The Historian's Dilemma, or Jonah and the Flatworm

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Abstract

Policy relevant research into human ecodynamics involves the study and management of historical systems. All too often this work is predicated on the historicist fallacy that history is like a motor car which clever drivers can steer to Utopia. This paper presents an historian's view of human ecodynamics as a complex, irreversible, self-organising or synergetic system and tries to explain why historical systems are as they are and to prove that such systems cannot be predicted or driven at will. Two simple ecosystem models are presented which illustrate the strengths and potential value of the synergetic approach.

Keywords: human ecodynamics. self-organisation, synergetics, unpredictability, Jonah's paradox, spatial pattern, multi-agent system, micro-simulation, overkill hypothesis

Introduction

The search for socially sustainable paths to environmentally sustainable futures is increasingly setting the research agenda in Europe (Liberatore and Sors 1997). This trend will continue as we enter the new millennium. More and more applied scientists will be employed to tell politicians how to change the course of history without disturbing the fabric of contemporary society. The grants will be competed for and support models will be built, either by those who understand historical processes, or by those who do not. Our collective survival may depend on the quality, wisdom and utility of these models.

This research will involve work on the interface of social and natural sciences. Human behaviour and cultural norms are powerful environmental forces and a new, applicable science of Human Ecodynamics¹ is emerging *ad hoc*. A new, scientific approach to the management of historical systems will only be possible if we develop methods that can be reconciled with our best understanding of historical processes. Ironically, it is not the natural scientists, but the social scientists (particularly economists and political scientists) whose understanding of historical processes is weakest. As the new science of human ecodynamics emerges, it is becoming clear that the fundamental unpredictability of historical systems is being systematically ignored.

Historians (*sensu lato*) should do more than criticise from the sidelines while others work to manage global lifesupport systems The task of the policy relevant scientist is to manage history and history, after all, is our particular area of competence. Yet very few historians become involved in this work, partly because of the ethical dilemma it creates and partly because politicians do not see the Humanities as applicable science. The social context in which policy relevant research takes place is such that the work tends to be predicated on historicist principles which, from our viewpoint, are absolutely untenable.

Two Types of Model, Two Types of Science

Pure scientists build *process models* as test-beds for *theories* about the world. The results of modelling exercises are articulated with data from experiments or systematic programmes of observation. Poor fit will result in the rejection or revision of the model. Applied scientists, on the other hand, build *support models* which they use as test-beds for *policies*. In support modelling, the model is also offered up to empirical data and may be rejected if goodness of fit is poor. However, the ultimate aim of the exercise is to use the model to generate scenaria corresponding to possible policy decisions.

It is easy to distinguish the work of the process modeller from that of a support modeller, one need only compare the sorts of models used by a theoretical ecologist with those used by political economists to forecast financial trends, for example. The classical support modelling approach is to derive a set of rules that correspond to our best understanding of the dynamic process under investigation. These are manipulated to characterise parameters which may be estimable from empirical data. The parameters are duly estimated and substituted into the equations. The dynamic system is initialised with data from the start of a known time series and a trajectory is simulated which may, or may not approximate the given time series. If agreement is poor, the model may be redesigned. However, more often, the system will be *aligned* by readjusting the values of parameters to improve goodness of fit between the expected time series (that generated by the model) and the time series observed in the real world. A model which tracks the observed data reliably, despite small adjustments to the starting configuration and system parameters, is said to have been *validated*. Once this has been done, the support modeller will use the model to generate scenaria and to experiment with policy options.

Thus process modelling and support modelling use broadly similar methods but appeal to very different axioms. In particular, the process modeller need assume nothing more than that the model simulates a theory about the world. The support modeller, on the other hand, must assume that the model faithfully simulates the dynamic properties of the real world. This is often an unwarranted assumption, especially in the social and natural sciences.

The support modelling approach is particularly useful in the study of mechanical, electronic and semi-mechanical processes which we can predict and regulate very effectively within limits. Production lines, queues, communication and traffic networks, for example, can all be managed more or less effectively and these are precisely the systems where support modelling has the most to contribute. The weaknesses in the support modelling philosophy became clearer when the methods are applied to economic, ecological, evolutionary and sociological systems in which unpredictable and uncontrollable behaviour is to be expected.

Real socio-economic and biological processes are *his-torical* in nature. What will happen tomorrow is imperfectly determined and uncertain today. They call for stochastic models. That is, for models capable of generating a range of outcomes in an unpredictable way from a single state. Some of these outcomes may actually change the balance of future probabilities in a dramatic way leading to spontaneous *self-organisation*. For the sake of distinction, I will call these non-deterministic, stochastic rule systems *historical* or *synergetic* models and the processes they represent *historical* or *synergetic* processes (Haken 1978; Allen 1990; Sanders 1997).

My definition of self-organisation, *events that change the balance of future probabilities in a dramatic way* is consciously non-mathematical though it can be made precise enough to permit mathematicisation (Winder 1998 and in press) and the application of synergetic methods. The earliest scientific model of a self-organising system, the Darwin-Wallace theory of evolution, was undoubtedly controversial; the so-called *evolution debates* raged for decades after the publication of the Darwin-Wallace lecture and still rumble on in the contemporary popular science literature. Yet my impression is that evolution by natural selection is not merely a self-organising process in its own right (Allen and McGlade 1987) but that it has produced many organisms which are predisposed to search for behaviours likely to result in further self-organisation. Even relatively simple organisms seem to be 'potent' agents of self organisation; their actions can nudge an ecosystem into seemingly improbable and yet sustainable configurations. Consider, for example, the flatworm.

Flatworms are wonderful experimental animals. They are scavengers, do not eat much, have rudimentary nervous systems. They can be chopped into little bits and each bit will grow a new worm. They have no segments and no body cavity (coelom). Rather surprisingly, they can learn. Biologists have developed Y-shaped tubes called choice chambers and have used rewards (meat) and stimuli (lamps) to train the worms to go to the light or to the dark. Flatworms seem to be predisposed to experimental behaviour and capable of privileging behaviours that facilitate survival. From an ecological viewpoint, the success of this strategy can sometimes be remarkable.

A choice chamber is not a large body of water and its net primary productivity is modest. Working from thermodynamic principles, one would guess that the probability of a flatworm subsisting in a choice chamber is very small. The flatworm is unaware of this and simply searches for behaviours that allow it to do so.

Of course the flatworm is not the only potent actor involved in this process. The presence of the human scientist is the key to the survival of the worm. Without the human, the flatworm has almost no chance of survival. Conventionally, we understand that the human is manipulating the worm but if we take a less anthropocentric viewpoint, the human and the flatworm are seen to be manipulating each other. The flatworm manipulates the human to get meat scraps and the human manipulates the flatworm to get data. It is remarkable enough that a flatworm can feed and reproduce in a bottle too small to support a viable aquatic ecosystem. When you realise that an 80 kg primate also meets its subsistence needs by fiddling around with a few of these bottles and writing learned papers, the ability of groups of potent actors to negotiate sustainability is hard to deny.

In human social systems, the effects of self-organisation are manifest everywhere. The biologist is sustained by taxes derived from the person who makes plastic whistles for Christmas crackers and the priest. The best archaeological evidence suggests that the Pleistocene ancestors of all these people were mobile hunters and gatherers; not a single insurance salesman among them. Human society has passed through so many self-organising events since the end of the Pleistocene that few of us are now capable of getting our own food, clothes and shelter or, indeed, have any need of these skills.

The archaeological literature suggests that the adoption of a sedentary life style, an agricultural subsistence base and life in large conurbations led to increasing social stratification and craft specialisation. This historical narrative points to a series of critical self-organising events which changed the balance of future probabilities (sedentism, agriculture and conurbation). However, it cannot explain the precise detail of the trajectory that led to our present condition or the minor differences that distinguish one cultural group from another. Why did the Old World 'discover' the New before the New discovered the Old? Why do some communities require a bride price to be paid to the parents of a marriageable woman while another requires the parents to give her future husband a dowry? These questions have answers and each answer refers to seemingly random events that changed the balance of future probabilities. By understanding these events, we understand history.

As we study the past we find ourselves characterising trajectories that can be defined with (relative) certainty. This perspective may trick us into imagining some inexorable, deterministic sequence leading to the present;

For the want of a nail, the shoe was lost; for the want of a shoe, the horse was lost; for the want of a horse the rider was lost; for the want of the rider the battle was lost; for the want of the battle the Kingdom was lost, and all for the want of a horse-shoe nail. Anon.

Things seem different when we look to the future because we are forced to confront the indeterminacy of socionatural systems, an indeterminacy characterised by a seemingly unbounded set of questions about future contingencies; *what if a nail falls out of a horse's shoe?* The ways we look at past and future are so different that van der Leeuw (1989) distinguishes *a priori* from *a posteriori* perception and argues that we must learn the trick of using *a priori* perception in historical research to understand history "*as it unrolls, in all its fullness*". This is undoubtedly true but for present purposes I am going to take the difference between the two modes of perception as given and turn my attention to the construction and negotiation of history.

The present is not static, as the anonymous wag put it, today is the tomorrow you worried about yesterday. While time passes, the uncertain future becomes a certain past and we humans fabricate a narrative to accommodate it. This narrative is a history. Humans seem predisposed to the construction of history and do it subconsciously. We can only overcome the tendency to turn the past into a neat, seamless story by a conscious effort of will. Consequently, natural and social scientists, whose business is to study histories, have two principal tasks. We must use inferential methods to find out as much about what actually happened in the past as possible. Our sources are never completely reliable and the information we get about the past is always incomplete and usually equivocal. The 'detective work' required for good palaeontological, archaeological or historical research is well understood. However, we have also to address the inherent complexity and unpredictability of historical systems, to remember that *what actually happened need not have happened* (Gould 1989; Popper 1936).

The better we do our detective work, the harder it is to shake off the impression that the past and the present are linked by an inexorable, deterministic chain. Formal mathematical models can help us to do this provided we choose modelling tools capable of representing the *quasi-deterministic* nature of synergetic processes. We need models which can underwrite self-organisation, irreversibility and unpredictability. These models can be used to investigate imperfectly characterised real trajectories *and* to make inferences about a class of trajectories which would also have been consistent with the given theory. This class should not only include the history that actually happened but also the set of histories which might have happened *but did not*.

The fact that today's actions may change the balance of probabilities tomorrow sets up contingency relations between past events and present probabilities which give a direction to time's arrow. Our survival and our ability to predict the future availability of essential resources is determined by the aggregate consequences of countless actions and reactions we can neither control nor predict with certainty. In such a world, humans cannot choose to have no ecological impact. Even the decision to do nothing may change the balance of future probabilities in an irreversible way.

The conventional support modelling approach 'validates' a model by ensuring goodness of fit between each simulated sequence and the observed time series. Often we only have one historical time series to work with (the history that really happened). Models that do not fit will be re-specified, adjusted or realigned until they do. In this way, support modellers remove the contingencies and tricky behaviours from a model before using it to predict the future behaviour of a contingent and tricky world.

This is the heart of the historian's dilemma. We humans are each part of a complex, dynamic socio-natural system, full of potent actors (not all human) making more or less autonomous decisions at a micro-level that may result in spontaneous self-organisation at a macro-level. These decisions open some doors and close others. We pass through those doors into a new world which we must live in and bequeath to the next generation. Not only is it evident that a support model can only simulate a theory about the world, it is also clear that, by validating their models with respect to one of a potentially unbounded set of possible histories, support modellers tend to privilege inferior theories. With historical systems, unwavering goodness of fit to any real time series may reasonably be said to *invalidate* a model.

So What About Jonah?

Those of us fortunate enough to live in a democracy get to vote for political leaders. Politicians get elected by promising that they will keep things good or make things better. The whole electoral process seems to be predicated on the historicist fallacy that history is like a motor car which clever drivers can steer to Utopia. Politicians need scientists to advise them but there are strong vested interests involved. Good science requires us to accept that history cannot be predicted and driven but scientists who say this are not usually among the favoured applicants. Yet the thesis that history is contingent and unpredictable is not merely plausible, it can be proven. Accordingly, I assert that either the course of history cannot be changed by individuals or the course of history cannot be predicted with absolute certainty. The proof is by *reductio ad absurdum*.

Suppose I have a model which predicts that candidate X will win the next election because of tactical voting. This can be a fairly sloppy sort of model, it does not need to predict exactly what every human being will do; it just has to determine what the most popular action will be. Suppose further that the theory on which I base my model is absolutely correct (the tactical voters really are going to put X into office) and that everyone knows I am a brilliant, indeed, omniscient modeller.

I don't favour candidate X but, as one voter among many, cannot change the outcome of an election. I take out an advertisement in the newspaper and communicate my fears to the populus. You are a potential tactical voter. When you read my advert, you must decide how to respond. Your first question might be: *is he right or wrong*?

You know that I can predict the result of the election and that I am omniscient. It might seem logical to vote as if I were right. Unfortunately, you also know that I have shared my knowledge with many others. If enough of these electors change their voting behaviour, my prediction (reputation notwithstanding) will be wrong and you should vote accordingly. However, if enough people disregard me, I will be right and you should act as if this were so, ...

This is very strange. As soon as I tell everyone what I know with absolute certainty, I generate an undecidable proposition. You have no basis to decide whether the asser-

tion is true or false *a priori* despite the fact that you know I am omniscient. You simply have to resort to guesswork or wait and see how it all turns out. Of course, if I hadn't taken out that advert, the truth of my prediction would be ensured, but then X would win the election and I would have failed to change the course of history.

This paradox has a very modern ring to it though it is actually an antique. It is there for all to see in the passage of Judaeo-Christian scripture called The book of Jonah. Jonah refused a direct instruction from God to prophesy the destruction of Nineveh. His grounds were that the iniquitous population would make reparation to God, who would forgive them and so falsify the prophecy. Jonah was so anxious to avoid false prophecy that he tried to hide from God. He ran away to sea where a storm and passing fish forced his hand. When he finally conveyed God's message, he was annoyed to see his prophesy falsified. The people made reparation and Nineveh was not destroyed. Jonah's paradox has been used to teach successive generations that we can most easily predict the course of history if we keep our insights to ourselves and can most easily change the course of history if we share them with others.

An Illustrative Example: the Overkill Hypothesis

Consider a hypothetical ecosystem in which each 'predator' is capable of consuming prey faster than prey can regenerate. Thus a herbivores corralled with just enough plant material to feed them for a short interval will eventually overgraze and be forced to find new food or move on. A carnivore which has access to just enough prey to keep it fed for a short interval will harvest those prey faster than they can regenerate and so on. If we create a set of patches, each of which has an initial colony of plants, herbivores and carnivores, allow migration to avoid predators and find available resources and constrain plant migration so that plants can only migrate at birth (i.e., as seeds) we can easily simulate an *overkill ecosystem*.

A deterministic model can be constructed, taking a recurrent death rate for all organisms of 0.1 with six patches each having a carrying capacity of 50 units of plant. Define 18 state variables to represent the expected population size of plants, herbivores and carnivores at each patch. For illustrative purposes, I present graphs of the total numbers of herbivores, plants and animals plotted against time in Figures 1, 2 and 3. Note that the carnivores seem effectively to restrict the herbivore population so severely that the plants run almost to the carrying capacity of the territory. As the sequence develops, herbivore and carnivore populations dwindle to extinction.



It is not difficult to understand why the deterministic model should run to extinction. The model assumes that species will migrate, breed and die at a rate perfectly determined by the given probabilities. Over successive iterations, all opportunities for growth are quickly exhausted. The result is a perfectly flat, even distribution of plants, herbivores and

Figure 4. Plot to show relationship between herbivore population at two patches. Note linear relationship indicating lack of spatial pattern.

carnivores across the six patches. Eventually, the lack of food prevents carnivores from breeding, and carnivory eats up all the new-born herbivores. The two populations gradually collapse as natural mortality drag both to extinction. Figure 4 plots the size of the herbivore population in patch 1 against that in patch 2. Note the perfect linear relationship indicating a complete lack of spatial pattern in the model ecosystem.

Conventional wisdom has it that nature abhors a vacuum, an adage used to persuade us that any opportunity for growth, whether in a biological or an economic system, will be or should be exploited. This model ecosystem provides the perfect antithesis to that view because it is actually destroyed by the over-effective filling of vacuums. What we see in the model is that the carnivores, which are unhampered by predation quickly run to the carrying capacity set by the availability of their prey. When this point is reached their reproductive rate and that of their prev are both curtailed. Both populations are subject to the same recurrent death rate and so enter an exponential decline leaving the ground clear for the plant population to expand to the local carrying capacity. The resulting double extinction marks the centre of a deep basin of attraction into which all sequences will be drawn.

Now consider what happens if we treat each organism as a stochastic micro-model, migrating, breeding and dying in accordance with the given rules. Because each migration decision will be made stochastically, organisms will sometimes 'make mistakes'. That is, will make decisions that generate a regular mismatch between the expected and observed values of state variables. These differences will result in some organisms one would expect to die, staying alive and some organisms one would expect to live dying. Each organism is a potent ecological actor, it is part of its own environment and of the environment of others. By breeding, migrating, feeding or dying it can change local birth and death rates and, with these, the course of history. It is possible that the net effect of all these stochastic decisions will be to create a propagator or sequence of propagators that underwrite resilience. Once again I can illustrate this by means of a simulation.

Take the same nominal six patches, each with a carrying capacity of 50 plants. Each plant can sustain one herbivore and each herbivore one carnivore with a recurrent death rate of 0.1. This time, every plant, herbivore and carnivore is represented by a distinct computer program, monitoring the distribution of plants, herbivores and carnivores and making stochastic decisions to breed, die or migrate in accordance with the appropriate probabilities. The aggregate behaviour of several hundred model organisms, all running simultaneous-ly will give us the population sizes of plants, herbivores and carnivores and carnivores and carnivores in such an ecosystem (Figures 5, 6 and 7).

The first thing to note is that this trajectory is not deterministic. A different run would employ a different random number stream and so replicate runs from identical starting configurations can be expected to diverge. However, there is no measurement error on the observations which Figures 5 to



Figure 5. Total number of plants under microsimulation.



Figure 6. Total number of Herbivores under micro-simulation.

7 summarise. The process we are looking at is quasi-deterministic; unpredictable *a priori* but fully determined *a posteriori*. Of course, the rules for computing probabilities would be invariant between runs so we may reasonably expect the dynamics of replicate runs to be qualitatively similar, even though the trajectories will diverge.



Figure 7. Total number of carnivores under micro-simulation.

The second and most obvious observation we can make is that the micro-simulation is jagged with peaks and troughs representing abrupt boom and bust events. Yet the model shows no sign of running to extinction. On the contrary, it seems remarkably resilient. The noise in the system generates a degree of spatial patterning among patches that maintains local vacuums or *statistical refugia* for small populations of animals and plants. Figure 8 illustrates this by plotting the number of herbivores in patch 1 against the corresponding number in patch 2. The perfect linear distribution of the macro-model (Figure 4) has been completely disrupted in the synergetic model. The pattern is a by-product of the stochastic, jerky time series, which is a more realistic representation of the hide-and-seek behaviour of resilient predator prey systems. It is resilient because the collective effect of the birth. death and migration decisions taken at the individual level actually alters the balance of probabilities. Stochastic noise generated by individual migration, birth and death 'decisions' continually bounce the system away from the deep basin of attraction into which the macro-model fell.

We should not abandon this simulation without considering empirical testability. As any good statistician can testify, the covariance structure obtained from a set of observables is often a valuable source of information about data structure. We can also compute covariances directly from the model's time series, thereby forging a link between system



Figure 8. Scatterplot to show numbers of herbivores at two patches (compare Figure 4)

dynamics and static observables. The covariance data obtained from the micro simulation run are the following:

	Plant	Herbivore
Carnivore	-73.2	215.7
Herbivore	-65.1	

Note that the number of plants covaries negatively with that of herbivores and carnivores, the numbers of which are positively correlated with each other. This means that when plant populations are relatively small, herbivore and carnivore populations can be expected to be relatively large, and vice versa. In fact the herbivore and carnivore populations drive each other through boom and bust cycles with each either rising or falling slightly out of phase with the other. As herbivore populations rise, plants are overgrazed but recover as the herbivore population crashes and drags the carnivore population down with it. These statistical generalisations are important because they can be taken as the empirical signature of the model. We would not expect a real-world ecosystem to track the given time series, even if the theory were correct. However, we could reasonably expect carnivore and herbivore numbers to be positively correlated with each other and negatively correlated with plants in the real world. If this were not so, we consider the theory under investigation to have been refuted by the empirical evidence.

Conclusions

In the body of my paper I argued from anecdotal evidence that historical systems are quasi-deterministic. That is to say that they give the impression of being fully determined *a posteriori* but are in fact indeterminate *a priori*. Then I showed that, as long as human actors can use a predictive model to change the course of history, the deterministic hypothesis leads us to paradoxical conclusions: simple competitive games in which only one player can win and no player can lose, for example.

This line of argument, though familiar to many from Old testament scripture, is directly analogous to well-known theorems of computer science which have been used to establish the limits of computability and to the famous result of number theory known as Godel's incompleteness theorem. In the form presented here it proves that multi-agent systems are capable of generating outcomes which were absolutely unpredictable *a priori* even though they may seem quite unsurprising *a posteriori*.

At a superficial glance, my argument is primarily theoretical and the two computer simulations that followed it seem to have little direct connection to the main body of the text. However, they serve to demonstrate that the issue of unpredictability has profound practical implications for those engaged in the management of historical systems and that some of the methodological problems raised by unpredictability can be solved in practice.

The first thing we must note is that *both* simulation models represent overkill ecosystems, each of which has the same carrying capacity, the same starting configuration and calculates birth, death and migration probabilities in the same way. The principal difference between the two is that one has an implicit assumption of predictability that the other lacks.

The classical support modelling approach *validates* a model in terms of goodness of fit between a simulated trajectory and the history that really happened. A support modeller would have to build a deterministic model and then reject the overkill hypothesis for poor goodness of fit. The trajectory observed and that obtained by simulation were simply too different for the model to be supported. In practice, however, it was not the overkill hypothesis, but the implicit assumption of predictability that generated the unrealistic behaviour.

Every simulation model represents a theory about a social or natural system. The use of deterministic methods (differential equations in this case) to implement an overkill model has *knock-on* effects for the simulation itself. The classical support modelling approach, with its close attention to single trajectories can lead us to refute perfectly good theories because of the hidden assumptions we incorporate into our computer programs. Indeed, the support modelling para-

digm almost obliges modellers to restrict their attention to demonstrably inferior theories.

My argument seems like a counsel of despair: scientists are damned if they assume predictability because their models will be suspect on theoretical grounds and damned if they assume unpredictability because their models can never be tested against the empirical evidence generated by observed time-series'. In fact, this is not necessarily so.

In the unpredictable case we can generate many time series, all consistent with the given theory, and use these to construct variance-covariance matrices. This is a well-established statistical technique and, by the Central Limit theorem of statistics, we may reasonably hope that these will provide stable *fingerprints* for given theories. Striking disparities between the variance-covariance fingerprints of multi-agent systems and those observed in real time-series data can reasonably be taken as grounds for empirical refutation of the underlying theory. Abandoning the assumption of predictability does not necessarily require us to abandon the scientific discipline of empirical testing.

In the predictable case, the overkill hypothesis drove the simulated ecosystem into a deep basin of attraction; a catastrophic extinction event in which predators had access to all populations of prey. The noisy time series and the dynamic spatial pattern generated by the hide and seek behaviour of a real ecosystem was replaced by a smooth, spatially amorphous collapse. In the unpredictable case, individual animals and plants failed to conform exactly to expectations: isolated pockets of prey and predators sometimes managed to survive in difficult circumstances and sometimes died in circumstances where survival would have been expected. Because each of these organisms was part of its own environment and that of others in the system, these local discrepancies between observed and expected behaviour actually changed the balance of future probabilities. Spatial pattern is generated thereby together with the characteristic jumpy trajectories so often observed in real ecosystems.

Unpredictability is not a problem for scientists to solve but a logically inescapable consequence of the way the world appears to be. As such, it provides an opportunity for scientific development. Both the life sciences and the social sciences have well established traditions of investigating static spatial patterns and dynamically evolving trajectories. However, building bridges between the static and the dynamic approach is notoriously difficult.

The evidence of these simple models is that, by building models of quasi-deterministic systems, scientists may see more clearly why socio-natural systems develop spatial pattern and how this spatial pattern is related to ecological resilience and to variance-covariance structure in time series data. The systematic study of self-organising or synergetic systems may enable us to forge stronger links between the static and dynamic arms of these fields.

Endnote

1. The term was coined by Dr. James McGlade of the Institute of Archaeology at University College, London.

References

- Allen, P. 1990. Models of creativity: towards a new science of history. Paper prepared for "Dynamic Modelling and Human Systems" a conference held at St John's College, Cambridge, December 10-13th.
- Allen, P., and J McGlade. 1987. Evolutionary Drive: the effect of microscopic diversity, error-making and noise. *Foundations of Physics* 17: No. 7, July.
- Gould, S. 1989. Wonderful Life: the Burgess Shale and the Nature of History. London: Hutchinson Radius.

Haken, H. 1978. Synergetics: an introduction. Berlin: Springer-Verlag.

Liberatore, A., and A Sors. 1997. Sustainable futures and Europe: a

research viewpoint from Brussels. *Global Environmental Change* 7:2, 87-91.

- Popper, K. 1936. The poverty of historicism. Paper originally read to a private meeting in Brussels, reproduced in abridged form in D Miller. 1983 A pocket Popper. Oxford: Fontana.
- Sanders, L. 1997. The past and future evolution of the French Urban System: a Synergetic Approach. In E Holm, (Ed.) Modelling Space and Networks: Progress in Theoretical and Quantitative Geography, 33-58. GERUM Kulturgeografi, Umeå Universitet.
- van der Leeuw, S. 1989. Risk, Perception, Innovation in S. van der Leeuw and R Torrence (eds.). What's New? A closer look at the process of innovation. London: One World Archaeology, Unwin Hyman.
- Winder, N. 1998. Uncertainty, Contingency and History: an archaeologist's view of Policy-Relevant Research in Human Ecodynamics. In S. van der Leeuw (Ed.). Policy-Relevant Models of the Natural and Anthropogenic dynamics of Degradation and Desertification and their Spatio-Temporal Manifestations. Second Report of the Archaeomedes Project (II) for the Directorate General XII of the European Union.
- Winder, N. In press. *The Path-Finder as Historian*. Unpublished book. SMC Spatial Modeling Centre. Sweden.