Sustainability through the re-contextualization of humanity:

Embedding our socio-economic system into natural ecosystems needs an increased understanding of the principles of spatial scale and topology

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Introduction

Our current economic system has been responsible for vast improvements to everyday human lives. The primary means by which this has occurred is through the adherence to the concept of Pareto Optimism, whereby every individual has 'sovereign' preferences leading to the maximization of their own welfare (Daly and Farley, 2003). In a world where the abundance of humans was scarce relative to the wealth of the global resources (commons), this paradigm created a highly adaptive, allocative mechanism that had little need for regulation at any level, from federal to inter-personal. For most of our industrialized history, the aggregation of individual, self-maximization through the mechanism of the 'invisible hand' appeared to add up to the wealth of the nation (Smith in Heilbroner, 1999). Since then however, we have moved from an empty-world paradigm, where capital and labor is limited and resources are abundant, to a full-world paradigm, where capital and labor are abundant but resources (natural capital) are scarce. With this shift, is the developing recognition that neoclassical economics has many negative side-effects which, are to the detriment of our natural ecosystems.

In this current economic system, it has been possible to mine natural capital, without readily-apparent, negative consequences impinging on the welfare of other humans and nature. One reason for this is due to the robust properties of these ecosystems, which fail to signal the long-term consequences of loss of resilience, continuing to function in the short term even as resilience declines (Folke *et al*., 1996). Yet, even when clear and present signals of failure or dysfunction are manifested in the ecosystem, society often fails to recognize the connection between their actions and this decline. As a result, attempts to solve environmental problems are often site-specific and reactionary rather than holistic and preventative. In much of our pre-industrial past, a sedentary community would readily see the effects of their actions on nature because they were closely tied to its productivity. Any damage caused to the environment would rapidly manifest itself in the form of lost productivity, which would reduce the current welfare of this community. This results in a clear incentive for avoiding negative environmental impacts. Today's society has lost the ability to recognize the relationship with nature as well as the ability to make adaptive responses to a problem once it is recognized. This is the phenomenon of disembedding, whereby our individual relationships with ecosystems (and human communities as well) have been lifted from a local context into a realm of infinite scales of time and space (Hansson and Wackernagel, 1999). Examples of this dimembedding, in time, can be seen in the indiscriminate mining of oil generated from countless eons (Mayumi, 2001) or, in space, as the appropriation of natural resources from across the globe, such as tropical timber. The primary culprit for this lack of perception has been our current monetary system of exchange. The universality and exchangeability (fungibility) of money has allowed the individual to transcend local relationships with both environment and community (Hansson and Wackernagel, 1999).

Objectives

It seems obvious then, that the prevailing and future environmental problems can only be solved through this re-contextualization of humans with their surroundings. Through this we can: more accurately receive the signals from nature and more appropriately respond to these signals. Norton and others (1998) describe this as the two parts of a model for managing sustainability: the Reflective Tier and the Action Tier.

But the amount of signals from nature can be overwhelming. How then, is it possible to filter what is vital information from what is 'noise'? As an initial step, ecosystem functions can be reduced to a more manageable set of ecosystem services. Yet, ecosystems are complex, adaptive systems that may have multiple locally stable equilibria (Folke *et al.*, 1996) and thus require society to make environmental decisions relative to the spatially heterogenous aspect of the problem.

This paper discusses the role of spatial scale and topology in filtering environmental signals. In addition, statistical methods for defining these elements are discussed. When we begin to understand the scale and topology of ecosystem processes for receiving signals, and the scale at which human communities can appropriately enact policy, we will be able to enact adaptive, co-evolutionary mechanisms that are necessary for a fundamental change to occur within our socio-economic system.

Ecological Concepts

Ecosystems and Services

Ecosystems are a physical environment that is defined by the interaction between biotic elements (*e.g.* species) and abiotic elements such as climate and soil (Tansley in Norberg, 1999). The extent of an ecosystem is defined by the observer who attempts to define boundaries by minimizing the interaction between a set of functions related to that ecosystem and all other functions. (Costanza *et al.*, 1993) As an example, a researcher who wishes to explore the interaction between fish and algae might use the lake as the extent of this ecosystem, for this excludes the terrestrial elements. However, another observer may wish to examine the impacts of suspended solids on fish and would therefore need to include erosion from land uphill of the lake. Their ecosystem definition might then be an entire watershed.

Because of the infinite combinations of biotic and abiotic elements that can be used to define an ecosystem, it is more manageable to work with ecosystem services. Ecosystem services are a specific set of ecosystem materials, energy or information that are beneficial to humans (Costanza *et al*., 1997). The benefits of these services do not necessarily transfer to benefits for all of biota (*e.g.* recreation services) but have been developed so as to lump the vast array of ecosystem functions into manageable and prioritized categories. A tentative classification of significant ecosystem services has been developed by de Groot and others (2002).

Spatial Scale, Levels, Equilibrium and Disturbance

In this paper, ‘scale’ refers to the physical dimensions for measuring/observing an ecosystem and is comprised of two components: extent and grain (resolution) (Marceau, 1999). The extent of this measurement refers to the outer boundary past which observations are not taken or are ignored. The resolution of this measurement refers to the precision used. Levels (or optimal scales) refer to specific locations along a scale where organization (or patterns) repeatedly occurs. In terms of an ecosystem, levels are the areas along a scale where equilibrium states are maintained or rapidly return to (Turner *et al.*, 1989). Equilibrium of an ecosystem refers to the multiple states that may exist where organization occurs and the efficiency of the exploitation of all niches is maximized. This is opposed to the idea of ‘thermodynamic equilibrium’, where energy has been completely dissipated and no organization or structure exists. A system is considered resilient when it can return to a state of equilibrium after a disturbance (*i.e.* the ability to absorb these disturbances without being transformed by them) (Dasgupta, 2000). Since the term "disturbance" has negative connotations, it may be better to use the term, "signals" (either natural or man-made). A sustainable level (operational scale) is an area over which an ecosystem process continues to operate (or returns rapidly to an operating condition) despite the repeated application of external factors. These are the levels that must be identified in order to understand how we can have a sustainable economy.

Hierarchy Theory

The importance of identifying operational scales can be examined through hierarchy theory. According to this theory, the processes that affect the structures and patterns of organization in an ecosystem change when one measures different operational scales. Rather than a higher level organization being the sum of structures from processes of lower levels, emergent structures are formed from processes unrelated to the processes affecting previous patterns of structure. Therefore, conclusions derived at one scale are specific to that scale and should not be expected to be valid at another scale (McCarthy in Marceau, 1999) (Sonnenschein in Constanza *et al.*, 1993). In terms, of society this means that we should not expect that policies enacted at one spatial scale to be effective at others.

The Second Law of Thermodynamics

The second law of thermodynamics introduces the concept that, in an isolated system, organization will decay until everything is at thermodynamic equilibrium. Inputs from outside this system must be captured in order for organization to be maintained and consequently, this organization comes at the expense of increasing entropy in the other system (Ayres, 1998). It is also recognized that there is less efficiency of systems further from thermodynamic equilibrium than those nearby. Anotherwords, a complex, highly-organized system must work harder and consume more external, low-entropy goods in order to maintain its current status.

Relationship of these Ecological Concepts with Society

The Second Law in Economics

The consequences of the entropy law are that the evolution of the human civilization into increasingly, complex and compartmentalized structures, comes at the ever-increasing expense of natural ecosystems. The greatest failure of the current economic system is the ignorance of the fact the development of structure (*e.g.* consumer products) must come at the cost of mining low-entropy matter (*i.e.* natural resources) from the nature and replacing it with high-entropy waste (*i.e.* pollutants).

Disturbance

These waste products are then applied to ecosystems as if they were passive objects with unlimited storage capacity (H&W p205). In reality, these systems must either find ways to store this waste or transform and transfer the waste. Either way, the deposition of high-entropy waste into an ecosystem acts as a disturbance that reduces the ability of the ecosystem to respond to other disturbances in the future and reduces the current ability to provide ecosystem services. This is similar to repeated attacks to the human immune system whose ability to fight the next infection has been significantly reduced by the constant application of disturbances (infection). By removing high grade (low entropy) products from the system and replacing them with low grade (high entropy) waste products we are forcing the system out of organizational equilibrium and back to thermodynamic equilibrium.

Scale

This is significant for humans in both their matter/energy transfer relationships with ecosystems and their information transfer. With human imposed disturbances on ecosystems (matter/energy transfer), such as pollution from acid rain, the effects to the ecosystem depend on the levels at which one is examining that system as well as the levels at which the disturbance occurs. In terms of information transfer, studies of social choice theory have found that it is impossible to simply scale up from all individual preferences (aggregation) to produce a group preference (Arrow 1951, via Gibson, 2000). The processes and inputs affecting individuals are different from those affecting society. Because of these two different relationships (matter/energy vs. info) we often have a disjunction between the scale at which a problem is perceived and the ecological scale at which the solution to a problem is likely to be effective (Rykiel, 1998). In addition, ecosystems with feedback signals that are displayed at larger scales than individuals are likely to be undervalued by individual preference (Rykiel, 1998). Therefore, the valuation process should not usually be developed through examination of individual preferences, rather through the levels of human organization that correspond to the levels of the ecological problem.

Measuring Operational Scales

Since organization occurs at levels of a scale (operational scales) and patterns are the outward manifestation of this organization, it is possible to expose these scales with spatial statistics that measure patterns. Furthermore, since patterns and organization of ecosystems are generated as a consequence of disturbance, it is possible to measure levels of ecosystem services by measuring levels of the scale of disturbance as a proxy (Turner, 1989b).

Human systems also show patterns of organization at multiple scales. Although the causes of these organizational patterns may be artificial (*i.e.* organized by political rather than ecological boundaries), the patterns themselves may be identified by the same statistical methods used in detecting natural levels. We can therefore develop policy from the scale of human organization that is related to the scale of human disturbance that is acting on the ecosystem.

There exists spatial metrics for defining operational scales as well as metrics for determining the spatial complexity of landscape elements. For point patterns, the output from the Ripley's statistic (Getis 1984, Getis and Franklin 1987) displays whether points are clustered, regularly distributed or random. Since the statistic measures this pattern at all increments within a search range, patterns appear as plateaus and trenches that stretch across specific ranges of the distance increment. These ranges where a pattern is pronounced are indicators of an operational scale for the subject being tested. Appendix 1 provides an example of the scale-recognizing capabilities of the Ripley's statistic.

Topology

Relating Ecological Systems to Topology

Topology refers to the spatial relationships that ecosystems have with each other. Ultimately, understanding topology is important because scales must be understood within a landscape context. Some categories of these relationships are listed in the table below (Wiens, 1993).

Feature	**Description**
Size Distribution	Frequency distribution of sizes of patches of a given type
Boundary Form	Boundary thickness, continuity
Perimeter:Area Ratio	Reflects patch shape
Context	Immediate mosaic matrix in which a patch of a given type occurs
Connectivity	Degree to which patches of a given type are joined by corridors
Richness	Number of different patch types in a mosaic
Dispersion	Distribution of patch types over an area
Predictability	Spatial autocorrelation

The functional value of an ecosystem service, regardless of the operational scales, depends on the contiguous, areal extent of that service. Often, there is a minimal area threshold associated with a particular service beyond which, that service will begin to deteriorate in functionality. For the ecosystem service of maintaining biodiversity, the need for a minimum area has been well documented by (MacArthur and Wilson, 1963). Failure to provide this area results in the phenomenon known as 'relaxation toward equilibrium'. This means that the system might return to an equilibrium state but this equilibrium will be at a lower level (less organized) than previous. From the view of a service, this means that the total output will be less than previous and therefore less valuable to humans. This notion is contradictory to the economic theory that the marginal value of products will always increase as that product becomes scarcer.

The functional capacity of a service (and therefore its value) is also dependent on its connectivity with other areas of similar functions. Often a system dissipates high entropy waste by transferring it to another system that ideally, exploits this waste. If that waste cannot be stored or dissipated within the system or transferred to another system, then it will begin to affect the functions of that system. Thus a human system that generates a novel waste or one whose temporal or spatial scale exceeds the natural range of variability for that system, will likely cause a disruption in that ecosystem's functions.

The richness of different landscape patches in a given area will affect the functional capacity of ecosystem services. Homogenization of the landscape will often erode the diversity of ecosystem function in the area, thereby reducing the ability of an ecosystem to be resilient to perturbations (Folke *et al.*, 1996). For this reason, just because one service has a higher value than another service does not mean that area should be maximized for the most valuable service.

Relating Human Systems to Topology

First, people closest to, or within the extent of, a service are more likely to value it higher than people that are further away, simply because they have more access to that service (Wilson and Carpenter, 1999). Second, these people are more likely to be affected by the externalities that may be negatively affecting the services on which they rely. Third, the functional capacity of that service is determined by the use of that service. A level of use of a service from a nearby dense population will lead to a decline in that service. Finally, the perception of the value of a service may change between broad scale geographic locations because of different cultures, economic well-being (standard of living) and population pressure.

As an example, Mitsch and Gosselink (2000) describe the effects of ignoring topology on wetland systems. For area, if wetlands are too small, functions such as flood prevention and water purification may be significantly impaired. For location, wetlands are a part of a larger system that includes watersheds and estuaries. The location of the wetlands must be viewed in this context. Anotherwords, wetlands mitigation by substituting one wetland for another (or creating an artificial wetland) may be ineffective if position in its functional landscape is not considered. One wetland may have different functionality than another wetland (such as riverine versus coastal). In addition to its functional context within a larger ecological system, wetland location relative to human population must also be considered. As a service, the value of wetlands initially increases as the surrounding population increases and the area of the wetlands decreases. These populations are inherently producing more waste than a smaller population and so must depend on waste filtration to a higher degree. However, as the wetland becomes increasingly isolated from the larger system and as the level of waste load increases on this system, the ability to process this waste diminishes and may become non-functional if sufficiently overloaded.

Spatial Statistics for Topology

The fractal dimension has been used in previous landscape level research to describe both patterns and the topological relationships of those patterns (Turner 1989a, Olsen *et al.* 1993, Milne 1988).

Relating Spatial Scale and Topology to Economic Scale

Typically when the term "sustainable scale" is used in economics, it refers to the sustainable throughput of resources (in the production process) relative to the environment (Daly in Jordan and Fortin, 2002). However, nature's services exist heterogeneously across the globe. The spatial relationships of regions experiencing human disturbances as well as the scale of a particular disturbance, will determine what is sustainable. Therefore, before we can begin to determine what is a sustainable economic scale we need to determine the scale and topology of the ecosystem services and of the disturbances that affect them. Without this understanding, the idea of sustainability becomes homogenized into a global phenomenon that can only be solved through global policy structures. While there are certain disturbances of a universal phenomenon, whose effects are evenly distributed and may require global regulation, there are many more that are disjunct, whose effects are local or regional (although the affected areas might be many) and require regulation appropriate for that area. Maintaining global biodiversity by focusing on global hotspots is an example of this problem. Without an understanding of the scale of disturbances, which may change from region to region and which may be larger than the reserves themselves, we may fail to successfully maintain the current level of biodiversity (Folke *et al.*, 1996).

Conclusion

Most environmental problems are driven by mismatches in scale between human responses and natural interactions (Lee, 1993) as well as the ignorance of topology. Although the relationship between operational scales of ecosystem processes and those of human processes is complex, the use of spatial statistics can help to identify corresponding human-natural scales within the landscape topology. By doing so, we can improve the ability to send and receive signals between humans and their environment and begin to reembed society within nature.

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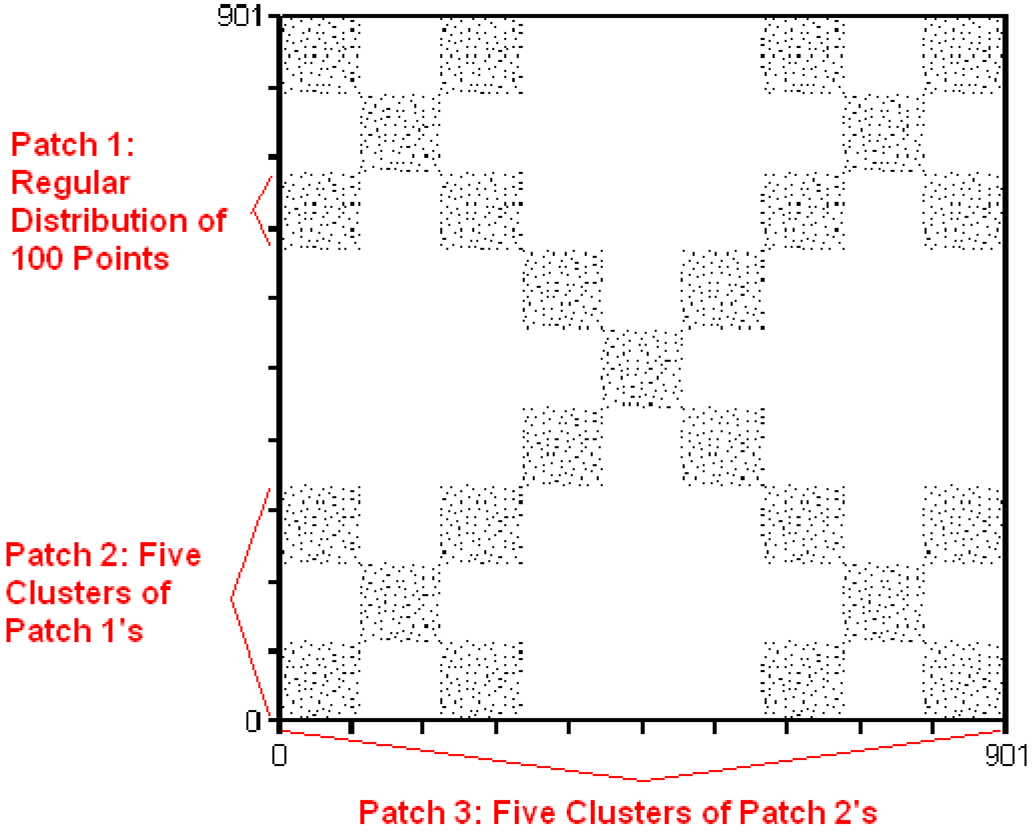
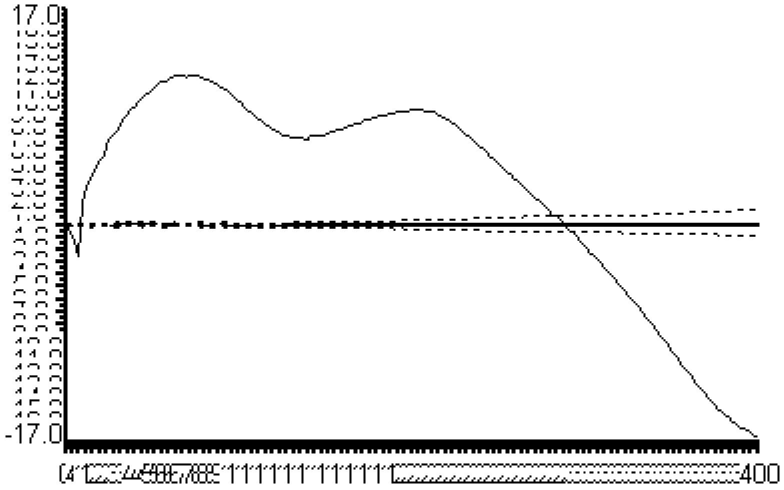
Appendix 1. An example of finding operational scales with the Ripley's Statistic. A layout of the point pattern (top) and the output from the statistic (bottom).

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