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Towards A Transdisciplinary Understanding of Emergy Accumulation

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ABSTRACT

It is increasingly apparent that global capitalism is not capable of generating fair and sustainable development. This has been criticized by system perspectives in natural as well as social sciences. General Systems Theory (GST) emphasizes flows of energy and materials between systems, and enables descriptive quantification of North-South relations. Meanwhile, World System Theory (WST) is more explanatory, in concentrating on the history and asymmetric power relations of the global capitalist system. Both perspectives have shown that global trade results in asymmetric accumulation processes, among other reasons due to ways of establishing value that underestimate the contribution by people and the environment. In this paper it is proposed that this problem be eased by determining what feedback mechanisms in the world system are positive and negative, and that this in turn may be operationalized by prioritizing processes that facilitate maximum empower. This calls for new approaches to global trade that are ecologically realist, and acknowledge unequal distributive aspects of resources and power. However, GST offers only limited articulation of the concept of political power. Similarly, WST proponents seldom specify what is being accumulated in world trade. Thus, whereas GST with its emergy concept provides a means for calculating flows and interactions, i.e., to quantify accumulation, WST offers a framework to emphasize power relations within different parts of the world system. However, there are intra-disciplinary difficulties in communicating the outcome from the two approaches. In this paper, critical arguments derived from this gap are presented, emphasizing opportunities and constraints in theory and terminology. The ambition is that those critical arguments will give an entrance and hints where pedagogical and information skills should be given first priority, in order to help each approach to understand the other, and ultimately push research towards a more transdisciplinary understanding of emergy accumulation.

INTRODUCTION

Across the world, resources are being extracted, transformed and traded in exchange for energies derived from or transformed in other regions. However, global trade is based on ways of establishing value that underestimate the contribution by people and the environment and seldom recognise that all economic and production processes ultimately depend on natural resources (Bunker 1985). Furthermore, due to unequal power relations, the North has managed to dominate poorer countries, e.g. by imposing terms of trade for their own benefit. This process may be conceived of as a control mechanism, resulting in unfair resource extraction and distribution, e.g. through cultural imperialism, political and economic dominance and war.

As argued e.g. by Bunker (1985), Odum and Odum (2001), one way to illuminate this exploitation is to study energy flows between regions. Recent studies of biophysical resource flows acknowledge that the South supports the North with great quantities of raw materials at low prices, only to receive

small quantities of value added products in exchange for these materials (Eisenmenger and Giljum 2007). Although money flows may be balanced, when measured in other units than money it is apparent that the current organization of global trade creates inequalities in terms of energy and other resource flows. In other words, there are net- winners and losers in global trade. By calculating emergy to money ratios, Cuadra and Rydberg (2006), and Brown (2003) have shown that trade between emergy-unequal nations results in net emergy benefits for more economically developed nations that purchase products from countries with less money in circulation in relation to local resource extraction (see also Bergquist 2008).

Aim

The tendency of global trade to generate unfair distribution of socioeconomic and environmental benefits and costs calls for new approaches that are ecologically realist and visualize unequal distributive aspects. In this paper, it is argued that the current global trade system is inappropriate and enabled through unequal power relations dating back to the days of colonialism. Global trade and exploitative North-South relations are by this view the result of both social (i.e. power relations) and physical processes (i.e. resource flows). As such, they may be visualized and explained better by merging system perspectives in the social and natural sciences.

General Systems Theory (GST) emphasizes flows of energy and materials between systems. It enables descriptive quantification of resource flows, e.g. between the North and South, and determination of net winners and losers in trade. Meanwhile, World System Theory (WST) is more explanatory, in concentrating on the history and asymmetric power relations between cores and peripheries in the global capitalist world system. By combining the two perspectives, the ambition with this paper is to articulate unfair exchange and enable a broader understanding and communication of accumulation, by drawing on concepts such as emergy and maximum empower.

GENERAL- AND WORLD SYSTEMS THEORIES

From a social science perspective, World System Theory (WST) emphasizes social and economic interactions and the interconnectedness of human societies in a transnational world system. Meanwhile, General Systems Theory (GST) focuses on how ecosystems are connected in a planetary earth system (Hornborg 2007). A notion shared by both, is that all complex systems (e.g. the biosphere as a socio-ecological system) are characterized by emergent properties, they self-organize in hierarchical structures that dissipate energy, create entropy, pulse and collapse, leading to nonlinearity and multiple steady states (c.f. Odum and Odum 2001; Abel 2007; Chase-Dunn et al 2007).

General Systems Theory

GST has been developed and highly dominated by the work of Howard T. Odum (*c.f.* Odum 1987, 1989, 1995, 1996a, b, 2007). Odum propagated a systems view on the world, which means that it is approached as one single open system (i.e., social-ecological system) within which all processes in nature and society are nested and constantly interacting in a web of energy transformations. GST hence offers a theoretical framework for inquiries into the relationships and interactions within and between systems. With regards to the global capitalist trade system, Odum and Odum (2001:146) claimed that although political control was withdrawn at the end of colonialism, “the economic colonialism of emergy inequity often continued”. The reason they argued, is that the world system organizes according to hierarchical spatial patterns, or webs of energy transformations, where resources flow towards centers of concentration, resulting in accumulation (Odum and Odum 2001). However, in GST the socio-cultural aspects of such flows and accumulation processes are seldom sufficiently articulated.

World System Theory

The concept of a world system was first coined in the 1970s by Immanuel Wallerstein (Abel 2007, following Wallerstein 1974). He argued that the world was organized as "a multi-state system of capitalist countries bounded in time and space, with a division of labor and trade relations that favored a core of one or several nations over a surrounding periphery of other nations" (Abel 2007:57). In this view, one society (system) dominates and exploits another (Chase-Dunn *et al* 2007).

WST conceptualizes the world system as interlinked spatial entities that appropriate, use and cycle energy and materials and information, and exercise power and control at several scales. Abel (2007) argues, that by this conceptualization, today there is a single hegemonic U.S.-E.U.-Japan world system that dominates the remaining countries as peripheries and semi-peripheries, thereby converging energy in the core. Hornborg (2001) argues that it is this very socio-ecological and political-economic structure that generates unequal distribution of resources, benefits and costs. An important argument in WST is that global capitalism leads to asymmetric accumulation processes. Some scholars (*c.f.* Gunder Frank 2007; Eisenmenger and Giljum 2007) have analyzed the exploitative ecological exchange through which the North is able to consume more by displacing ecological costs elsewhere. This process is sometimes referred to as entropy displacement (c.f. Hornborg 2001; Gunder Frank 2007).

Systems Principles and Concepts – Definitions and Cross-disciplinary Pitfalls

In this paper it is argued that WST offers an opportunity to widen the socio-political scope of GST, and achieve a better understanding of the history and organization of colonialism, imperialism, global trade and unequal power relations. However, there are some important discrepancies between terminologies in the two perspectives, which potentially result in integrative problems. Some critical arguments derived from this gap are therefore presented below, emphasizing opportunities and constraints in theory and terminology.

Emergy, power and empower

Emergy is defined as the available energy of one kind previously used up directly and indirectly to make a service or product, usually quantified in solar energy equivalents (Odum 1996a). Ecological systems and human social and economic systems alike are energetic systems that reinforce energy use according to the maximum power principle. GST defines power as useful energy (exergy) flow per unit of time. Empower is defined as the emergy flow per unit time. However, in WST, power, and also empower have different connotations. For example, a common standpoint in WST is that the North reinforces exploitation by exercising political and economic power. This may be described as a control (feedback) mechanism that materializes in e.g. unfavorable terms of trade, war, economic domination, political and cultural imperialism (c.f. Bunker 1985; Hornborg 2001) and further amplifies initial emergy advantages. Hence, there is a discrepancy between what is meant by power when the concept is used within GST and WST respectively, i.e., as energetic performance versus political or economic capacity for action. Similarly, empower either refers to maximizing emergy flow (see below), or the process of socially/politically strengthening for example a country, region or specific group of people.

Maximum power and maximum empower

Maximum power was coined by Alfred Lotka in 1922 (Hall 1995). Lotka proposed that the maximum power principle was to be considered as the fourth law of thermodynamics, since it guided self-organisation of all open systems (Odum 1995). It states that systems reinforce those processes that are best at maximising energy use, in competition with other systems and processes.

Odum's (1987; 1995) principle of maximum empower offers a refined alternative to Lotka's maximum power. According to the maximum empower principle, systems set performance goals of their own accord. Smaller units (i.e., subsystems) of larger and more complex systems are all ascribed goals that are defined on basis of what works for the system as a whole. The distinction between the two principles has less to do with semantics and more with incorporation with the network concept of energy hierarchy. There is a complex relationship between different parts and processes, which means that different energy forms have different energy quality, and hence a specific place in the global energy hierarchy. In GST, this is expressed as transformity (i.e., as a measure of a specific type of energy's position in the energy hierarchy). Maximum empower thereby combines quantity (exergy) with quality (transformity), to express relations between different forms of energies that may be more or less appropriate for achieving overall emergy efficiency = empower. It is a more appropriate principle for analyses of processes higher up in the energy hierarchy and at multiple and large system scales. An example is the global social-ecological world system in which are embedded the human social and economic as well as ecological sub-systems.

To maximize empower, emergy transformation needs to generate products and services that are useful for the system as a whole, so that all parts work together to further improve available resources and efficiency of the overall system. In order for a system to prevail, it therefore has to generate positive feedback that amplifies and reinforces input production processes. In other words, products and services that are generated need to be distributed and re-distributed in an efficient way, i.e., though flows and feedbacks that are beneficial to all parts.

A TRANSDISCIPLINARY SYSTEMS VIEW ON GLOBAL TRADE

Unequal relations between cores and peripheries may be traced back to the days of colonialism, if not as far back as to feudal Europe, when appropriation of resources from the countryside sustained urban growth. After some time, when the domestic European resource base became fully exploited, expansion had to find new ways, e.g. by moving resource extraction elsewhere through colonialism.

Although the specific ways of control have changed through time, imperialism continues to degrade cultural, social and natural capital in the South. Some scholars have argued (e.g. Griffin and Gurley 1985; Hornborg 2001, 2007; Hodder-Williams 2001) that one important reason why this exploitation has been able to continue for so long is that the core has found new ways to exercise control. Cultural imperialism, economic and political domination and war are by this view all modern day examples of control that degrades negotiation power in the South, alongside environmental resources. Potentially, there is a risk that these exploitative North-South relations will ultimately result in collapse of the current world system. Indeed, all civilizations seem to have followed such a pulsing trend, i.e., by iterating between exponential growth and collapse (c.f. Diamond 2005). However, there are responses emerging that counteract exploitative North-South relations. Mercosur is one such example, which proposes a common South-South market with the purpose of re-gaining control over resources, increase negation power and the ability to protect domestic environmental resources (Brown et al 2003). Still however, a majority of the world's South nations remain dominated by the North.

In addition to degrading natural resources, it may be argued that the hidden imperialism of the current world system also reinforces exploitative North-South relations, thus operating as a negative feedback mechanism from a South perspective. This is illustrated in Figure 1.

Seen from a North perspective, the same process may be conceived of as positive feedback, since money flows to the South as compensation for resources exchanged. However, market prices seldom correlate to the true value of resources or products exchanged, since conventional methods for establishing prices tend to underestimate the contribution by people and the environment. While price may appear fair in economic terms, the contrary is more common if exchange is measured in emergy terms (c.f. Bergquist 2008). This implies that whether feedback is experienced as negative or positive depends on two things; (1) methods of analysis and (2) ones position in the world system. Important questions to ask are therefore: beneficial for whom, and where? Or in other words, whether global

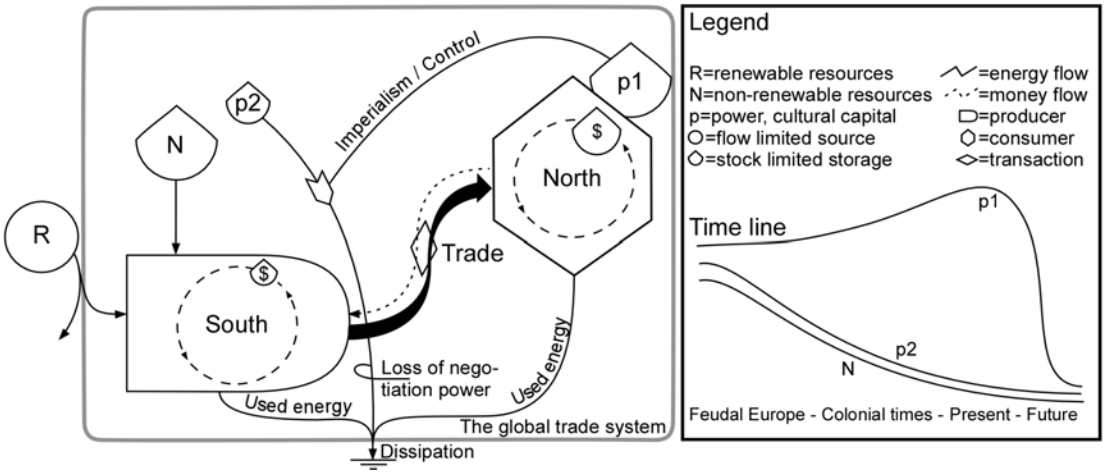

Figure 1. *Since the days of colonialism, the North has found new ways to reinforce its ability to appropriate emergy and increase its political and economic power (p1). Through unequal power relations, the North in this way exercises control that degrades natural resources (N) and negotiation power in the South (p2). Following Odum 's pulsing paradigm, it may be expected that this way of accumulating emergy in the North may only continue as long as there are natural resources left to exploit in the South, after which it is increasingly probable that the current world system enters a period of decomposition, or collapse.*

trade generates adequate feedbacks? Only then may exchange be beneficial for the world system as a whole. In this paper, it is proposed that positive versus negative feedback may be defined and identified by determining whether it results in maximum power or maximum empower.

When systems are constituted by several scales, as is the world system, maximum power implies that processes which appropriate more energy with less investment are given priority. Such systems would therefore compete better with others due to their better ability to utilize available energy. This may partly explain why the North is successful in appropriating resources (accumulating emergy) from the South. That is, the North competes well at the global market since it is good at maximizing its power. It is by this process that the North builds up emergy and power storages, e.g. trough resource imperialism. Initially in the world system, maximum power may have been logical, since global resources were abundant. However, in times of increasing resource scarcity, such as today, other strategies are needed for emergy transformation to be useful.

The principle of maximum empower has somewhat different implications for analyses of global trade and North-South relations, mainly since it refers to processes that are beneficial at multiple scales, and not only for individual parts. Maximum empower here implies a world system that facilitates those processes that are beneficial at several scales, and that does not allow for parts to maximize emergy use on expense of others. This is why maximum empower may be a better guiding principle for organizing global trade. In the world system, maximum empower would apply if processes at all system scales work together to improve available resources and efficiency of the system as a whole. This is done by facilitating exchange of products, services and information in several directions within and across different parts of the systems, i.e., though flows and feedbacks. The result is a symbiosis between all parts of a system, where all are mutually stimulating (Odum 1987). This view is far from a correct description of today's world system. Rather, the current state may be described as one of illogic emergetics, where maximum power rules at the expense of maximum empower.

In relation to global trade, establishing which of the two principles apply in a given situation may thus help to determine the efficiency and fairness of exchange. In addition, such a distinction may also shed some light on the processes behind the emergence and maintenance of unfair and unsustainable trade patterns. With this knowledge, today we would have an opportunity to switch from maximum power to empower. However, as long as our tools to establish value fail to acknowledge and visualize exploitative power relations, global consciousness and support for such a decision will remain absent.

CONCEPTUALIZING ACCUMULATION OF EMERGY AND POWER

Resource use and distribution can never be fully understood without explicit emphasis on power relations (c.f. Johnston and Sidaway 2004). As argued earlier, unfair distribution of emergy may be seen as a self-reinforcing process facilitated by power relations dating back to the days of colonialism. However, it is difficult to quantify the significance of colonial exploitation in terms of its contribution to current resource flow patterns. The same goes to power relations. Political and economic power in the North is today supported by emergy and power that was accumulated during colonial times. The historical significance and emergy support to such power storages are potentially underestimated, since few analyses apply a broad enough time perspective on the accumulation of power through time. This, we argue, is the reason why emergy synthesis would benefit from a broadened historical and socio/cultural scope, and where WST has the most to offer. There are examples of historians working with systems ecologists (e.g. Sundberg et al 1994), who called for a new field of history – an "emergy systems ecology of history". It would perhaps be even more interesting to use such new historic emergy knowledge in transdisciplinary analyses of the current world system, in order to better understand emergy imbalances in both trade and power relations.

Emergy Accumulation

As illustrated in Figure 1, the current global trade system is in many ways a means for accumulation similar to colonialism, and hence WST have much to add to the analysis. However, when the concept of accumulation is applied in WST, it is seldom stated precisely what is being accumulated (Hornborg 2001). Therefore, it is proposed here that emergy be used for conceptualizing what is actually being accumulated. Such an integrated systems approach would have much to offer for a more transdisciplinary understanding of global trade and the world system. However, there are some potential pitfalls that deserve mentioning.

First, suppose that emergy was to be used as unit of analysis and for organizing global trade. Suddenly another problem emerges. If producers were to be compensated based on emergy to dollar ratios, it would motivate higher prices (c.f. Bergquist 2008). However, raising the price potentially results in entropy displacement to other producing nations, as increased economic costs means additional emergy (in money) needs to be taken from somewhere else. Therefore, also emergy based trade would potentially fail to counteract exploitation, since there is a risk that additional costs and entropy are simply displaced to other parts of the world system. Increasing prices may hence not alone resolve current unfair trade patterns. Equally important is that payments are put into fair and sustainable use, i.e., that adequate feedback is provided. In the context of the world system, this may translate into improvement of socioeconomic and environmental conditions in the South, such as nature conservation and restoration schemes, education, promotion of social justice etc.

Another critical issue concerns limitations in global resource storages. Studies of many kinds of systems indicate that resource availability and reproduction oscillate over time (Odum and Odum 2001). Furthermore, the systems perspective generally accepts that a period of descent in terms of energy consumption is to expect (cf. Odum 1996a, 2007; Holling 2004). Therefore, if current levels of energy and resource consumption are to be sustained, it is increasingly probable that the world's resources are simply not enough. Hence, it is likely that a restructuring of the current world system would also need some element of decomposition.

In its current state, the word system thus fails to appropriately compensate resource use, distribute benefits, as well as to reduce global aggregate resource use. In this paper it has been argued that this may be eased by prioritising those processes that are beneficial for the world system as a whole, i.e., to facilitate positive feedback. Useful policies then, are those that that maximise performance (empower) for the system as a whole (Ulgiati and Brown 1998) and provide positive feedback at all scales. However, since the availability of resources follows cyclical processes, policies that will prevail are those that are able to maximize empower and adapt to pulses in the resource base. This will most probably require some form of prioritization. An important problem to solve, therefore, is how to determine a particular policy's tendency to generate maximum empower as opposed to maximum power. In this paper it is proposed that this may be achieved by distinguishing positive from negative feedback, and that emergy be used as an operational tool and unit of analysis for doing so. It is also claimed that such an approach would be even more powerful by merging GST and WST. Perhaps then, unfair emergy accumulation may be revealed more easily. This, however, first calls for a simplified emergy systems language that facilitates cross-disciplinary communication of systems theory and research findings. Hopefully, the critical arguments presented here will open up for such transdisciplinary dialogue, where pedagogical and information skills should be given first priority, in order to help each approach to understand the other, and ultimately push research towards a more transdisciplinary understanding of emergy accumulation.

REFERENCES

Abel, T. (2007). World-Systems as Complex Human Ecosystems. In: Hornborg, A. and Crumley, C. (eds.) *The World System and the Earth System. Global Socioenvironmental Change and Sustainability Since the Neolithic.* Left Coast Press, Walnut Creek, California.

Bergquist, Daniel. A. (2008). Colonised Coasts. Aquaculture and emergy flows in the world system: Cases from Sri Lanka and the Philippines. Doctoral thesis, *Geografiska Regionstudier* 77, Department of Social and Economic Geography, Uppsala University, Sweden.

Brown, M. (2003). Resource Imperialism: Emergy Perspectives on Sustainability, International Trade, and Balancing the Welfare of Nations. In: Ulgiati, S., Brown, M., Giampietro, M., Herendeen, R. and Mayumi, K. (eds). *3rd biennial international workshop. Advances in energy studies*.

Brown, M. T., Ferreyra, C., and Bardi, E. (2003). Emergy Evaluation of a cCommon Market Economy: MERCOSUR Sustainability. In Brown, M. T., Odum, H. T., Tilley, D., and Ulgiati, S. (eds.). *Emergy Synthesis 2: Theory and applications of the emergy methodology*. Proceedings of the 2nd Biennial Emergy Conference. Center for Environmental Policy, University of Florida, Gainesville.

Bunker, S. (1985). *Underdeveloping the Amazon. Extraction, Unequal Exchange, and the Failure of the Modern Sta*te. University of Chicago Press, Chicago and London.

Chase-Dunn, C., Hall, T. and Turchin, P. (2007). World-Systems in the Biogeosphere: Urbanization, State Formation, and Climate Change Since the Iron Age. In: Hornborg, A. and Crumley, C. (eds). *The World System and the Earth System. Global Socioenvironmental Change and Sustainability Since the Neolithic.* Left Coast Press, Walnut Creek, California.

Cuadra, M &. Rydberg, T. (2006). Emergy evaluation on the production, processing and export of coffee in Nicaragua. Ecological Modelling 196, 421-433.

Diamond, J. (2005). *Collapse. How societies choose to fail or survive.* Penguin, England.

Eisenmenger, N. and Giljum, S. (2007). Evidence from Societal Metabolism Studies for Ecological Unequal Trade. In: Hornborg, A. and Crumley, C. (eds). *The World System and the Earth System. Global Socioenvironmental Change and Sustainability Since the Neolithic.* Left Coast Press, Walnut Creek, California.

Gunder Frank, A. (2007). Entropy Generation and Displacement: The Nineteenth-Century Multilateral Network of World Trade. In: Hornborg, A. and Crumley, C. (eds). *The World System and the*

Earth System. Global Socioenvironmental Change and Sustainability Since the Neolithic. Left Coast Press, Walnut Creek, California.

Griffin, K. and Gurley, J. (1985). Radical Analyses of Imperialism, the Third World, and the Transition to Socialism: A Survey Article. *Journal of Economic Literature* 23:3. American Economic Association.

Hall, C. (1995). What is maximum power? In: Hall, C. (ed). *Maximum Power. The ideas and applications of H.T. Odum*. University Press.

Hodder-Williams, R. (2001). Colonialism: Political Aspects. *International Encyclopedia of the Social and Behavioral Sciences:* 2237-2240, Elsevier.

Hornborg, A. (2001). *The Power of the Machine. Global Inequalities of Economy, Technology and Environment.* Altamira Press, U.S.

Hornborg, A. (2007). Introduction: Conceptualizing Sociological Systems. In: Hornborg, A. and Crumley, C. (eds). *The World System and the Earth System. Global Socioenvironmental Change and Sustainability Since the Neolithic.* Left Coast Press, Walnut Creek, California.

Holling, C. S. (2004). From complex regions to complex worlds. *Ecology and Society* 9:1:11. [online] URL: http://www.ecologyandsociety.org/vol9/iss1/art11/.

Johnston, R. and Sidaway, J. (2004) Geography & Geographers. Anglo-American Human Geography since 1945 (sixth edition). Arnold, UK.

Odum, H. (1987). *Living with Complexity*. The Crafoord Prize in the Bioscience. Crafoord lectures. The Royal Swedish Academy of Science.

Odum, H. (1989). Ecological Engineering and self-organization. In: Mitsch and Jorgensen. (eds). *Ecological engineering – An introduction to ecotechnology*, John Wiley & Sons.

Odum, H. (1995). Self-organization and maximum power. In: Hall, C. (ed) *Maximum Power. The ideas and applications of H.T. Odum. University* Press.

Odum, H. (1996a). *Environmental Accounting: EMERGY and Environmental Decision Making*. John Wiley & Sons, New York, pp. 370.

Odum, H. (1996b). Scales of ecological engineering. *Ecological Engineering* 6:7-19.

Odum. H. (2007). *Environment, Power, and Society for the Twenty-First Centurey. The Hierarchy of Energy*. Columbia University Press, New York.

Odum, H. and Odum, E. (2001). *A Prosperous Way Down: Principles and Policies*. University Press of Colorado, USA.

Sundberg, U., Lindegren, J., Odum, H. T., and Doherty, S. (1994). Forest EMERGY Basis for Swedish Power in the 17th Century. Scandinavian Journal of Forest Research. Supplement no. 1 (1994). Scandinavian University Press, Stockholm.

Ulgiati, S. and Brown, M. (1998). Monitoring patterns of sustainability in natural and man-made ecosystems. *Ecological Modelling* 108:23-36. Elsevier Science.

Wallerstein, I. (1974). The rise and future demise of the world capitalist system: Concepts for comparative analysis. *Comparative Studies in Society and History* 16:387-415.