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Transformation of social and ecological systems

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Abstract

The evolution of social ecological systems is characterized by a lengthy process of steady of slow population growth, appropriation of natural resources, and ever growing complexity. From hunter gatherers first, to extensive and then intensive farmers, to urban industrial aggregations has taken place worldwide in episodic and highly differentiated geographical distribution. It is in the last 50 years that this process has begun to go exponential and to have planetary significance. What used to be episodic periods of regional growth and expansion in the use of resources has grown into a cumulative process that now threatens the planet through the emission of global warming gases, climatic change, and the loss of cultural and biological diversity. The paper identifies some of the changes needed to begin to address this conundrum.

Keywords: social ecological systems, evolution, transformation, land use, land cover change.

Introduction

Hominids have been on this planet for some 3.5 million years and our species for several hundred thousands of years. We

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Política & Sociedade - Florianópolis - Volume 10 - Nº 19 - outubro de 2011

have grown in our capacity to use information, and our technology is impressive in its capacity to do work. What is not widely recognized, is that we have in the recent past (the past 50 years, really) brought about changes in our social ecological systems with planetary consequences for the functioning of these systems. The Industrial Revolution, which began some 300 years ago, was a major turning point in terms of fossil fuel consumption and carbon emissions but our impact goes further back. We have been gradually increasing our impacts on the Earth. In the past 10,000 years, in various times and places, we have had impacts that were considerable at local to regional scale (Redman 1999; Redman et al. 2004; Diamond 2005) largely through the domestication of plants and animals, and gradual intensification of production. But it is in the past 50 years that our impact has had planetary scale consequence, and that capacity for transforming the dynamics of coupled social ecological systems is what we are having trouble understanding. As a species we tend to think and act locally—except that we have for the first time in human evolution begun to have a cumulative, global impact.

1. The evolution of social ecological systems

As a species we relied on our capacity for sociality and communication in order to surpass our physical limitations. Our success as a species in spreading and colonizing the planet was through operating as relatively small groups of hunter-gatherers (HG). HG keystone advantages were their behavioral flexibility, based on small group trust and reciprocity, in response to opportunities and their highly mobile strategy of resource harvesting. This strategy served our species well for most of our time on the planet. However, as we grew in population size this strategy began to demonstrate its limitations in providing for an ever larger population. Hunter-gatherers knew about plant reproduction and carried out light management of plants of interest to them long before they began to turn into farmers (SMITH, 1989).

This first major transformation in social ecological systems, from hunter-gathering to farming, was a result of population increase, growing confrontation of HG bands over resources, and of rising costs and risks of moving into marginal environments. It took a couple of millennia for the transformation from a mostly HG landscape to one increasingly occupied by farming groups (i.e. in North America at least, SMITH, 1989). Whether famine played a role is not clear from the archeological record. Like many other transformations in social ecological systems, it probably had the shape of the diffusion of innovations with a few adopting the change early, followed by a very slow adoption by others, and finally substantive adoption when the benefits were absolutely clear to most (and the price of non-adoption was dear). The greater density of farming communities allowed them to occupy preferred territories, and HG increasingly were pushed into marginal areas which could not be cultivated. The keystone features of this new farming mode of production were the evolution of community institutions, shifts in the scope of reciprocity and trust, domestication of plants and animals, and sedentarization. The shift in reciprocity and trust led to features of social cooperation being associated at first with the settlement, and as settlements grew in size to kin-based groupings such as lineages, clans, and moieties. This reduced flexibility in HG systems since the common form of descent was bilateral, meaning that individuals traced their descent from either the paternal or maternal sides, and band membership was highly flexible. In settled farming communities, control over land through inheritance grew over the years. In order to ensure control over the better land, and eventually over investments such as irrigation and homes, lineal descent (through either father or mother) came into play in order to provide clear forms of inheritance, and to the development of rules of preferred marriage, and even endogamy, to ensure control over resources. Whereas exogamy had been preferred before, and indeed it is a preferable evolutionary strategy from a biological perspective, with the growing importance of land, and

Política & Sociedade - Florianópolis - Volume 10 - Nº 19 - outubro de 2011

accumulated wealth, interest in keeping wealth intact among those already well-off favored inter-marriage among favored families. This resulted in extreme cases in caste endogamy, and class-consciousness in marriage choice. The deleterious biological impact of this strategy is well-known in the genetic aberrations found in some royal families.

The evolution towards kin-based lineal systems also provided a more rigid form of passing on cultural values, identities, norms, and religious preferences. This process took hundreds of years to occur as groups developed their own combination of workable ways of controlling resources as a function of population density, competition, and resource availability. In areas with great resource patchiness, where control over favorable patches was key to success, the development of sophisticated forms of kin-based control was more rapid given the stakes, whereas in areas with widely distributed resources and patches it was often easier for resource competitors to just move elsewhere and maintain a more flexible and less restrictive set of community rules.

Over time, as agriculture moved from extensive production systems to more intensive systems based on irrigation and eventually mechanization, social stratification, ethnicity, and complex rules for resource use and exclusion, came into being. Whereas in the former extensive systems it was a value to share accumulated resources with other less fortunate members of the community, thereby acquiring social capital and prestige, in the latter the amount of shared resources declines, prestige still goes to those capable of concentrating resources but those resources are only sporadically redistributed thereby increasingly rewarding those who already have more resources and productive capacity or wealth. Control over land becomes the greatest source of wealth, and by extension this provides greater control over labor, as more and more people are not able to control access to land—especially in patchy environments such as semi-arid landscapes.

Boserup (1965) and others (NETTING, 1968, 1981, 1993) have shown that the most important driver of the intensification implied by the shift from HG to agriculture has been population growth leading to greater applications of technology to production in order to stave off famine and meet the basic needs of growing populations. It is associated with greater competition over resources and the growing need to store supplies for times of scarce resources. The need to store provisions, rather than move to get them, resulted in a shift in how labor was invested, and in the settlement pattern of peoples worldwide.

As these populations grew more numerous chronic warfare ensued as groups competed for the prime lands, the prime spots along the river or mountain, and sought ways to recruit more members to their communities. In a world of hand-to-hand combat, having strong, and numerous men to field was the top determinant of success in holding on to territory. Over time, some groups developed from single village communities into networks of communities and chiefdoms emerged that provided some capacity to mobilize larger social units when any of its member communities was threatened. The evidence is quite substantial that as human communities grew more successful in production, the temptation was great for other communities to take away their accumulated wealth (often in the form of grain or animals). As in the shift from HG to extensive cultivation, the shift from extensive cultivation to intensive cultivation appears to have been driven by population growth putting too much pressure on resources (BOSERUP, 1965; NETTING, 1993). One study showed that a given area of irrigated land could support 14 times as many families as it could under shifting cultivation (PALERM, 1968; SPOONER, 1972). However, another explanation offered by scholars has been that this intensification was forced upon people either by external domination and colonialism (cf. GEERTZ, 1963) or by internal domination brought about by elites wishing to control land resources for their own political and military objectives (DEMAREST, 2004).

Política & Sociedade - Florianópolis - Volume 10 - Nº 19 - outubro de 2011

It was just a matter of time, and opportunity, for people to have their growing villages develop into larger and more complex entities that we have come to call cities. Urban areas provided a site for trade, for the exchange of information, for specialists in a large number of skills to meet the needs of a more technologically intensive society, and for redefining the nature of social ecological interactions. The rise of urban centers is most commonly associated with irrigation and the rise of complex water control. As these systems grew in size and complexity, breakdown became more common and more costly. In time, when they had grown to pharaonic proportions, the systems could collapse when either information or climate or both, were beyond the capacity of managers (BUTZER, 1976).

If the rise of cities and a growing network of linked villages into states proved to be a considerable source of disturbance in social ecological interactions, imagine what happened with the rise of that technological wonder that is the industrial revolution. Cities are symptomatic of human transformation of social ecological systems: they are creative centers where some of the best and brightest of every society are concentrated to develop the arts, technology, education, science, and commerce. Yet, they are also often chaotic, with erosion of social controls, and distant enough from day-to-day realities of environment to ignore environmental feedbacks. That is because urban areas have too many layers of information between the environment and the decisions managers take -who are motivated by many other incentives than just ensuring good environmental management: political pressures, mis-valuation of the resources, self-interest, and corruption.

The industrial mode of production is accompanied by major technical innovations that also result in a reorganization of the division of labor. The industrial revolution's larger environmental impact is the product of discovering the use of fossil fuels. First, and for a very long time, this involved only the use of coal. Oil and natural gas came much later. In using fossil fuels humans did not have to compete with any other animal species to use the resource, as we had often had to do with the use of plants (hervibores) and animals (carnivores). This would seem to be a win-win situation, and it certainly allowed a quantum increase in the amount of energy that humans could harness for productive purposes. Unfortunately, the exploitation of the huge amounts of fossil fuel materials stowed away for geologic periods of time in subterrestrial sinks and the launching of the byproducts from their use into the biosphere kicked off biogeochemical changes in the atmosphere that took a couple of centuries to be felt and which now threaten our planet. But these changes were not entirely surprising. Local and regional consequences of the use of fossil fuels were felt early on: the 19th century fogs of industrial cities like London, with serious health consequences for people living in these locations being the most recognized. While the rich could escape to their rural estates to breathe fresh air, the poor in the cities grew sick from the constant exposure to foul air. Social stratification and the use of police and power to maintain this mode of production, with its high human and environmental costs, took place then and continues into the present as developing countries industrialize with similar consequences (e.g. the current urban pollution in China industrial centers). The result has been a growing loss of trust and the virtual extinction of reciprocity except in the bosom of families, growing disparities between people in wealth and access to resources, an increase in the amount of time spent working, and a growing emphasis on consumption to support the productive capacity unleashed on the planet.

In short, over a period of 400 generations, or 10,000 years, the human population has grown from a few million to more than 6 billion. This change has taken place quickly in recent decades; and has changed the nature of how we deal with each other (RAVEN, 2002). The biggest shift has been since World War II and is connected to rising living standards and rising consumption levels for materials and energy. This compounding of population and

Política & Sociedade - Florianópolis - Volume 10 - Nº 19 - outubro de 2011

consumption is recent and without precedent. An important question to ask ourselves is how well prepared we are to think in new ways about our relationship to the environment. Human populations do not respond in homogeneous ways to the environment, or anything else. Human society and culture is characterized by high diversity, and in the past this has gone along with biological diversity. The number of people who live by hunting-gathering today is shrinking, and most of them are connected to the global economy to some degree. Horticultural populations still constitute significant populations in rural areas of developing countries—and among those in developed countries who seek to return our food production system to more organic methods. The latter is a fast and expanding movement that questions the industrial mode of food production and seeks to return to more organic ways to take care of the land and produce the food we need. Pastoral peoples have been under pressure for decades to abandon their migratory ways, but they still constitute an important component of how grasslands are managed, despite efforts to block the routes of their movements. Intensive farming is growing ever more intensive, now including genetic modification to a degree that has not been seen before. As single-minded ways of thinking about materials and energy have arisen –i.e. trying to think of these things in largely monetary terms—the question is whether this simple way of thinking about complex human-environment interactions may not be appropriate and may, in fact, be destructive.

Our impact in the past 50 years has no analogue. We have no equivalent experience in our entire history as a species for what we are currently doing to the Earth. For the past 20 years, we have begun to acquire data and information at global scale that has begun to alert us to the magnitude and seriousness of the processes we have unleashed. In the past 50 years we see not only an increase in carbon dioxide that is exponential in its increase, but also ozone depletion and nitrous oxide concentrations in the atmosphere, losses in tropical rainforests, frequency of natural disasters, and species extinctions. The same can be said for fertilizer consumption, damming of rivers, water use, paper consumption, the number of people living in cities, the number of motor vehicles, and the number of international tourists. While we see a few cases of nations and regions where we can point to a growing middle class and improved living standards, more often than not in the past 20 years we see a decline in the living standards of the poor and the middle class, with the gap growing and the concentration of wealth becoming as pervasive as the loss of species.

This exponential increase is clearly tied to two factors: the increase in the human population, and to our consumption habits. Indeed, one must think of these two factors in tandem. One Euro-American citizen consumes 25 times the resources than one average citizen from India, Guatemala, or other less developed country does. So, while birth rates have declined to replacement level or even below in developed countries, these populations continue to impact the earth's resources far more than the many more billions of people in developing countries. But let's be honest: both "the North" and "the South" have a huge impact on Nature, and both the North and South will need to change how they go about their business. Yet, changing business-as-usual, i.e. "culture", world-view, and such, is easier said than done.

Whether in the North or South, specific societies have deeply in-grained cultural and historical traditions that have both positive and negative elements that facilitate and hinder our capacity to respond to the current crisis in the Earth System. Looking at North America and European society, we can point positively to the democratic institutions that are in place, and that provide an effective mechanism for citizens to respond to information provided to them whether about schools, politics or the environment. This is all to the good. Yet, how do we explain the lack of responsiveness in the U.S. to the growing evidence for a global environmental crisis? Side by side with our democratic institutions, the U.S. has (unlike Europe) a culture of individualism, and a much

Política & Sociedade - Florianópolis - Volume 10 - Nº 19 - outubro de 2011

greater value given to capital accumulation as a measure of the person's worth than in almost any other society. This pair of cultural values tends to sway a great portion of the citizenry against environmental regulations-- seeing them as costly and thus likely to increase taxes on individuals, and raise the cost of environmental goods and services. Even the promotion of public transportation as a response to reducing fossil fuel emissions is opposed by many on the grounds that it limits personal freedom in moving with complete freedom, despite the costs to the country (in terms of dependence on foreign oil supplies), and the globe (in terms of emission of earth warming gases).

This, close to home, example can be made for many other countries. Each will have a slightly different twist to it: a product of the historically contingent nature of human affairs. Other countries may lack, for example, the democratic institutions' capacity to mobilize the populace in its own interest, but they may have enlightened rulers who respond quickly to evidence for environmental crisis: witness the rapid reforestation of China in the past 20 years, following decades of rapid deforestation. The pace of the reforestation has been without equal in the world, despite the many economic constraints faced by China and its vast population. In short, there is no one solution to finding environmentally-appropriate solutions to the current global environmental crisis. Human agents in specific places will need to work within the constraints and opportunities provided by their physical, social, economic, and cultural setting.

In the past, human agents went out from their communities to gather needed resources to sustain their population at very local level. We must recall that for most of our experience as a species, we were hunter-gatherers. The range of hunter-gatherers was fairly limited, and when they over-used resources they would be forced to move considerable distances until they could find another, familiar, territory not occupied by others, to sustain them. As hunter-gatherer populations increased, they found themselves running into other bands, and perhaps experiencing conflict with them. In short, it was preferable in many cases to limit the group's consumption to sustainable levels, rather than face a very uncertain future access to territories far and possibly dangerous to them.

Even with the advances in control made possible by domestication of plants and animals, human agents could experientially understand how the local land and water responded to their agricultural management. What was happening in China was of no interest to those living in Europe, or those living in Africa. Products came from relatively close distances and anyone could assess whether they were putting themselves at risk. Surely, there were many cases of poor judgment in human history, but in those cases populations paid a dear price and had to move or take some other radical path to survive.

Those familiar ways to adjust our behavior to existing resources are completely changed now for much of the human populations of the Earth. Today, whether in China, Germany, Argentina, or the U.S. human agents are provided with coffee from Brazil, bananas from Honduras, Philippines, or Gabon, fish from oceans on the other side of the world, and powdered milk from places unspecified on the labels. The human consumer has no way to know how much forest was cut to grow that coffee, what people were displaced to make room for those banana plantations, what fish stock was depleted, or what smallholder was displaced for that dairy farm. In short, we have a complete disconnect today between what we use on the Earth, and the consequences of that use on social ecological systems.

2. Human agency: individuals making a difference

There is a very fine line between endowing individuals with agency, or the ability to take decisions and actions, and ignoring them altogether. In giving individuals the attention they deserve, and in trying to understand their actions, we can also fail to see patterns in their actions. After all, human agency takes place within an environmental and social matrix, and individuals are members of social groups with distinct shared economic, social, cultural, and political interests. Thus, in ensuring that we give individual human agents their due, we must balance this attention with a concern for how many other agents there are that share similar values and make similar decisions that have given cumulative impacts.

It is all too appropriate to consider how human agency can make a difference, and how social movements can make an even greater difference. Individuals, as members of given societies, do not represent the entire society but some segment of it characterized by a given social and economic origin, acquired education and wealth, and political linkages to segments of society. As such, when individuals act they commonly represent the interests of those parts of the social fabric within which they are embedded—although on occasion they rise above those origins and represent the interests of those less fortunate than they socially, economically or politically. Time and again we see evidence of how an individual through his or her actions can change how we think about the world, and what we might do. Think of Rachel Carson and her book, *Silent Spring* (1962), and how it launched the modern environmental movement. She, herself, may not have had the right characteristics to lead the environmental movement, but she laid the foundations for public concern and outrage over what was happening to our streams and water. Others, more capable at leading and mobilizing others, followed and took action that over the next several decades provided protection of species, of air and water, and of landscapes under threat.

In short, human agency does make a difference whether expressed as ideas in books and articles, in speeches, or in action. Until 1985 there were hardly any stories in any major magazine or newspaper about Amazonian deforestation—even though there had been a growing discussion of it in scientific journals, and research attesting to the rapid rates of forest destruction. But the appearance of an interview with Tom Lovejoy in the New York Times, Science Times section, in 1985 overnight mobilized the considerable resources of the press and other media and over the next decade there was an exponential growth in the number of stories in major newspapers and magazines that resulted not only in stories but in considerable international pressure on Brazil to stop the subsidies which were fueling the deforestation.

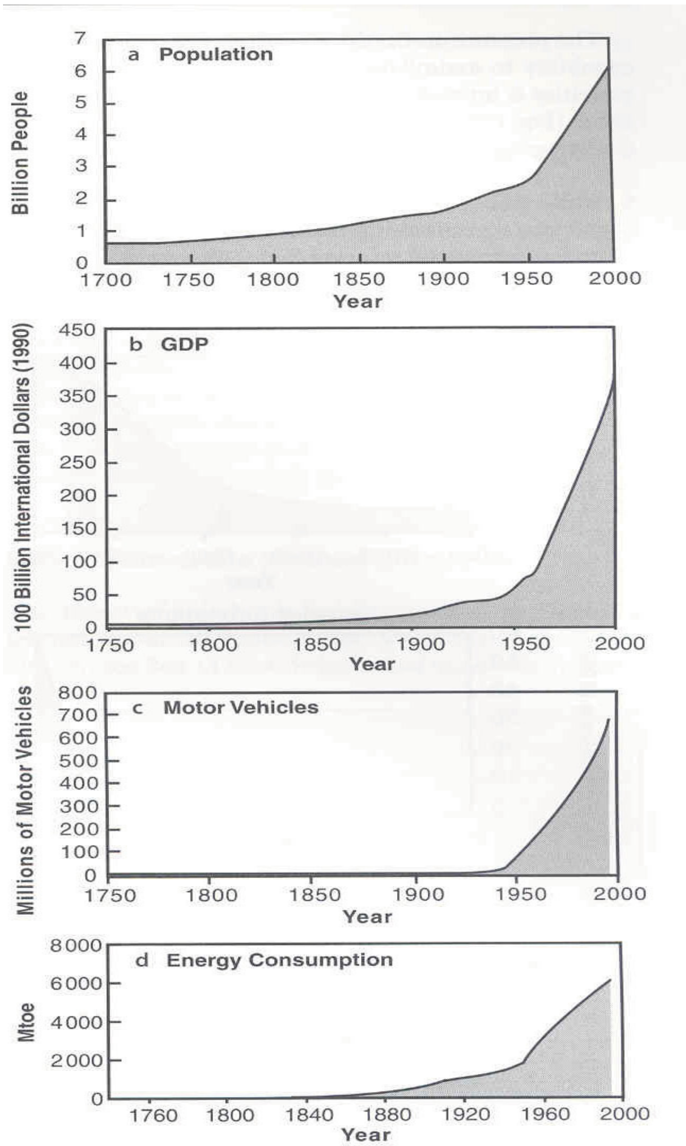
So, one characteristic of human agency seems to be that we need to have the accumulation of information over an extended time, gradually shaping into a picture of a process that results in concern in some quarters, and in some individuals taking action. When that action is associated with some notable event or overwhelming evidence, it appears that public response to this news can result in remarkably rapid mobilization and effective action. But none of this would happen if individual agents did not take the considerable risks involved in trying to change business-as-usual and to advocate a significant shift in how we do things. Change is resisted by all complex systems, largely in self-defense, and because it can be very costly if the change was unnecessary or wrong-headed. Thus, human political and economic systems, like ecological systems, resist changing their common patterns until there is overwhelming evidence that something fundamental has changed which requires a shift in the structure and function of the system, if it is to survive.

3. Overwhelming evidence

> The Earth is currently operating in a no-analogue state. In terms of key environmental parameters, the Earth System has recently moved well outside the range of natural variability exhibited over at least the last half million years. The nature of changes now occurring simultaneously in the Earth System, their magnitudes and rates of change are unprecedented (STEFFEN *et al*. 2003).

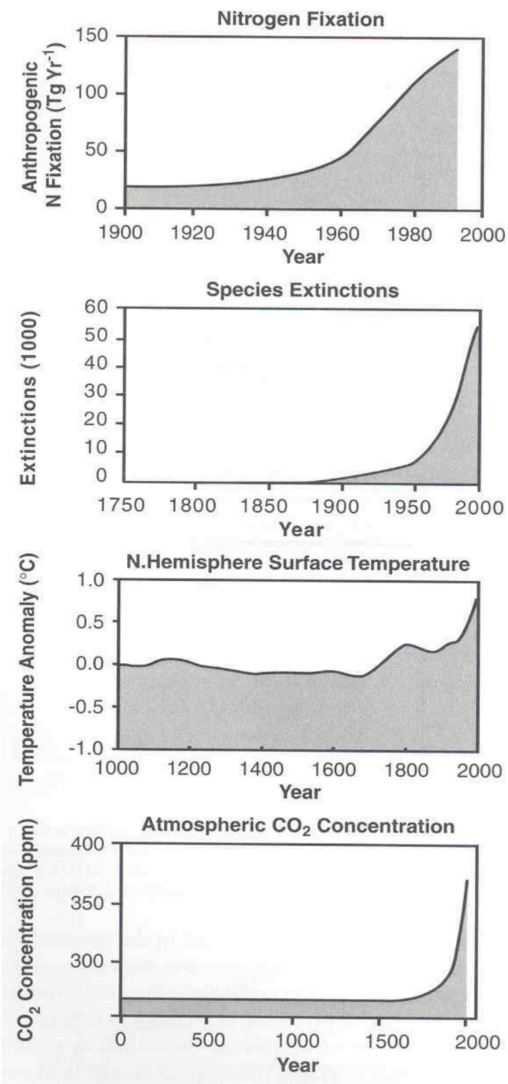
Figure 1 and 2 (next page): changes in last 50 years, socioeconomic and ecological variables

Figure 1.: Rate of increase in many spheres of human activity for the last 300 years a) population (U.S. Bureau of the Census 2000); b) world economy (Nordhas 1997); c) motor vehicles (UNEP 2000); and d) energy consumption (Klein Goldwijk and Battjes 1997)



Source: STEFFEN *et al*. 2003, pg. 5.

Figure 2. Responses of the Earth System to increasing pressure from human activities. a) nitrogen fixation (Vitousek 1994); b) species extinctions (Smith 2002); c) northern hemisphere surface temperature (Mann et al. 1999); and d) atmosphere CO2 concentration (adapted from Keeling and Whorf 2000).



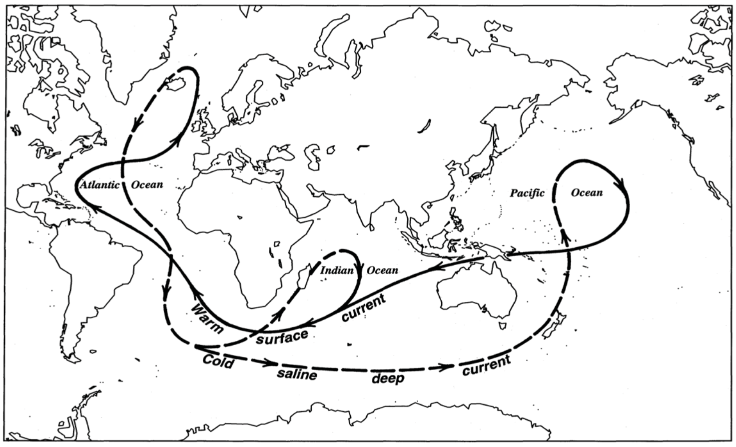
Source: STEFFEN *et al*. 2003, pg. 6.

Política & Sociedade - Florianópolis - Volume 10 - Nº 19 - outubro de 2011

Figure 1 illustrates what is happening in the realm of socio-economic variables - and it should be reason for concern. Population has been increasing rapidly since 1750 but it is really since 1950 that the exponential nature of this growth is manifest, and shows very little sign of subsiding in the next 30 to 40 years. By that time the human population will be in excess of 10 billion (it is now about 6 billion). Total Gross Domestic Product, foreign direct investment, damming of rivers, water use, fertilizer consumption, urban population, paper consumption, the number of McDonald's Restaurants, the number of motor vehicles, the number of telephones, and the number of international tourists have all jumped exponentially since 1950, with no evidence of a turn around in this upwards increase. If this increase was not enough to cause concern, it is all happening simultaneously.

As if this were not bad enough, similarly synchronous events are happening on the Earth System side: CO2 concentrations, N2O concentrations, CH4 concentrations, ozone depletion, N. Hemisphere average surface temperatures, the number of natural disasters, the loss of fisheries, the increase in nitrogen fluxes in coastal zones, the loss of tropical rain forests and woodlands, the amount of land dedicated to cultivation, and the number of species gone extinct have all jumped exponentially since 1950 (see figure 2). While some might argue, for example, that there is evidence that CO2 concentrations are actually beneficial to many plants and that there is increased productivity, experimental studies have shown that following increases in CO2 concentrations to 56 Pa, when this concentration reaches 70 Pa, there is a decline in productivity (Granados and Korner 2002). There are also notable differences in how different species and types of forest vegetation respond to CO2 enrichment. At Duke Forest, *Pinus taeda* increased 20-25% in both net primary production and in woody biomass, whereas in nearby Oak Ridge, Tennessee, *Liquidamber styraciflua* increased only 7% in woody biomass (Norby et al. 2002).

Figure 3. Oceanic Conveyor Belt – Global warming is expected to disrupt the conveyor belt that regulates climate

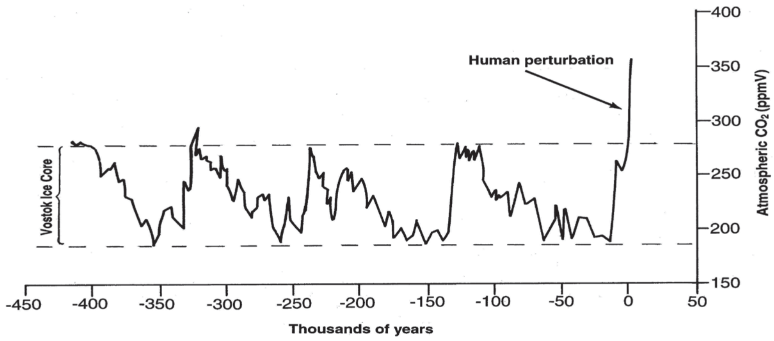


Source: BROECKER, 1991, p.79.

In short, the simultaneous inter-connectedness of these changes in human ecological relations since 1950 suggest that human activities could inadvertently trigger abrupt changes in the Earth System with consequences that we can only faintly imagine. The most troubling of all if, of course, triggering a disruption in the oceanic conveyor belt, as it is called, which regulates the world climate (see figure 4 and BROECKER, 1991). The increases in greenhouse gases can trigger changes in the North Atlantic circulation and simulations have most of the scenarios resulting in rather dramatic collapses. We know already that the Atlantic thermohaline circulation (THC) can have multiple equilibria and multiple thresholds, that THC reorganization can be triggered by changes in surface heat and in freshwater fluxes, and that crossing thresholds can result in irreversible changes of ocean circulation (Rahmstorf and Stocker 2003). Our current situation with regards to CO2 alone, not to mention all the other gases, is well above the recorded experience of the past 500 million years as recorded in the Vostok Ice Core (see Figure 4).

Política & Sociedade - Florianópolis - Volume 10 - Nº 19 - outubro de 2011

Figure 4. Vostock Ice Core provides the best current record of CO_2 for the past 450,000 years



Source: PETIT et al., 1999.

Hopefully it is clear that over the past millennia, social ecological systems have undergone a sequence of transformations of considerable proportion. The transformations have taken place gradually—over millennia in the change from HG to farming, and from extensive to intensive farming, and over centuries in the change from farming to urban-industrial. There is also clear evidence that the rate of change has been accelerating particularly since the end of World War II. One of the consequences of the exponential rates of change is that it has been difficult for social systems to grasp how different the consequences of their actions are today when compared to the past.

One of the notable features of this evolution in social ecological systems is that as human communities grew in size from bands to villages to cities, there was a decline in trust and reciprocity, a growing value given to wealth and material possessions accumulated, and a growing distancing of individuals from critical decisions made about ecological systems (as systems grew more complex decisions were made at higher levels with concomitant restrictions on local autonomy to make decisions). This has exposed individuals and populations in social ecological systems to harm, in the interest of greater efficiency and higher level values (such as ever increasing GNP per capita). These values may regularly overlook, for example, distributional problems in GNP whereby it is possibly to have a growing GNP and a gradually impoverishment of the population because of wealth concentration. Without correction of this maldistribution, the system exposes itself to instability from within which can eventually result in system transformations and even breakdown.

Many processes of globalization amplify or reduce the impact of transformation in the earth's landscapes. Rapid land use changes tend to be associated with the incorporation of regions into global markets and capital and information flows. When that occurs local processes and relationships can be replaced by external drivers, and bring about devastating impact on local social and political processes. It can also change the biodiversity present in a region by forcing a market-driven specialization of production to fit global standards or expectations that drive out the rich variety previously present in less market driven production. Yet, we also know that this is not necessarily so. Witness the recent expansion into urban-industrial areas of products previously restricted to the Amazon such as the consumption of Acai (*Euterpe oleracea*) in Rio and Sao Paulo, and it is now a global phenomenon.

Understanding of the role of population has also changed. From thinking that more people always meant less forest, a growing number of cases suggest that forests can persist under high population densities (e.g. MORAN & OSTROM, 2005). The role of communities and institutionalized rules of management plays a critical role in such cases, emerging from a variety of sources, among them scarcity of the valued good (LARIS, 2002; TURNER, MD 1999). Studies have shown how political and economic structures constrain individual choices about management of land resources (e.g., ARCHER, 2003; ROBBINS, 1998). Cultural traditions, and land tenure rules, are critical in influencing how land can be used and by whom (TUCKER, 1999). A notable advance has been the growing use of orbital earth-observing satellites linked to ground research to address regional to local issues of land change (FOX *et al*. 2002; LIVERMAN *et al*. 1998; WALSH & CREWS-MEYER, 2002; WOOD &

PORRO, 2002), contributing novel insights to the interpretation of land-cover change on topics rarely addressable with any accuracy at global or regional scales—e.g. land change in areas undergoing urbanization (SETO & KAUFMAN, 2003); and stages of secondary succession and their management (BRONDIZIO *et al*., 1996, 1994; MORAN *et al*., 2000).

An initial rationale for emphasizing land-change dynamics in global environment change science was to enhance earth system models. The modeling community, from economics to engineering responded to this element of land-change research. Significant advances are underway in a variety of modeling approaches, almost all of which focus on spatially explicit outcomes, aimed at explaining and projecting land-change (LAMBIN, 1994; IRWIN & GEOGHEGAN, 2002; ROTMANS & DOWLATABADI, 1998; VELDKAMP & LAMBIN, 2001). Logit and other types of models explore the specific causes of land change drawing on various theories of the same (CHOMITZ & GRAY, 1996; GEOGHEGAN *et al*., 2001; PFAFF, 1999; VANCE & GEOGHEGAN, 2002). Empirical models explore the robustness of land-cover change projections based on patterns of past change (DALE *et al*., 1994; TURNER, COSTANZA & SKLAR, 1989; TURNER *et al*., 1989). Significant advances are underway in agent-based integrated assessment models in which the synergy between socially constrained human decision making and environment are linked to provide spatially explicit outcomes (FISCHER & SUN, 2001; PARKER *et al*., 2002, 2003; REIBSAME & PARTON, 1994; VELDKAMP & FRESCO, 1996; DEADMAN, *et al*. 2004.). It is noteworthy, however, that the advances underway require new metrics by which to judge the results of the models. These, too, are being developed by the land modeling community (PONTIUS, 2000, 2002).

In short, research over the past decade on land use and land cover change is making increasingly productive use of case studies by linking them to regional and global modeling exercises that challenge past simplifications, and in more nuanced regional and global understanding of pathways of change that capture not only the complex socio-economic and biophysical drivers of land use change but that also account for the specific human-environment conditions under which these drivers operate. One of the areas where we must invest greater efforts is in giving a more nuanced understanding of demographic processes through population-and--environment studies. Modeling over the next decade is likely to also make our contributions more usable by biophysical sciences and policy.

Conclusions

The question must be asked: what makes social ecological systems more vulnerable and less resilient? Hypercoherence, loss of redundancy, loss of trust and a sense of community, and the misuse of information by decision-makers. In studying the evolution of social ecological systems it is clear that as we went from direct interaction with the resources that provided for us to ever greater distancing between the decision makers and environmentally significant consumption, social systems developed hypercoherence or an effort to continue to give specific decisions all the way down the chain of decision makers, rather than give greater autonomy for decisions to local decision makers. This results in a loss of biodiversity, misallocation of resources such as water for irrigation, and in general a loss of a capacity to deal with social and environmental variability.

Loss of redundancy is also related to hypercoherence, as it reflects a system's effort to achieve efficiency to the point of not making allowances for error, new information, and the importance of non-economic values such as reciprocity, resource sharing, redistribution, bartering, which are important to a system's capacity to respond rapidly and to deal with unexpected conditions. We are perhaps least at risk when we deal within our families, one domain where one is most likely to still find those most fundamental, and inefficient, patterns of trust, reciprocity, consultation, and a sense of being part of a community of shared values.

Most damaging to the resilience of social ecological systems may very well be the loss of trust and reciprocity that has taken place over the years as our systems have grown large and distant from the concerns of individuals far from the centers of power and wealth. Increasingly complex social ecological systems make efforts to use information effectively but as the systems grow larger they are often forced to aggregate the information to such a degree (so that decision makers at very high levels can understand it), that the consequences of those decisions will often result in considerable unintended negative consequences to many parts of the social or ecological system. This contributes to a loss of trust by citizens in their government, given the statements that claim that a policy is in the best interest of citizens, and is followed by clear negative consequences. Without trust it is very difficult to have a community of shared values, and thus to act in the best interest of the system.

To ensure the resilience of social ecological systems it will be necessary to do away with hypercoherence and return systems to a capacity to adjust their decisions to the highly diverse information about social and ecological system variables. It will be necessary to increase redundancy in systems so that multiple agents can make decisions in the best interest of competing elements of society. A major task will be to begin to restore trust and reciprocity by building community institutions wherein trust can be restored through making decisions which incorporate the diverse interests of civil society.

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Resumo

Transformações dos sistemas ecológicos e sociais

A evolução de sistemas ecológico-sociais caracteriza-se por um longo processo de constante e lento crescimento populacional, de apropriação de recursos naturais e de aumento na complexidade. Começando pelos caçadores coletores e evoluindo para a agricultura extensiva, depois intensiva, e então, para aglomerações urbano-industriais, o processo tem ocorrido em todo mundo de forma episódica e com diferenciada distribuição geográfica. É nos últimos 50 anos que este processo passou a ser exponencial e ter significado planetário. O que antes eram episódicos períodos de crescimento regional no uso dos recursos tornou-se um processo cumulativo que agora ameaça o planeta através da emissão de gases que provocam o aquecimento global, das mudanças climáticas e da perda de diversidade biológica e cultural. O trabalho identifica algumas das mudanças necessárias para se começar a resolver esse problema.

Palavras-chave: sistemas ecológico-sociais, evolução, transformação, uso da terra, alterações da cobertura vegetal.

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