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Sustainable systems as organisms?

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Abstract

Schrödinger [Schrödinger, E., 1944. What is Life? Cambridge University Press, Cambridge] marvelled at how the organism is able to use metabolic energy to maintain and even increase its organisation, which could not be understood in terms of classical statistical thermodynamics. Ho [Ho, M.W., 1993. The Rainbow and the Worm, The Physics of Organisms, World Scientific, Singapore; Ho, M.W., 1998a. The Rainbow and the Worm, The Physics of Organisms, 2nd (enlarged) ed., reprinted 1999, 2001, 2003 (available online from ISIS website www.i- sis.org.uk)] outlined a novel "thermodynamics of organised complexity" based on a nested dynamical structure that enables the organism to maintain its organisation and simultaneously achieve non-equilibrium and equilibrium energy transfer at maximum efficiency. This thermodynamic model of the organism is reminiscent of the dynamical structure of steady state ecosystems identified by Ulanowicz [Ulanowicz, R.E., 1983. Identifying the structure of cycling in ecosystems. Math. Biosci. 65, 210–237; Ulanowicz, R.E., 2003. Some steps towards a central theory of ecosystem dynamics. Comput. Biol. Chem. 27, 523–530].

The healthy organism excels in maintaining its organisation and keeping away from thermodynamic equilibrium – death by another name – and in reproducing and providing for future generations. In those respects, it is the ideal sustainable system. We propose therefore to explore the common features between organisms and ecosystems, to see how far we can analyse sustainable systems in agriculture, ecology and economics as organisms, and to extract indicators of the system's health or sustainability.

We find that looking at sustainable systems as organisms provides fresh insights on sustainability, and offers diagnostic criteria for sustainability that reflect the system's health.

In the case of ecosystems, those diagnostic criteria of health translate into properties such as biodiversity and productivity, the richness of cycles, the efficiency of energy use and minimum dissipation. In the case of economic systems, they translate into space-time differentiation or organised heterogeneity, local autonomy and sufficiency at appropriate levels, reciprocity and equality of exchange, and most of all, balancing the exploitation of natural resources – real input into the system – against the ability of the ecosystem to regenerate itself.

Keywords: Thermodynamics; Organised complexity; Cycles; Coherent energy storage; Indicators of sustainability; Minimum dissipation

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1. What is life?

Schrödinger (1944) wrote: "It is by avoiding the rapid decay into the inert state of 'equilibrium' that an organism appears so enigmatic... What an organism feeds upon is negative entropy. Or, to put it less paradoxically, the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive."

In a footnote, Schrödinger admitted that by "negative entropy", he perhaps should have said free energy; but the latter did not really have the right connotation. What he wished to capture was the ability of the organism, not only to avoid the effects of entropy production – as dictated by the second law of thermodynamics – but to do just the opposite, to increase in organisation, which intuitively, seems like the converse of entropy.

Schrödinger was struggling to make explicit the intimate relationship between energy and organisation. To make progress, we need to see life with fresh eyes.

By half accident, one of us discovered that all living organisms look like a dynamic liquid crystal display when viewed under the polarising light microscope that geologists use to look at rock crystals and other birefringent materials (Ho and Lawrence, 1993; Ho et al., 1996; Ross et al., 1997). The fact that living moving organisms, with all their molecules churning around transforming energy could appear like a dynamic liquid crystal display is evidence that living organisms are coherent (organised) to a high degree, right down to the alignment and motions of the protein molecules in their tissues and cells (Ho, 1993, 1998a).

There is obviously something very special about the way the organism uses energy that harks back to Schrödinger's "negative entropy", which will be made more explicit in a reformulation of thermodynamics (presented in detail elsewhere (Ho, 1998a)). This turns out to have features in common with the dynamical structure of ecosystems that Ulanowicz (1983, 2003) has identified previously. We shall explore the similarities between sustainable ecosystems and economic systems on the one hand and the ideal organism on the other, with a view to extracting diagnostic signs of health or sustainability for the system concerned. Preliminary versions of these ideas were presented earlier (Ho, 1997, 1998b).

2. Sustainable systems as organisms?

Looking at sustainable systems as organisms is not such an outrageously novel or outlandish idea. The idea of 'ecosystem as organism' is hardly foreign to ecology; Clements (1916) was an ardent champion early last century, although ecologists in general had roundly rejected it after the mid 1950s.

Here, we use the term 'organism' without invoking consciousness or will, or that it need follow a rigid programme of development. As Ulanowicz (2001) pointed out, subtracting those still leaves one with a significant residuum of organic-like behaviour, such as homeostasis, and dynamic wholeness or coherence that is the hallmark of an organism.

At a Royal Society conference, Abrupt Climate Change (2003), many speakers drew attention to records from the ice and deep-sea cores, which showed detailed globally correlated changes in temperature and carbon dioxide concentrations on our planet, going back at least 800,000 years. These do give the impression that the earth has been behaving from moment to moment as one coherent whole, rather like a 'super-organism' – called Gaia by Jim Lovelock – that has sustained life for billions of years (Bunyard et al., 2003).

But the organism can be sick, as the earth's ecosystem has been sickened by the excessive and wasteful uses of fossil fuel since industrialization, and abrupt climate change is happening, according to the gathering of experts. That is presumably why we are increasingly suffering extremes of climate, heat waves, floods, droughts, hurricanes, accelerated melting of the polar ice caps and the sea levels rising.

One of the most important questions raised by climate change is whether we can still grow enough food to feed ourselves.

Lester Brown (2003) of the Earth Policy Institute writes of the dire state of our planet, and rightly blames the economy: "We have built an environmental bubble economy, one where economic output is artificially inflated by overconsumption of the earth's natural assets. The challenge today is to deflate the bubble before it bursts." Furthermore, he thinks that the most vulnerable economic sector may be food.

The United Nations Food and Agricultural Organisation (FAO) defines food security as follows: "When all people, at all times, have physical and economic