HISTORICAL ANALYSIS OF THE SOURCES OF LAND-USE CHANGE IN TROPICAL AMERICA

Preliminary ideas for discussion

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Introduction

This document is intended as a catalyst for getting the reactions from researchers in History regarding potential interest in research collaboration with the Land Use Program of the CIAT (Centro Internacional de Agricultura Tropical).

If the initial reactions were in general positive, the next steps could be to incorporate the suggestions and comments into the document, and to hold a small-scale workshop. The workshop will aim to discuss the issues in depth, to define a research agenda, and to initiate mechanisms for cooperation.

Purpose of the research

To examine and (possibly) test the hypothesis that drastic change in land-use can arise from properties of complex systems and dissipative structures, and to analyze the associated theoretical and policy implications.

Background and justification

There is a widening consensus in that many of the present patterns of land use in tropical America are destroying the ecological base for development, and at the same time generating social problems and gross economic inefficiencies.

If fast and drastic whole-system re-structuration can occur in the systems determining land use, as suggested by the evidence arising from studies on the behavior of complex systems, it becomes of great practical importance to understand which are the factors or processes defining the likelihood of those deep changes. The degree to which those structural changes can be anticipated is also very relevant. Situations approaching the threshold of structural changes should be treated specially both in technological and policy terms. The knowledge gained along the described lines could contribute to the generation of new styles of land use management.

From another viewpoint, the knowledge obtained could have important theoretical and methodological implications for the fields of systems theory, history, geography, economics, and ecology.

Land-use patterns result from human decisions and human activities exerted upon ecosystems. Those are not passive receptors of external influences, but they have their own dynamics, often resulting in complex responses and interactions between the human and biophysical elements. As a consequence, actual land-use (and particularly its sustainability and productivity) is often quite different from that anticipated.

The understanding and anticipation of land-use patterns therefore requires to broaden the scope to the consideration of the whole socio-ecological system determining the use of the land.

A *socio-ecological system* is viewed here as any system composed by a societal (or human) subsystem and an ecological (or biophysical) subsystem. The levels of aggregation may range from a local community and the surrounding environment with which it directly interacts, up to the system constituted by the whole of mankind and the ecosphere. In the case of land-use, the levels of aggregation of major interest lie between the landscape and the continental (and even planetary) scales.

For the purposes of the present discussion, however, case-studies at the level of landscape (involving a recognizable social structure -above the scale of the individual farmer- and a minimum spatial and ecological heterogeneity) are the focus of attention.

Change may result from gradual, cumulative processes, or from a sudden, often unexpected, shift of the social and/or the ecological subsystem (due to the sheer power of external forces, to flips in the state of the system, or to structural reorganizations originated in internally or externally generated fluctuations).

The latter two are the most interesting situations for research and policy-making. In them, change may arise from non-obvious variations in the external variables, or even from internal oscillations in the values of the variables of the system (see Annex I for a more technical discussion).

Drastic changes in land use can often be explained as the effect of some clearly identified driving variable, such as the international price of agricultural commodities, colonization policies, opening of new roads, etc.

However, because there are so many instances in which resulting land use departs from what is planned, and often unexpected changes take place, it is likely that in some cases land use changes are triggered and/or determined by systemic restructurations, arising from non-obvious interactions.

Gradual change is usually perceived as non-threatening, or at least manageable (and paradoxically, it is often ignored until it reaches unbearable levels). By contrast, sudden (and particularly, unexpected) social or ecological change tends to be viewed as a threat. Perhaps not unnaturally, ecologists and environmentalists have usually focused upon *catastrophic* changes (sudden changes from a "desirable" to an "undesirable" system organization) arising from the interactions between society and nature, while the builders of the theory of dissipative systems, some evolutionists, and some development schools (i.e. the take-off approach) emphasized what I have defined elsewhere as *"anastrophic"* changes (sudden moves towards new and higher organization levels). This notion of the possibility of catastrophic or anastrophic changes in human-ecological interacting systems as a consequence of internal or external fluctuations, and its implications for the understanding of the processes associated with the sustainability of land use in tropical America is an element to be explored in the research discussed here.

ISSUES FOR DISCUSSION

These are tentative questions to initiate the interaction:

- Is the central hypothesis interesting for historical research? Is it testable in some sense? Should it be changed?

- Are the concepts associated with systemic change, dissipative structures, etc. (basically derived from the natural sciences) relevant for the social sciences and particulary History, where purposeful behavior and planned actions play such an important role?

- Methodological criteria for characterizing change as sudden/gradual, structural/incremental.

- What kind of historical information would be necessary? Availability of the appropriate data in tropical America.

- Is historical analysis an appropriate entry point for this question?
  What challenges for the discipline are involved?

- Under which general types of situations can socio-ecological systemic restructuration be expected *a priori ?*

- Definition of a research agenda.

ANNEX I

DYNAMICS OF CHANGE IN COMPLEX SYSTEMS

Gilberto C. Gallopín, July 1993
(modified from Gallopín, G.C.; P. Gutman and H. Maletta. 1989. *Global impoverishment, sustainable development and the environment: a conceptual approach.* Int. Social Science J., **121**: 375-397)

Among the various theoretical approaches to complex systems, the one derived from the theory of dissipative structures (developed essentially by Ilya Prigogine and his collaborators[1]) seems particularly suitable as a basic framework for investigating the dynamics of change and persistence in socio-ecological systems. This theory deals with the processes of self-organization in systems fulfilling some basic conditions: openness towards their environment[2], a global system state far from thermodynamic equilibrium, and autocatalytic[3] non-linear self-reinforcement of certain steps in their internal processes.

The theory of dissipative structures shows that open, self- organizing systems maintain their structural order by keeping their internal state far from thermodynamic equilibrium, through active exchanges with their environment. Those dissipative structures are in principle stable as long as the exchanges with the environment are maintained and as long as the continuously occurring fluctuations (or perturbations) are absorbed within the framework of the given dynamic regime. However, any structure of a non-equilibrium system may be driven beyond a threshold into a new regime when the fluctuations exceed a critical size. This corresponds to a qualitative change in the dynamic existence of the system. An important point is that such fluctuations may be originated not only from the outside of the system, but also they may be internal fluctuations that become self-amplified through positive feedback. In either case, after passing through phases of instability and high entropy, the system may evolve to a different stable regime with a new characteristic structure.

The fluctuations referred to here are not fluctuations in the values of the variables of the system, but in the mechanisms and relationships between elements of the system, resulting in structural modifications.

The probability that a fluctuation spreads and attains a macroscopic amplitude and range depends on the competition between the amplifying and damping forces within the system. The size and complexity of the system are important factors for the formation of new dissipative structures; a dissipative structure comes into being when a specific critical size can be realized. A system that is too small will always be dominated by the boundary effects. Besides size, the penetration of fluctuations and the formation of new dissipative structures depend on sufficiently dense packing or cohesion of the fluctuating elements or subsystems on the one hand, and on flexible, not too strong and rigid coupling with the rest of the subsystems on the other.

The basic characteristics of dissipative self-organizing systems (openness, non-equilibrium and autocatalysis) underlie the possibility of internal self-amplification of fluctuations and their ultimate breakthrough at the system ("macroscopic") level. In this case, the system may evolve through an indefinite sequence of stages of stability and instability; each instability may lead to the spontaneous formation of a new dissipative structure, a process called by Prigogine "order through fluctuations".

When the state of the system is away from the transition threshold, a deterministic description can be applied; however, near the threshold, stochastic elements become essential in determining the new structural regime (See Figure 1). The path which the evolution of the system will then take cannot be predicted, there being always more than one emerging, qualitatively different, structure available. This transition to a new regime, depending on the properties of the system and of the fluctuation, may be relatively "smooth" or may represent an abrupt jump to a new domain (See Figure 2).

In broad terms, the framework proposed by the theory of dissipative structures seems, in principle, applicable to socio-ecological systems, as all of them are open, non-equilibrium systems characterized by strongly non-linear dynamics. Even in its qualitative conceptual form, the approach allows the posing of new questions and new hypothesis, and provides a suggestive unifying perspective.

Human societies display many of the characteristic features of nonlinear non-equilibrium systems: unpredictability,complex interdependencies, time-lags, transitions from one state to another and the importance of a critical mass in producing and sustaining change. However, a theory designed to explain the collapse of social systems (and the emergence of new structures) would have to take into account the *interference* between spontaneous development and planned action[4].

The approach associated to the theory of dissipative structures has been already explored in a small number of cases involving social and biophysical systems[5].

Its usefulness in the study of land-use is worth exploring. This would require adaptations of at least two kinds: a) the specification of some of the fundamental concepts in concrete terms in particular case-studies of land-use changes and sustainability and b) their combination with other relevant concepts originated in social, ecological, and general systems understanding concerning change, decision-making, purposeful behavior, etc.

Other developments in ecological theory regarding the dynamics of change seem particularly relevant to the treatment of socio-ecological sustainability.

Natural ecosystems at different scales (from local up to the ecosphere) are complex ever-changing entities. Ecosystems are open systems maintaining an active exchange of matter, energy and information with their environment. No ecosystem is ever at thermodynamic equilibrium; equilibrium in ecology is used in the sense of a dynamic steady or quasi-steady state. Ecosystems have homeostatic mechanisms that regulate their functioning and their interchanges with their environment, and those are essential for the continuity and the integrity of the ecosystem, despite the myriads of minor changes taking place all the time within it and its elements.

The self-regulatory mechanisms at the level of the ecosystem arise from the interplay of different processes and mutual adjustments, such as the interactions between preys and predators, plants and herbivores, the competition between organisms of the same and different species, co-operative and symbiotic relationships, the exploitation or utilization by the organisms of the resources available to them (nutrients, light, food, refuge, etc.), and the dynamics of the physical environment (soil, water, climate, etc.).

Those self-regulatory mechanisms operate in such a way as to counteract or compensate internal and external disturbances in the variables critical for the survival of the system. Because of self-regulation (and of the functional couplings between the elements of the system), the functioning of the system is constrained. Therefore, regularities in behavior and responses arise in ecosystems, and often there is a substantial degree of predictability about their behavior.

One of the earliest perceptions of this predictability in natural ecosystems is related to the concept of the "equilibrium of nature" (often popularized by stating that Nature is poised in a delicate and fragile steady or dynamic equilibrium state, and that any change made by man risks destroying that equilibrium). A more modern view is that ecosystems tend to recover from perturbations by moving towards a steady or quasi-steady state.

This relates to the classical concept of stability of dynamic equilibrium points, limit cycles or, in its most general form, limit trajectories. It refers to the ability of a dynamic system to return to an equilibrium trajectory, cycle or state after a temporary disturbance; the more rapidly it returns, and the less it fluctuates, the more stable it would be (See Figure 3). This concept focuses on the local stability of particular states or sets of states, and it has been often applied to ecological systems.

This concept is well illustrated by the classical studies of ecological succession, describing a trajectory starting from an initial state of bare space of rock surface, sand dunes, etc. (or a state in which a pre-existing community has been removed), being colonized by organisms, and passing through a directional series of cumulative transformations until the climax community or ecosystem is reached. That climax is, basically, viewed as an equilibrium (steady-state) ecosystem, determined fundamentally by the general climatic and physical properties of the area, and not by the initial starting point. The processes that drive succession may be both internal (the internal environment being moderated by the organisms themselves, such as the fracturing of rocks or the stabilization of shifting sands by plants, or the incorporation of organic matter into the soil), and external (inputs from outside the ecosystems, such as the importation of nutrients, organic detritus, or outside species from an adjacent ecosystem). Succession where the "driving force " is internal to the ecosystem is termed autogenic succession. When the driving force is mainly external to the ecosystem, the term allogenic succession is used. While this view of all ecosystems converging to a single climax is not accepted today as universal, its imbedded implication that ecosystems have a final steady state, and only one, permeated implicitly the perception of ecosystems by planners, managers of natural resources, and economists. This has led to direct attention to the dynamic equilibrium or near-equilibrium conditions, and to management that emphasizes control, homogenization, stabilization and constancy. After all, if it were true that ecosystems have one single stable equilibrium state to which they tend to return when perturbed, they could be managed with the confidence that, should anything go wrong, it is sufficient to reduce the pressures on the ecosystem and allow time to recover its equilibrium. The only problem will be how fast will the system recover.

While homeostatic mechanisms resulting in the maintenance of the steady states are basically constituted by negative (self-regulatory) feedback loops, the forces driving change in autogenic succession are essentially represented by positive (self-amplifying) feedback loops (for instance, as when changes in the internal ecosystem environment, making it less severe, lead to the successful introduction of increasingly specialized species which further stabilize the ecosystem and allow the establishment of even more specialized forms, replacing the earlier species).

It is clear today that in most situations succession is not a simple, deterministic process, and in many cases, depending on the current state of the ecosystem, the environmental factors, and chance factors, there are several paths by which succession can proceed over time in a given area, culminating in different climaxes. Still, the climax ecosystems are generally viewed as quasi-steady state ecosystems, with inputs roughly balancing outputs, and fluctuations of species remaining bounded in time. This is true at a broader scale for ecosystems that exhibit what is called "cyclic stability", where the climax condition is represented by cyclic alterations of different vegetational assemblages rather by a single stable assemblage. In this case, the cycle itself represents a steady situation. Natural or man-made disturbances at any stage of succession can set back succession, or maintain a transient succession stage indefinitely. In general terms, (except in retrogressive successions) it is accepted that biomass, structural and functional complexity, closure and slowness of mineral cycles, dampening of the external environment, slowness of change, biological diversity and other factors tend to increase between the early and late stages of succession, while net total primary productivity decreases (not always monotonically).

The time-scale of ecological succession often ranges over hundreds of years. Over shorter time-spans, ecosystems (in climax or transitional stages) also show homeostatic mechanisms, and the concepts of quasi-steady states were applied to them too, as well as to ecosystems managed by man. The common underlying assumption was often maintained: that ecosystems have a single steady state, or, in other terms, global dynamic stability, leading to an essentially static view and providing little insight on the transient behavior of ecosystems that are not near the steady state.

Holling[6] introduced a new, non-equilibrium vision in ecology with the concept of ecological resilience, arising from the analysis of different empirical studies, mathematical models, and experience with managed ecosystems. He showed that even natural, undisturbed ecological systems are often in transient states, and demonstrated that many of them are multistable[7], that is, they have two or more stable domains of attraction (determined by the interactions within the systems and with the outside) where the system variables tend to stay (See Figure 4). Within each domain the system's state may fluctuate widely (i.e. may be highly unstable), but as long as it stays within the boundaries of the domain, the system is resilient. Resilience determines the persistence of relationships within a system and is a measure of the ability of the system to absorb changes of state variables, driving variables and parameters, and still persist within a basic mode of behavior. In this view, the combination of internal processes and external perturbations (even small incremental perturbations) driving the system over the boundary of the current domain of attraction, may result suddenly and unexpectedly in large changes in the values of the state variables as the system "falls" into another domain of attraction (including those signifying extinction). The system may thus exhibit sudden qualitative changes in behavior (i.e. jumping from a high-equilibrium level to a low-equilibrium level, from a low-variability situation to stable limit cycles of various amplitudes, or even to "chaotic" behavior, or it may show a continuous, dynamic disequilibrium shifting between stability domains, occasionally residing in extinction regions[8]. It is important to emphasize that those sudden shifts in behavior occur even in the absence of structural change in the system. Holling also showed that in a number of cases, the size and shape (and the genesis or disappearance) of the domains of attraction can change because of the unperceived evolution of parameters of the system (implicitly assumed constant), parameters often affected by long-term management, or internally determined by processes that link variables. Thus, the stability domains themselves may expand, contract, and disappear in response to charges in slow variables[9].

A variety of genetic, competitive, and behavioral processes maintain the values of the parameters that define the system and its "stability landscape", and nonlinearities, variability, instability, spatial heterogeneity and diversity keep the system resilient. The balance between stability and resilience of ecosystems is an evolved property, a consequence of the history of external variations that the system has experienced. In a number of examples[10] it was shown that the very success in management to constrain the natural variability of a target variable (forest insect populations, forest fire frequency, salmon numbers, cattle stocking density, malarial vector populations) made the ecological systems to evolve to a situation which is more fragile and more dependent on vigilance and error-free management, often at a time when greater dependencies had developed in the socio-economic and institutional environment for continual success[11], increasing drastically the risks of unprecedented catastrophes or collapses.

One overall conclusion is that discontinuous change is an internal property of many ecological systems. For long periods change is gradual and discontinuous behavior is inhibited. Conditions are gradually reached, however, when a jump event becomes increasingly likely and ultimately inevitable[12].

Paramount importance is attributed by Holling to the interactions between a small number of key variables (slow, intermediate and fast) in determining the dynamics of the system, as well as to the spatial heterogeneity or spatial scales.

This view leads to a management of ecological systems that attempts to retain variability while producing economic and social benefits, allowing the variables to exceed flexible limits so long as natural and designed recovery mechanisms are encouraged[13], or else to a nature engineered to keep the system's variables away from dangerous neighboring domains (assuming the stability landscape is fixed and known or that sufficient knowledge is available to keep it fixed), as for instance in the cases of set environmental standards, nuclear safeguards, etc.

It is important to notice that the concept of resilience and Holling's approach deal essentially with sudden changes in the behavior and the "stability landscapes" of ecological systems within a given structure (in the sense of the configuration of elements and relations composing the system). That is, structure is preserved, and the consequences of jumps between stability domains is reflected in qualitative different behavior modes involving the same critical variables. The exception is when the system is driven to extinction, implying its collapse. In all other cases, structural stability is assumed, and the discussion centers about changes in the stability of the states of the system.

Recently Holling[14] proposed a general hypothesis of ecosystem dynamics and succession. His proposal implies that ecosystems move from a phase of exploitation (of available resources by biota) to one of conservation (consolidation, increasing organization or connectedness), then to creative destruction (sudden release of accumulated resources by fire, storms, pests, senescence, etc.), and finally to renewal (mobilization and retention of the stored resources), after which the cycle starts again:

> "Ecosystem succession has been usefully seen as controlled by two functions: exploitation where rapid colonization of recently disturbed areas is emphasized, and conservation where slow accumulation and storage of energy and material are emphasized. Recent studies indicate two additional functions are needed. One is that of release where the tightly bound accumulation of biomass and nutrients becomes increasingly fragile (overconnected) until it is suddenly released by agents such as forest fires, insect pests, or intense pulses of grazing. The second is one of reorganization where soil processes of mobilization and immobilization are organized so that nutrients become available for the next exploitive phase. That pattern is discontinuous and is dependent on the existence of multi- equilibria that are essential to the release and reorganization functions. Resilience and recovery is determined by the release and reorganization sequence and stability and productivity by the exploitation and conservation

sequence.

These four functions generate a classic pattern of spatial and temporal change that is usefully analyzed, modelled, and interpreted as a life history sequence of distinct events, perturbed by various frequencies and intensities of external disturbance. In ecosystems, time flows unevenly and each phase differs in its sensitivity to external disturbance. The progression in the ecosystem cycle proceeds from the exploitation phase slowly to conservation, very rapidly to release, rapidly to reorganization and somewhat slower back to exploitation. Connectedness and stability increase and nutrient and biomass capital is slowly accumulated during the sequence from exploitation to conservation. The system eventually becomes overconnected so that rapid change is triggered. The stored capital is then released, and the system becomes disconnected to permit renewal of the same stable state or change to a new one. The particular state depends on the condition of the renewal capital that has accumulated. This determines the physical properties of the soil and hydrological regime that is controlled by the biota. If it becomes greatly eroded, then the ecosystem abruptly shifts into a sustained degraded state. Its maintenance or enhancement determines the opportunity for renewal of the previous states, or evolution to a new one.

Investments that ignore those properties are liable to backfire, producing effects opposite to those intended, including possibly, catastrophes. This view of ecosystem development also suggests that different attributes of investment might be adequate at different times, depending upon the development phase which the ecosystem is experiencing. This concept of ecosystem change and its possible analogies with economic, technological and social change is reviewed in Holling, C.S. 1986. The resilience of terrestrial ecosystems: local surprise and global change; in: W.C. Clark and R.E. Munn (eds) "Sustainable Development of the Biosphere", IIASA/Cambridge University Press, Cambridge."[15]

Following the above discussion, it is useful to distinguish three levels of change/stability. The first level refers to the local stability of a particular equilibrium trajectory (steady states or points, and steady or "limit" cycles are particular cases of a trajectory) defined by the dynamics of a system with a given structure. If the state of the system tends to approach that trajectory, even after being perturbed away from it, the trajectory is said to be stable. A system possessing only one stable trajectory (independently of how many unstable ones it has) is globally stable (that is, no matter how large the perturbation, the state of the system will eventually approach the stable trajectory).

The second level is resilience, applicable to systems exhibiting two or more stable domains of attraction, and referring to the likelihood that the state of the system (even if no stable trajectory exists) will tend to stay within a given domain (associated to a basic mode of behavior) after being subjected to perturbations. A multistable system is not globally stable, because depending upon the kind and magnitude of the perturbation, its state may move into different domains of attraction. However, those domains are part of the dynamical "landscape" of the system (i.e., they are implicit in its structure and dynamic rules) and resilience refers fundamentally to changes in the behavior, not in the structure, of the system.

Finally, the third level refers to the stability of the structure itself, of the mechanisms and the relationships between elements of the system, including the possible addition or deletion of elements. The concept of systems's vulnerability is applicable here. Structural change implies the possibility of true novelty and evolution, as the new structural regime arising when the limits of structural stability are exceeded cannot be predicted even in simple physico-chemical systems.

NOTES AND REFERENCES

1. Nicolis, G. and I. Prigogine 1977, Self-organization in Non-equilibrium Systems: From Dissipative Structures to Order Through Fluctuation; Wiley, N.Y.; Prigogine, I. et I.Stengers. 1979, La Nouvelle Alliance. Métamorphose de la Science; Gallimard, Paris; and Jantsch, E. 1980, The Self-organizing Universe; Pergamon Press, Oxford.

2. A system is called open if it maintains exchanges of energy, matter and information with its environment. Systems without those exchanges are called isolated. An exchange with the environment can be maintained by the system itself (as opposed to by the environment) only when its internal state is not at thermodynamic equilibrium; otherwise, the processes would die down.

3. Or crosscatalytic. This means that certain units (e.g. molecules) participate in reactions in which they are necessary for the formation of units of their own kind (autocatalysis), or first for the formation of units of an intermediate kind and subsequently of their own kind (crosscatalysis). Both represent nonlinear processes. The concepts are used here in their general sense; in ecosystems, for instance, autocatalysis is represented by the self-reproduction of organisms in the presence of sufficient supply of food in the environment. (Jantsch, E. 1980, The Self-Organizing Universe; Pergamon Press, Oxford).

4. Mayntz, R. 1992. Chaos and Social Order. WORK IN PROGRESS (United Nations University) **14**(1): 5.

5. See, for example, Allen, P. 1985, Towards a new science of complex systems; pp. 268-297 in: The United Nations University, The Science and Praxis of Complexity; The United Nations University, GLDB-2/UNUP-560; Tokyo; and García, R. 1988, Biospheric Change and Food Systems, IFIAS/UNRISD, January 1988.

6. Holling, C.S. 1973, Resilience and Stability of ecological Systems; Ann. Rev. Ecol. & Systematics, **4**: 1-23.

7. The property of multistability seems also relevant to the study of economics as well as of the relationships between environment and development; see, for instance, Arthur, W.B. 1988, Competing technologies: an overview; pp. 590-607 in G. Dosi et al (Eds.): Technical Change and Economic Theory; Pinter, London, 646 pp., and Gallopín, G.C. 1980, Development and Environment: An Illustrative Model; Journal of Policy Modelling 2 239-254.

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13. Holling, C.S. 1986, The resilience of terrestrial ecosystems: local surprise and global change; pp. 292-317 in W.C. Clark & R.E. Munn (eds): Sustainable development of the Biosphere; IIASA/Cambridge Univ. Press.

14. Holling, C.S. 1986, The resilience of terrestrial ecosystems: local surprise and global change; pp. 292-317 in W.C. Clark & R.E. Munn (eds): Sustainable development of the Biosphere; IIASA/Cambridge Univ. Press.

15. Source: Project Proposal to IDRC: Processes of Impoverishment and Sustainable Development: A Research Proposal, presented by C.S. Holling and G.C. Gallopín, 1987.

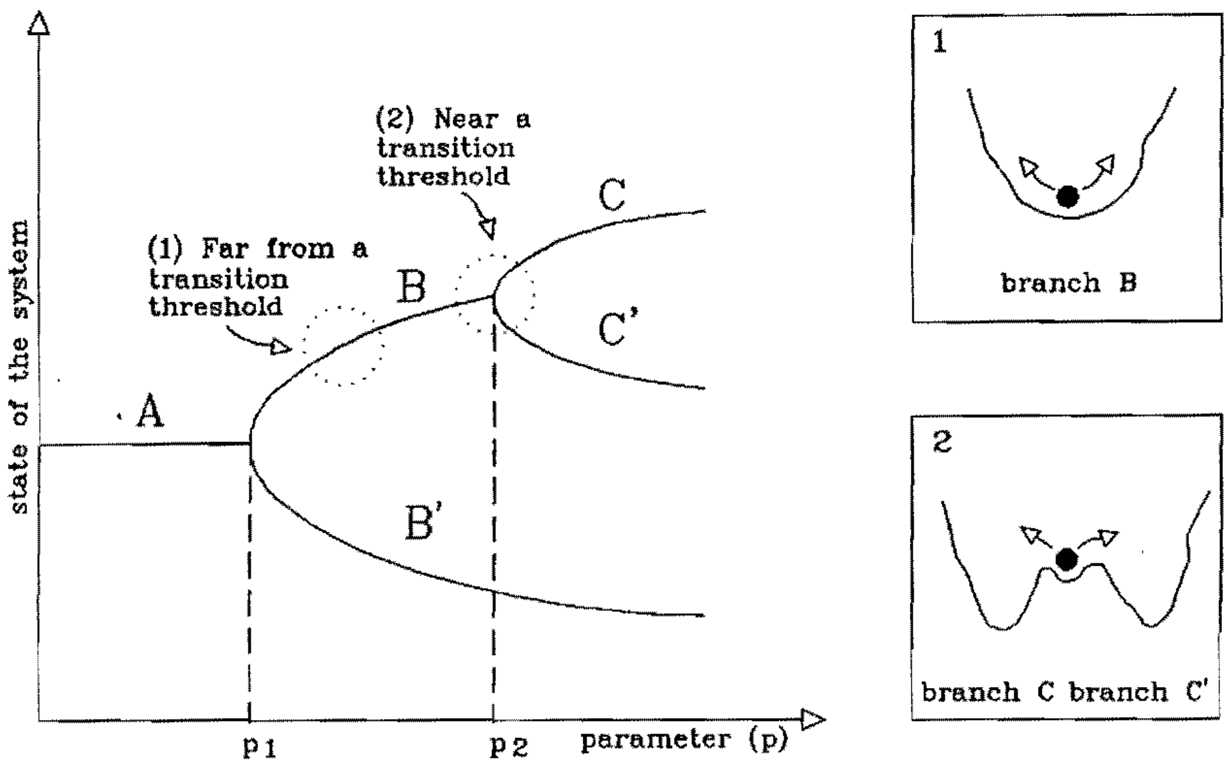

Figure 1. Macroscopic indeterminacy in the evolution of a dissipative structure. Full lines, indicate equilibrium values for the system, For **p** < **p_1**, only one steady-state exists for each value of the parameter **p** (branch A). For **p** = **p_1**, (first transition threshold) two other families of states become possible (branches B and B'). For **p** = **p_2**, (second transition threshold), two other stable branches (C and C') appear. When the state of the system is near a transition threshold, small disturbances can be decisive in nudging the system into one branch rather than another. *Modified from* Prigogine, I. and I. Stengers, 1979 La Nouvelle Alliance. Métamorphose de la Science. Gallimard, Paris.

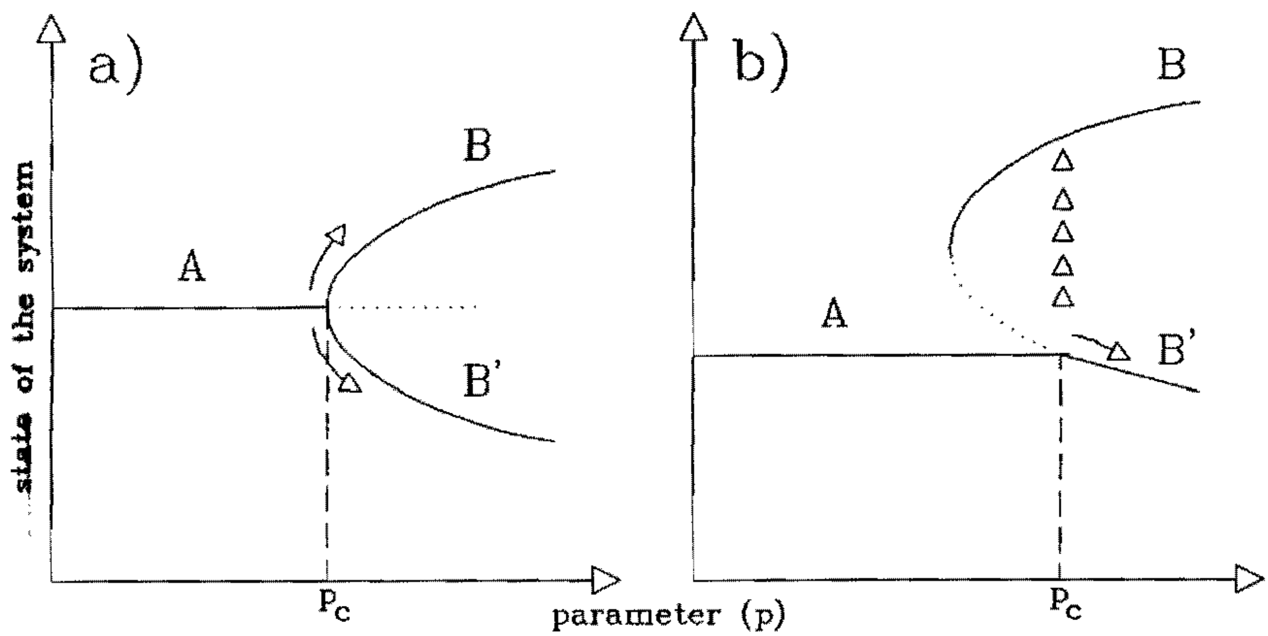

Figure 2. Transition from the equilibrium conditions to two possible dissipative structures B and B′ when the critical threshold p_c is reached. Full and dotted lines denote stable and unstable equilibria, respectively. (a) The transition to one of the two new solutions B and B′ is "smooth"; (b) The transition occurs by way of a *bistable* domain in which the new solution B is separated by a jump from the stable equilibria in branch A. Modified from Jantsch, E. 1908 The Self-Organizing Universe; Pergamon Press, Oxford.

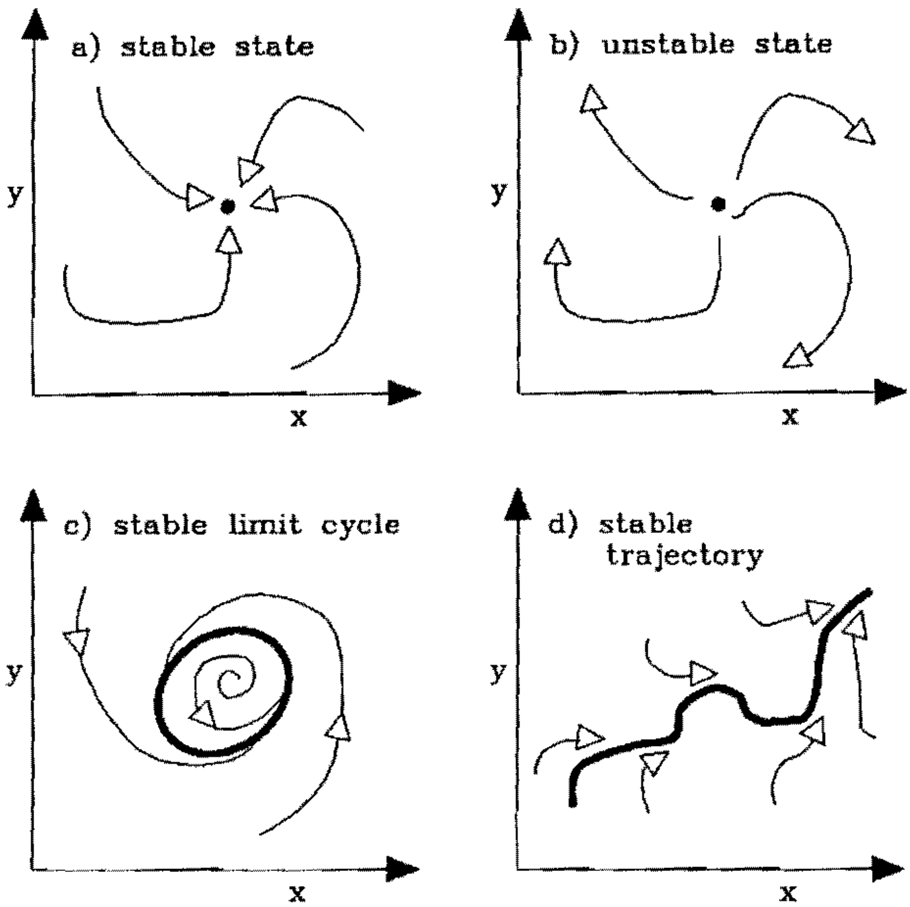

Figure 3. Some local stability situations. The state of the system is represented by the points defined by the values of variables **x** and **y**. Dots or heavy lines represent equilibrium states or trajectories. Arrows indicate the direction of movement from different states of the system.

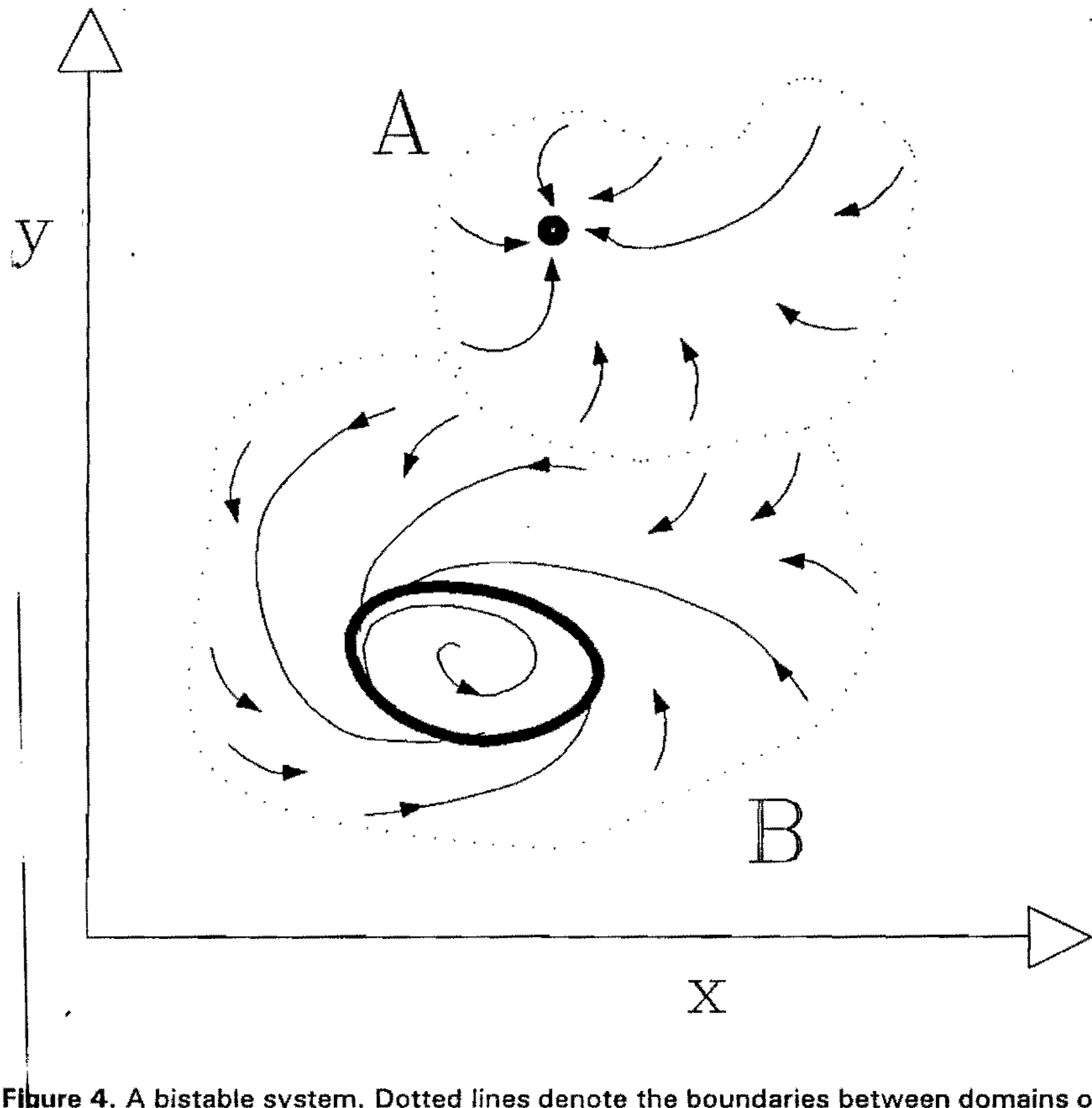

Figure 4. A bistable system. Dotted lines denote the boundaries between domains of attraction. Arrows indicate the direction of movement of the state (**x**, **y**) of the system. Domain (A) contains one stable state; domain (B) contains a stable limit cycle. If the state of the system enters the domain (A) it will tend to settle down to a steady state; if it enters domain (B), the system will exhibit oscillatory behaviour.