Resilient Social Ecological Systems: bridging the rural urban dichotomy

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Abstract. Models of resilience derived from the biosciences tend to reply at least implicitly on a measure of speed of return to pre-existing states after distubance. Core models rely on a ball-in-the-cup metaphor in which disturbance dislodges the system from a pre-existing equilibrium. Social Ecological Systems generally change continuously, rework their adaptations and are future oriented. This paper suggests that a new concept of resilience in messy SESs is indicated and proposes a different metaphor.

Keywords: messy SES, resilience, panarchy, search function, urban, rural, ABM, transformational growth martrix.

1 Introduction

There are several diagnostic criteria distinguishing social ecological systems (SESs) from traditional ecological systems (TESs) that argue against direct borrowing of computational models designed for TESs to model SESs. I will make the case using both urban and rural SESs that the introduction of social analysis using well accepted theoretical approaches leads one to the conclusion that a number of core modeling assumptions must differ for models of each type and that these differences have largely been ignored in the field. An examination of panarchy and resilience theory will provide a framework for making this argument. Examples will be drawn from data collected in the course of two NSF funded projects.

A number of reviews of the literature touching on panarchy and resilience concur in concluding that models developed for ecological systems can be profitably borrowed for the study of SESs. The most fundamental reasons social scientists find such attempts simplistic are both ethical and theoretical. In an ecosystem, hierarchy has no ethical significance while in an SES the distribution of power and assets raises fundamental ethical issues. The modern notion that each individual has rights and capacities that demand respect has also been the basis of a vast literature on human rights and empowerment. This paper begins with two examples where these concerns are apparent and then draws some theoretical conclusions.

2 Two Versions of a Messy SES

I and my colleagues have been involved in NSF funded research on large urban areas in Africa and the Near East[1] as well as research on small villages in the Sahel of Africa.[2]

A brief introduction to the key aspects of each project will provide a context in which the subsequent theoretical section will be more easily appreciated. It is my position that these two projects are representative of messy SESs [1, 13] in general and illustrate many of the issues not typically addressed in models imported from the ecological sciences.

Our recent rural project is still in the data collection stage but already the data seem to illustrate quite radical adaptation to climate trends involving both new adaptive strategies and development of those strategies primarily by younger households over the course of a decade or more. Our research has focussed on areas where greening trends, as viewed through satellite imagery, are in excess of what might be expected on the basis of rainfall. Briefly, we have started from rainfall and greening indices over two decades and regression that teased out those areas where the most recent ten years show excess greening relative to that which the previous ten year record for the same places would predict if you assumed rainfall was the sole driver of greening. We have then interviewed in control villages (where there is no "excess greening") and in "excess greening" villages. This methodology is intended to eliminate the raw influence of rainfall itself (and associated soil based responses) and allows us to concentrate on other factors such as anthropogenic influences (e.g. degradation causing the proliferation of invasive weeds or new adaptive strategies that increase overall greening).

So far we have completed serious work in two sites: south west of the Foum Gleita reservoir in Mauritania and in the south east of Senegal. In

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[1] 1999-2003 NSF [9817743, 0138217] "Creation of a GIS for six Cities in Arid Environments: in Morocco, Senegal, Mali, Niger, Tanzania, and Botswana." PIs Thomas Park, Mamadou Baro, Gary Christopherson and Stuart Marsh. Mohammed al-Yasri Qadi Ayyad University in Marrakech, Magatte Ba and the Centre de Suivi Ecologique in Dakar, Sadio Traore of CERPOD in Bamako, Nafoga Adamou of Systèmes de Prévention Précoce in the Cabinet du Premier Ministre in Niger, Elifuraha Mtalo of University of Dar Es Salaam - Ardhi Institute, and Onalenna Doo Selolwane of the University of Botswana.

[2] 2007-2012 NSF [6757504] "Desertification' or 'Greening'? Human-Environment Relationships in the Face of Climate Variability: Case Studies in Mauritania and Senegal." PIs: Stefanie Herrmann, Thomas Park, Mamadou Baro, Randy Gimblett. Birane Wane of University of Nouakchott, the Centre de Suivi Ecologique in Dakar and Assistants Aminata Niang, Amadou Hadji and Abdoul Aziz Diouf.

both areas, much of the "excess greening" area represents new adaptive strategies responding to a mix of environmental change and government policies. In the Mauritanian case, poor management of an irrigated perimeter fed from a reservoir destroyed the canal network and caused it to be abandoned. The reservoir remained and a steady year-long westward outflow in the Gorgol river has been required to prevent massive inundation of the downstream city of Kaedi during the rainy season. While the project has not had the resources to do an hydrological study, locals claim that the annual flow in the Gorgol, which used to be intermittent, has slowed the outflow of its tributaries and in particular that of the northward flowing Ko river along which our study was centered. Consequently, the locals claim the water table stays elevated to within a foot of the surface throughout the dry season.

The recent proliferation of trees in the region is said to be due to infilling of trees behind dikes used to retain rain for cultivation in the rainy season. Apparently, in the last decade the water table has been high enough to facilitate cultivation in many areas and, in order to maximize yields, people alternate their crops more frequently between lowland plots in small water-courses and fields behind dikes. They now use the dike areas only for a year or two and abandon them for other fields. New villages have been developed by younger, resource poor families and the newest villages are now said to have the best returns to labor and unit area. While the population has grown there are still abundant resources relative to demographic levels. The water availability is such that people from other valleys now come regularly to this valley to water their animals (goats and camels): a small depression dug in the "dry river course" of two feet in depth will half fill with water even in the dry season and the abundant trees provide ample nourishment for animals transiting through the valley.

While we have yet to model this case, to do so we may have to include micro climatic changes, the influence of donor states on dam and perimeter construction, perimeter mismanagement, urban risk down stream and the rapid change in agricultural and pastoral production due in part to hydrological changes. It will also have to include the development of new villages by younger families and their pursuit of different livelihood strategies in response to both political systems and environmental changes. The former perimeter is now invaded by new weeds, which also show up to satellites as greening, but some of these invasive species (reeds), growing in the abandoned canals, now produce the standard thatch used in the region's villages. This process of sorting out an appropriate adaptation to a major environmental impact, the construction of a large reservoir and subsequent collapse of its associated irrigation perimeter, took at least a decade, is still continuing and there is neither a likelihood nor an expectation of things returning to the way they were.

We have found a similar situation in south eastern Senegal. There our greening villages were demographically younger households, often immigrants from other regions, who practiced a different mix of crops and had distinctly higher returns per hectare. In comparison to the households of the control villages they had a much higher regard for agricultural possibilities: viewing a majority of recent years (53.3%) as good while control villages viewed only a third (35%) of recent years as good years for agriculture. In both sets of villages there is a gradual transition away from culturally valued cattle toward small stock that do better with less moisture. Because the control villages have more depleted soils and tree cover, the switch to small ruminants who browse lower on the trees may only enhance the "greening" visible by satellite in the "excess greening" areas which have a more substantial tree cover: not only do cattle browse higher, shepherds are more prone to cut quantities of high branches to nourish lactating cows when ground cover is sparse. Changes in pastoral patterns followed by Mauritanian and Senegalese pastoralists also contribute to this pattern of excess greening as the development of an extensive system of boreholes in the arid northern parts of Senegal has led pastoralists to keep large stock (cows and camels) in the north while sending small stock south. The latter now also use an extensive network of cell phone communication to decide where the vegetation and water supplies are available at any moment so they can efficiently distribute their livestock and not overload the landscape or the water resources.

We have been modeling our urban data and have progressed to the point of planning new and more targeted data collection. The initial project in six cities interviewed households around forty urban points in each of the six cities. The points were selected by computer based on a diachronic analysis of almost twenty years of ground truthed remote sensing imagery for each city. The selection was intended to be representative in terms of urban residence construction: distinguishing both urban form (e.g.slum, apartments, low income houses, villas etc) and history (e.g. a slum in 1998 that was unbuilt in 1981 from a slum in

1998 that was also a slum in 1981). The original intent, amply confirmed, was to see if the history of urban form also defined homogeneous socio-economic strata in the present. While our data confirmed this in all six cities we were led to model the data set further in response to additional findings. The project also led us to a new conceptualization of urban areas.

As our initial ABM model has been described elsewhere [14, 15], I will outline our current thoughts on modeling urban areas in poor parts of the world. Our research showed that the relationships between socio-economic variables differed significantly in different sectors of each city. This led us to reconsider the Chicago school of sociology's idea that variables are contextual [2]: e.g. three years of western oriented education interacts with income, health, household dynamics etc in quite different ways in different places. In order to understand local causality we cannot assume the existence of universal variables exerting given amounts of causality regardless of context. In short, most socio-economic variables differ fundamentally from variables such as mass or momentum in physics. Purchasing power parity figures are a very partial and obviously limited attempt to contextualize prices. We imagine, more generally, that socio-economic variables would be better assessed through a system of agents (an ABM) acting within a local context of rewards and opportunities. To create such a local context we plan to create multiple transformational growth matrices (TGMs): one for each distinct urban class (defined by urban form and urban history). Each matrix [11] would be constructed to show the normalized (normalized to between +/- 1) interactions between a set of indexical variables (e.g. aan indexical variable amalgamating educational data or health indicators).

The TGMs we would construct would derive their values from survey data as well as theory and would represent influences between variables in both directions (e.g. influence of education on income and of income on education). They would thus provide the context within which agents of an ABM would optimize their behaviors and emulations. Such an ABM could allow us to model the differential impact across urban areas of policies (e.g. national or SAPs). Perhaps most sigificantly, we would neither assume model uniformity within an urban area nor causal uniformity for specific variables across cases from different TGMs.

3 Panarchy as a Model of Global Systems:the Adaptive Cycle

Holling [9] argued that the basic model of an ecosystem is a figure eight plot conceived as an adaptive cycle with four phases (exploitation, conservation, release and reorganization) associated with the bottom left, upper right, bottom right and upper left quadrants respectively. The plot places potential on the Y-axis and system connectedness on the X-axis).

This model imagines a simultaneous increase in resource incorporation and system organization culminating in a highly productive state that then becomes rigid and maladaptive leading to decline first in productivity and then in system organization. A process of decline leads to rapid loss of system organization and simultaneous increases in productivity within a simpler less complex system followed by its decline and reorganization into more complex systems giving rise to another cycle. Earlier ecologists had a logistic model that suggested small rapid growth species [r] might be replaced by slowly growing larger species [K] (e.g. large trees replacing quick growing opportunists). The Holling model added two terms to turn the model into an **adaptive cycle**. This model was then modified in two ways:

1) by adding a third dimension (resilience) to make the argument that some parts of the cycle are more resilient to perturbation than others (e.g. low connectedness and high resilience foster creativity [α] but a perturbed system with such high connectedness as to be brittle [Ω] has little resilience and perturbations clear the way for later creativity.

2) by combining multiple adaptive cycles into a global system.

These changes facilitate the transformation of the original model into a global model of four nested adaptive cycles at different spatial scales with associated interactions that purport to extend the original ecosystem model to social ecological systems at the global scale.

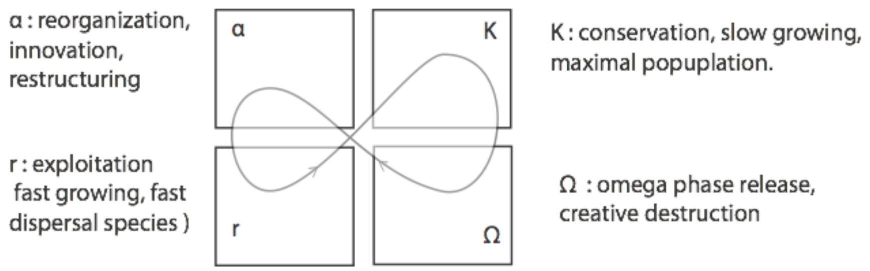

Fig. 1. Original model of adaptive cycle

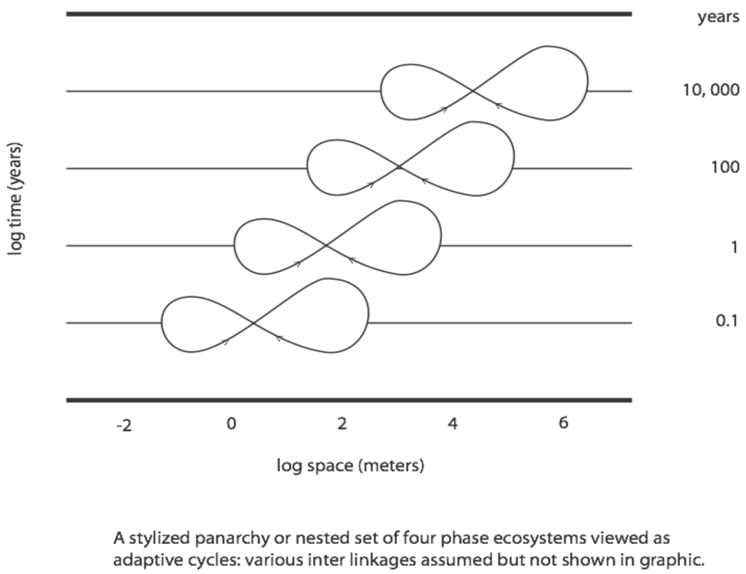

Fig. 2. The extended (Panarchy) adpative cycle

The basic characteristics of the extended panarchy model [7] include:

- Adaptive cycles (figure eights) all the way up and down, any flow in the system is allowed as long as it follows a figure eight.
- Each adaptive cycle can have autocatalytic properties and influence the adaptive cycle above or below it in scale via the nonlinear dynamics of a set of 3-5 key variables.
- Scale in time (periodicity) is tied to scale in space: the model ignores long term trends and the arrow of time and all but local entropy.
- Sustainability is equivalent to keeping four phase adaptive cycles interlinked: even up to the level of human socio-economic systems.
- While the model's causality is not bottom up (i.e. not reductionistic), the global system has limited nonergodicity: creativity and openness are reduced by scaling characteristics, by constraints on cycle flows and by basic structural features.

Social scientists will have a number of reasons to be skeptical:

- A cyclical version of history is an old idea but not a persuasive one these days.
- The extension of an adaptive cycle model to modern global social systems is problematic: in particular the notion of tying spatial and

time scales together is unpersuasive in an era in which even pastoralists scope out resources by cell phone.

- We have ample evidence of long-term trends in increasing consumption and permanent cumulative impacts on the environment since the industrial revolution yet the adaptive cycle provides few clues to why this should be.
- In a seriously nonergodic world, there are likely to be complex causal influences including chaotic ones in which very small changes beget very large ones across scales but the panarchy notion that these reach the lowest levels only by propagating through a series of auto-catalytic loops defies our knowledge of global processes
- Human culture and social organization have provided tools, that allow rapid and major transformations, not found in simpler ecosystems. Holling et al extend a basically territorially and thermodynamically bounded idea [10] from ecology to cultural systems even though culture and trade are less ideologically or thermodynamically constrained. Ulanowicz [20, 21] provides a better interpretation of autocatalytic loops that are less territorial, intrinsically open to outside influence and potentially more creative.
- Economists [e.g. 17, 11] have long recognized that human behavior is social and global: norms and values are linked through modern communication systems and human action can easily short-circuit or leap across levels: corporate greenwashing, development policy and environmental movements don't propagate through a nested series of adaptive cycles.

Panarchy may be one of the most popular attempts to borrow ecological models to explain social ecological systems but most social scientists find it unpersuasive for one or more of the reasons listed above. Rather than elaborate the critique here, I will turn next to the way in which models of resilience developed for ecological systems have been rather uncritically extended to social ecological systems. This will provide greater generality for my conclusions.

4 A Theory of Resilience for Messy Social Ecological Systems

A messy SES may be characterized as a social ecological system that is not self-contained in as much as it is influenced by and influences the outside world in significant ways. Most human SESs are messy to a degree but with the development of larger civilizations even remote villages became increasingly messy from a systems point of view. The revolution in global communications in recent years has put in jeopardy the very existence of any non-messy SESs.

A number of assumptions common in the literature on resilience in ecological systems are also problematic when extended to messy SESs [3, 12, 16, 19]. I would argue that what appear to be reasonable assumptions and implications in the context of well defined ecological systems are quite unreasonable when extended to messy SESs as well as that even the basic resilience model needs to be questioned.

The dominant metaphor for resilience is the idea of a ball in a cup where a shock (disturbance) temporarily knocks the ball of the cup and the resilient system responds in such a way that the ball is **returned** to its former stable position or an adjacent one [3, 5]. Modern theory talks in a more sophisticated way, using the same basic metaphor, of multiple basins of attraction (states) and resilience comprising the **return** of elements of the system to each or some of these basins of attraction. With the introduction of autocatalytic processes and adaptive cycles the cup becomes the cycle and in panarchy each cycle has its own timescale. While Holling [8] designates the simple reliance on rate of return to the stable state as an “engineering” resilience, in his own adaptive cycle ecological resilience, though far more sophisticated, still has a timed cycle of return in its conception.

It may be natural for theorists of resilience to wish to define resilience in terms of the rapidity of return to a stable state or to view resilience as linked to a normal cycle. From this perspective, a resilient system is one that is not perturbed from its stable optima or natural cycle for long. While there may be some sense in which this is a reasonable approach to spruce forests [9], it has been a very long time, historically speaking, since human SESs have stood still or returned to the previous way of doing things after any significant shock or perturbation. Even the daily insecurities due to conflict in its many forms have for millennia introduced continuous transformations in daily life and governance structures. In short, the ball in the cup metaphor must be seen as misleading when it comes to messy SESs.

This common metaphor directs attention away from a number of key issues. Some engineering systems have a single optimum, some have several optima, but in both cases they are pre-existent or built into the system: the system does not usually re-engineer itself. Social ecological systems have emergent features [22] and typically engage in continuous and transformative re-engineering. SESs regularly erode their optimal adaptation (soil their nest) and rework their approach to adaptation. Neither the ball-in-the-cup engineering metaphor nor a reliance on periodic cycles are really appropriate to SESs, messy or not. In fact any reliance on time of return to a pre-existing state as an adequate measure of messy SES resilience has to be resisted.

We can define **resilience (R)** for a messy SES as medium term sustainability of social **and** environmental resource levels conducive to a good quality of life. More formally:

Let R = f [SES Interactions among {A: biodiversity, resource diversity and redundancy, economic capital including productivity (per unit of area, exergy or labor), B: inequality and empowerment, individual and institutional social and cultural capital including technology, demography, communication quality, and C: system ascendancy at various spatial scales}]

"R" may usually be stabilized or improved with variables at intermediate levels. Adaptation to nonlinear transformational change requires diversity and precludes maximization of any single production function. παν μέτρον άριστον (all in good measure; everything in the right proportion).

"A" includes variables subject to stochastic as well as nonlinear biophysical processes

"B" includes socio-cultural variables usually subject to both stochastic processing and ideological manipulation

"C" includes Ulanowicz's term "ascendency" which is a measure of information (or product) flows (constraints) within the system

Such a model makes many assumptions of course but it does not imply any utility for a measure of the speed of return to a pre-existing system as a proxy for resilience. Nor does it constrain the directness of interactions or ignore the causal influence of hierarchy and the distribution of power within the system or normative (as opposed to efficiency) considerations tied to the development of hierarchy. The complexity of messy SESs such as those briefly described above suggest that information is critical and that one might consider some estimate of the robustness of an SES's search function as a probable proxy for resilience rather than "speed of return" to a "pre-disturbance" state. Attempts to salvage the ball-in-the-cup model by vague definitions of the pre-disturbance state such as a measure of production or happiness merely disguise its inutility. Social scientists agree that empowerment of the many to contribute to finding solutions to significant system shocks is morally preferable and often more effective than allowing the few to so dominate the many that the latter's lack of resources and education provide prohibitive obstacles to any contribution they might make to a search for solutions. For years, few have viewed development without reference to empowerment.

Our perspective is in line with Ulanowicz's conclusions that healthy ecosystems are those in which the dominant species do not overwhelm the others. It also reflects a general precept of development that human capacities are one of the most important resources available. Any non-reductionist SES model must also recognize the ermergent social and cultural production of value and the consequent irrationality of describing SES resilience with purely material measures.

5 Conclusion: an Alternative Metaphor for Messy SESs

A **Dust Devil model**: Imagine all messy SESs as existing in multi-dimensional variable space with (when viewed in any three dimensions) multiple shallow depressions whose sides are eroded when occupied. The SESs can be viewed as "dust devils" inhabiting depressions until the side is eroded and then moving on to create or dwell in new depressions (long term stability and return are illusory). SESs respond to changes in the environment of the continuously transforming multidimensional space or to emergent properties linked to internal or contextual changes that clear a path "forward" by means of a search function - the arrow of time goes only forward and the present and future dominate over the backward glance.

There are several critical differences between such an approach and the norms derived from the physical and biological sciences but the core reason for each difference is the assumption of emergent properties in SESs that reflect human rethinking and reevaluation leading to transformative changes in incentive structures and capability sets. Once we turn our back on simplistic reductionism we open the door to reconceptualizing emergence as involving not just new yet similar causes at a subfocal level but the emergence of causes at the focal (social) level that cannot be sufficiently explained by any set of subfocal level explanations. Mario Bunge's notion of emergence as ontological novelty [22:68] denies only the sufficiency of subfocal (reductionistic) explanations.

Yet, perhaps Bunge's CESM's [22:55] most important point is its criticism of the epistemological version of emergence: if only we had more knowledge we could reduce our social explanations to ones in terms of psychology, biology or even particle physics. Once we accept ontological novelty at multiple levels the obtuseness of such reductionsim can more readily be conceived. The tranformational growth matrix approach simply proposes to develop models that help us view and deal with such ontological emergence.

In the literature on poor urban and rural areas of the world we have for decades focused on simplistic and reductionistic measures (e.g. aid to those with less than $1 per day) with scant success. The current best thinking suggests that we should instead focus on local clusters of disadvantages that together impact the capability sets of a subset of a population [18, 4, 23]. Current research simply does not support the antiquated notion that disadvantage is caused by a particular set of figures in an algorithm confined to universal reductionist variables. Unless this is the case we need to consider the possibility that each messy SES generates its own emergent causality (within limits of course) and we may best understand this causality with models that allow for such emergence.

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