying capacity is a dynamic variable that depicts changes in the structure of the ecosystem acting with a feedback effect on the dynamics of total biomass. The basic assumption about a dynamic carrying capacity is that, while evolving, ecosystems organize themselves into more complex systems, with more diversity and indirect interconnections between their components at all levels [2], which conditions the ecosystem capacity to support more units of biomass.

Manipulating the system of two state equations for biomass and carrying capacity, we get a single ecological production function,

$$\frac{dN}{dt} = r\,N\left(CC_l + l\,\log\left(\frac{N+h}{b}\right) - N\right), \tag{1}$$

similar to the usual logistic growth model, where r is the specific growth rate and N is the total biomass.

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This equation includes a term depicting feedbacks on the ecosystem carrying capacity $-l\,\log\left(\frac{N+h}{b}\right)$. Next, we perform a bifurcation analysis of the ecological production function proposed on the parameter space $l-h$ for several relative values of b and CC_l. From this analysis it is concluded that the ecosystem has very different dynamics depending on the intensity of feedbacks. The ecosystem dynamics ranges from pure compensation to depensation and critical depensation passing in some cases through unconditional extinction. In particular, this model leads to the prediction of the existence of threshold stock levels and bifurcation points, instead of building them in from the outset, hence providing theoretical basis for thresholds.

The main conclusions are that if feedbacks on carrying capacity are sufficiently high, the ecosystem exhibits depensation, or critical depensation for even higher feedbacks. On the other hand, if feedbacks on carrying capacity are low enough the ecosystem exhibits pure compensation. It is also shown that for sufficiently intense feedbacks on carrying capacity the climax of an ecosystem is much higher than for ecosystems with weaker feedbacks.

In some situations, if in some way the feedbacks on carrying capacity are intensified, the ecosystem climax biomass may decline and the ecosystem may even extinguish. In this last case, if feedbacks on carrying capacity become constant there is no initial biomass level possible to replenish the ecosystem. Thus the ecosystem is permanently extinguished unless some structural change occurs.

References

[1] Cohen, J. E., 1995. 'Population Growth and Earth's Human Carrying Capacity'. Science, 269: 341-348.

[2] Kutsch, W. L., Steinborn, W., Herbst, M., Baumann, R., Barkmann, J., Kappen, L., 2001. 'Environmental Indication: A Field Test of an Ecosystem Approach to Quantify Biological Self-Organization'. Ecosystems 4: 49-66.

[3] Rodrigues, J., T. Domingos, P. Conceição, 2002. 'Irreversibility in Human-Nature Interactions: A Dynamic Carrying Capacity for Natural Capital', (submitted to Ecological Economics).