A Management Perspective on Social Ecological Systems: A generic system model and its application to a case study from Peru

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Abstract

This paper suggests a framework for operationalizing the concept of a social-ecological system (SES), through a generic system model that can be applied to different situations and used as a management tool. Four functional subsystems are identified: natural (N), worldview (W), control / management (C) and technology (T). These encompass four orders of system complexity: physical, biological, social and semiotic. Emergent systems properties are conceptualized as arising through exchanges of matter and meaning between subsystems, and between the system as a whole and its environment (E). The second half of the paper draws on field work undertaken in the Manu Biosphere Reserve, Peru, to illustrate how the generic model can be applied to the case of family farm systems in the reserve. The aim is to facilitate collaboration among specialists from a range of disciplines, and non-academics, working together to address social and environmental issues from a systems perspective.

Key words: *Social-ecological system, management, Manu Biosphere Reserve, family farm systems*

Introduction

Societal and ecological problems facing the planet are both systemic problems and management problems. They are systemic because they arise from deep-rooted, complex, interrelated processes that operate across and between different scales from global to local. They cannot be understood by separating them out for analysis by single academic disciplines. They are management problems because their solution requires a sustained, coordinated and goal-driven response by policy makers: there are no quick fixes. This paper explores the potential of adopting a systems approach to address these challenges. We suggest that they can be usefully conceptualized as arising within social-ecological systems. As will become clear, the term ‘social-ecological system’ simply indicates a commitment to adopt a holistic, systemic perspective towards human and non-human elements of a problem situation of interest. We suggest a procedure for operationalizing this approach in the form of a generic model of a social-ecological system which can be applied to different situations and used as a management tool.

The first half of the paper discusses theoretical issues relating to the concept of a social-ecological system and provides a rationale for the features of the generic system model that is proposed. The second half draws on field work undertaken in the Manu Biosphere Reserve, Peru, to illustrate how the generic model can be applied to a particular case: that of family farm systems in the reserve.

The systems approach

The term ‘systems approach’ covers a number of distinct methods of enquiry (Troncale, 1985) that have in common that, in contrast to the traditional reductionist scientific method, they all try to understand situations by looking at the properties of wholes rather than breaking them down into their constituent parts. A system can be defined in the most general terms as an entity with certain properties that can be distinguished from its surrounding environment (Hall & Fagen, 1956). The entity interacts with its environment; and it consists of components which interact with each other. These interactions give rise to system properties, which can be described and investigated. The key point is that the ‘whole system’ has properties which make it more than the sum of its parts.

These general properties of systems were explored in detail by General Systems Theory, whose founders aimed to identify universal principles underlying scientific endeavor in different fields. They saw systems thinking as a way of counteracting the tendency towards fragmentation into increasingly specialized and self-contained scientific disciplines. In short, they saw the systems approach as a means towards the unification of science (von Bertalanffy, 1956, 1968; Boulding, 1956; see Midgley, 2003, for a review).

This is possible, in principle, since any entity (consisting of two or more components) can be described as a system: an atom, a clock, the universe, a single plant or animal cell, an ant colony, a business corporation, a city transport network, a human family, a garden, or a language. However, it soon became clear that, for systems thinking to be useful, it was necessary to distinguish between different classes of systems. Otherwise the systems approach was in danger of remaining no more than a woolly-minded expression of holistic philosophy (Marchal, 1975; Troncale, 1985). The most well-known attempt to do this is Boulding's seminal paper on systems theory "The Skeleton of Science" (Boulding, 1956), which describes a range of systems classes, ordered according to presumed complexity, with simple mechanical systems, such as a clock, near the top of the list, and social systems near the bottom. It is notable that neither social-ecological nor even ecological systems appear in Boulding's list. This omission reflects the general lack of interest in ecology at the time (Midgley, 2003).

The term social-ecological system (SES) is increasingly, although still not widely used. Interest in the term has grown with the realization that "the ecosystems that many want to protect are embedded in different levels of social organization" (Brondizio et al., 2009). Thus human societies and institutions are central in the study and management of ecological systems. Its usage in this sense is particularly associated with the work of the Stockholm Resilience Centre (http://www.stockholmresilience.org; see for example Berkes and Folke, 1998; Walker et al., 2002) and its journal *Ecology and Society* (http://www.ecologyandsociety.org). At the same time, the concept of the social-ecological system has been taken up by earth systems analysis, in acknowledgement of the fact that we are now living in an era, the Anthropocene (Crutzten, 2002), where humans have a determining influence of patterns of global change (Schellnhuber et al., 2004). In short, there are good reasons to suppose that this is a concept whose time has come, since it responds to the need for an integrated, coordinated response to crises facing humanity at multiple scales from the local to the global level.

Definition of a social-ecological system

As a working definition, a social-ecological system can be considered as a system composed of organized assemblages of humans and non-human life forms in a spatially determined geophysical setting.

Taking the example of the family farms to be discussed in the second half of this paper, the humans are the people living on the farm, organized as a family. Non-human life forms are populations of plants and animals, including some domesticated species introduced by people, and others which are naturalized or native to the area. In broad terms, the organization of the farm is determined by the farmer(s), but the plants and animals also organize themselves in ways which may be accepted, resisted or taken advantage of by the farmers to different degrees, or simply ignored. Spatially, the system boundaries in this case are those of the farm, which are determined by law or by custom. Geophysical elements include water and soils, which also undergo organizational processes that are only partially under the control of the farmers.

This is a description of a situation of interest. By calling it a 'system', those with an interest in the situation signal their intention to consider how all these elements interact together, and with what goes on in the surrounding environment, to give rise to outcomes on the farm. However, just giving it the name 'system' does not make this possible. Agreement is necessary among those involved on procedures to set about analyzing the system. This presupposes a basic level of agreement on the nature of what is to be analyzed. This is why definitions are important.

Becker (forthcoming) suggests that the term 'social-ecological system' is currently used in scientific discourse as a 'boundary object', that is, a loosely or generally defined concept that serves as a tool for communication and cooperation among different scientific disciplines. (The term 'boundary' here refers to the borders between scientific disciplines.) To operationalize the concept, a further step has to be taken. The SES has to be defined as an 'epistemic object', by which Becker means simply an object that is amenable to study by organized scientific methods. He takes it as self-evident that different branches of science would define a SES as an epistemic object in different ways. However in this paper we consider social-ecological systems from a management perspective: as arenas of practice rather than as discipline-specific objects of study. The aim is to describe a generic decision making model that could be used by people from a range of applied and theoretical disciplines working together to address social and environmental issues from a systems perspective.

The above definition of a social-ecological system differs from other approaches that define SES in terms of the relations between humans and nature, for example those of the Stockholm School (Berkes and Folke, 1998), the German Society of Human Ecology (Glaeser,1989; Glaeser & Teherani-Krönner, 1992; Teherani-Krönner, 1992; Steiner, 1993) and the Vienna School of Human Ecology (Knötig, 1976, 1979).

More formal definitions along these lines refer to linked social and ecological systems, for example to "ecological systems intricately linked with and affected by one or more social systems" (Anderies et al., 2004), and "integrated systems of ecosystems and human society with reciprocal feedback and interdependence" (Resilience Alliance, 2007).

However we will argue that, while such definitions have the merit of focusing attention squarely on human-nature relations which are at the heart of the problem, the key terms 'nature' and 'human society' are highly problematical as a starting point for systems analysis. Our working definition suggests an alternative approach by defining a social-ecological system without reference to these troublesome concepts.

If one considers a SES as being composed of linked social and ecological systems, to begin with, as Becker (forthcoming) notes, "a distinction must be made between nature and human society... [otherwise] the interaction between them is unthinkable." However, it is immediately clear from the description of the above situation of interest that this first step will be problematical. Where is the boundary between humans and nature located?

It may be possible to clearly demarcate 'nature' and 'society' in some instances, but these will be exceptions. In the majority of cases the boundary between nature and society will be blurred and impossible to define precisely. For example, it is well known that many landscapes that people consider to be 'natural' are in fact the product of human intervention, often over a period of hundreds or even thousands of years. Oliver Rackham, writing about the English countryside, notes that:

> *The landscape ranges from the almost wholly artificial ... to the almost wholly natural ... with many features it is still not possible to say where nature stops and human activity begins* (Rackham, 1986, xiii).

Furthermore he suggests that the entire British Isles 'belonged' to somebody as early as the Iron Age. Thus, the intermingling of the 'human' and the 'natural' was already underway.

From a theoretical standpoint, the division of a social ecological system into social and ecological subsystems is also problematic. To start with, our social-ecological world might be conceptualized in thorough-going holistic terms, as:

> *An intrinsically dynamic interrelated web of relations [with] no absolutely discrete entities and no absolute dividing lines between the living and non-living, the animate and the non-animate, or the human and nonhuman* (Eckersley, 1992, cited in Jermier, 2008, 464).

However, systems analysis aims to go beyond this kind of intuitive appreciation and to provide a rational understanding of pervasive patterns that are encountered in this 'web of relations'. This is only possible if we are able to distinguish 'discrete entities' that make up the system and, normally, also to identify subsystems that group together these system components. This analytical procedure is what distinguishes the systemic approach from a holistic one (Bunge, 1977). It is true that the investigation of these pervasive patterns will rely heavily on inputs from existing knowledge systems, which are of course grouped conventionally into natural and social sciences. However, 'nature' and 'society' are not groupings of discrete entities but essentially ideological concepts (Latour, 2004; Norgaard, 1996) — or, from a less critical perspective, can be considered 'boundary objects' in the sense explained above. As such they are too vague to be of much practical use for systems research.

Thus it comes as no surprise that the question of how 'social' and 'ecological' systems stand in relation to each other is also problematic. As Walker et al. (2006) note:

> *Prior work suggests that social-ecological systems ... are neither humans embedded in an ecological system nor ecosystems embedded in human systems but rather a different thing altogether. Although social and ecological components are identifiable, they cannot easily be parsed for analytical or practical purposes.*

This paper aims to provide an alternative approach to 'parsing' social-ecological systems (that is, identifying subsystems and the relations between them), which is both plausible and robust enough to be applicable across a wide range of situations where people from different disciplines are working together.

It goes without saying that the generic system model proposed here is not the only way to operationalize the concept of a SES, and it is appropriate to indicate at this stage the approach to be taken. The reference to 'organized' human and non-human life forms in the working definition raises the question 'organized for what?' and draws attention to the fact that living systems are generally considered as purposeful entities (cf. von Bertalanffy, 1956; Hall & Fagen, 1956; Miller, 1965, 216; Lazlo, 1972, 105). In fact the purpose of a living system can be conceptualized in two ways. Particularly in the study of social systems, the question arises to what extent the system components should be considered as autonomous agents; this relates to the perennial debate between structure and agency in the social sciences. A functionalist approach places emphasis on the contribution of system components to overall system goals. An agent-based approach investigates how the properties of the system arise from the interaction of embedded system components, striving to achieve their own goals.

Without going further into this debate (see Sawyer (2005) for a detailed review from a social science perspective) it can simply be noted here that these two approaches give rise to two further definitions of a social-ecological system. From a functionalist perspective a social-ecological system is a complex system whose goal is the well-being of a community of humans and non-human life forms and their geophysical environment. From an agent-based perspective a social-ecological system is seen as a complex system in a determined geographical location whose properties emerge from the interplay of goal-directed human and non-human agents. In reality of course the emergent properties of the system emerge from the interplay of 'top-down' and 'bottom-up' causation, as well as interactions between the system and its environment.

In what follows, the approach taken is essentially a functionalist one. That is, from a management perspective, the aim is to understand the functioning of the system as the basis for interventions oriented towards the achievement of 'whole system goals'. The following section defines the field of interest of SES in general terms, by locating their places within the wider systems landscape. This provides the basis for a (functionalist) generic system model for a SES that overcomes some of the problems arising from the initial conceptualization of linked social and ecological systems. The case study from the Manu Biosphere Reserve in Peru is used to show how a real system can be parsed in practice and to outline some possible applications of the generic system model.

Social-ecological systems in the wider systems landscape

The field of interest of SES as a class of system can be appreciated by locating them within typologies of system classes. Here we will draw on two such typologies, similar in scope to Boulding's skeleton of science, put forward by two leading systems thinkers from other fields. M.A.K. Halliday is the founder of Systemic Functional Linguistics (M.A.K. Halliday, 1994). Peter Checkland is the originator of Soft Systems Methodology (SSM) (Checkland, 1984 [1981]; see (Checkland, 2000) for a historical review). The two authors are near contemporaries but their systems typologies have a different significance within their respective careers. Halliday's is a late work, the result of reflection on a lifetime's activity in the field of linguistics; Checkland's formed the starting point for the development of a new and influential systems methodology, which has been widely applied to management problems, particularly in business and local government. However, to our knowledge, neither author has explored the implications of their system typologies for work in other fields.

The relevance of linguistics and business management to SES may not be immediately obvious. Nevertheless, the concerns of linguistics and SES coincide in one key respect: they both focus on the relation between humans and their environment: on how humans interpret, live in and change their world. Moreover, our principal reason for studying SES is, surely, to learn how to manage them better. To do this, we need not only to learn more about SES, we also need to learn how to become better managers.

Orders of system complexity

Halliday's starting point is to postulate two realms of human experience: matter and meaning. A key term in his work is *semiotic* which means 'having to do with meaning' (M.A.K. Halliday, 1978). He states, "whatever is not matter, is meaning" (M.A.K. Halliday, 2005, 78); these are "two distinct phenomenal realms, each an essential component of the human condition, and neither reducible to the other" (M.A.K. Halliday, 2005, 65). This provides the basis for his classification of systems, which like Boulding he describes as a hierarchy of increasing complexity, in the following terms:

> *A physical system is just that: a physical system. What is systematized is matter itself, and the processes in which the system is realized are also material. But a biological system is more complex: it is both biological and physical — it is matter with the added component of life; and a social system is more complex still: it is physical, and biological, with the added component of social order, or value. ... A semiotic system is still one step further in complexity: it is physical, and biological, and social —and also semiotic: what is being systematized is meaning. In evolutionary terms, it is a system of the fourth order of complexity* (M.A.K. Halliday 2005, 68).

Halliday proposes this system of systems to clarify what is involved in the study of language. He explains why language, as an example of a semiotic system, contains all four levels of organization as follows:

> *First, it is transmitted physically, by sound waves traveling through the air; secondly, it is produced and received biologically, by the human brain and its associated organs of speech and hearing; thirdly it is exchanged socially, in contexts set up and defined by the social structure; and fourthly it is organized semiotically as a system of meanings* (M.A.K. Halliday, 2006, 68).

Thus language pertains to all four orders of complexity. In fact, nothing we perceive is pure matter or pure meaning but different classes of phenomena in our world of experience can be distinguished according to the relative amounts of matter and meaning they contain. Halliday suggests that even physical systems are also systems of meaning in some sense; maybe, he says, "all organization, all departure from a purely random state, is a form of meaning" (M.A.K. Halliday 2006, 68). Other systems thinkers, such as Bateson (1970), Laszlo (1972), Enmerche et al. (1997) and Capra (2007), have made a similar point, often expressed in terms of the immanence of mind in matter. However we prefer Halliday's term 'meaning' rather than 'mind'. As will become clear, this term has greater resonance with Checkland's ideas and provides for greater precision in the formulation of our own generic system model.

A Systems Map of the Universe

Checkland's work is focused on management systems. His starting point is to ask: what is the appropriate method of inquiry? Broadly speaking he maintains that traditional scientific methods are appropriate for the inquiry into phenomena which can be quantified ('hard systems'). The systems approach — and in particular his own brand of systems thinking, Soft Systems Methodology — responds to the need for a similarly standard method for the investigation of qualitative phenomena.

To take an example from the industrial sector where Checkland first worked, the problem of how to manufacture a car most efficiently can be addressed through quantitative analysis. The problem "shall I buy a new car?" *also* involves emotional and value aspects which cannot be quantified. It is in this class of problems, viewed as systems, that Checkland is principally interested. He calls them 'human activity systems'.

The fact that human activity systems describe qualitative phenomena gives them characteristics which are very different from what Checkland terms 'natural systems'. Most importantly, there is no automatic correspondence between a particular human activity system and a system in the real world. This conclusion, which as Checkland stresses, is a practical result of his research rather than philosophical conviction (Checkland 1984 [1981], 247, 278) can be summarized as follows. For any given human activity system, while the underlying situation of interest is (of course) real, the systemic description is constructed by systems practitioners, with the aim of giving meaning to the situation. The meaning you attribute to a situation depends on your perspective. In the systems description, it is shown by where you set the boundaries of the system, to include some elements and exclude others from consideration.

Checkland's insistence on meaning as a defining property distinguishing soft from hard science resonates with Halliday's distinction between matter and meaning. The central position of meaning in each system is the common ground that links these two, otherwise very different approaches. Both authors are careful to distinguish *meaning* which has an irreducible qualitative component, from *information*, which is purely quantitative and can be measured in bits (Shannon & Weaver, 1949).

Like Halliday, Checkland feels the need to situate his own systems class of interest within a broader, universal, systems landscape. But while Halliday's primary interest as a linguist is in the emergence of meaning as a phenomenon of the natural world, Checkland's focus on management relates more to the purely 'human' realm. In fact, his Soft Systems Methodology has its roots in Operational Research (OR), a systems approach first developed in the Second World War to facilitate the control of complex military operations, which evolved into what it now regarded as a branch of management science (The OR Society, http://www.orsoc.org.uk). Checkland's typology of systems puts emphasis on the distinction between what he calls natural and human systems (Checkland 1984 [1981], 119-20).

Checkland identifies four classes of knowable system. (Following Boulding, he also allows for the existence of unknowable 'transcendental' systems.) The class of natural systems includes the broad range of systems studied by traditional science: physical, chemical, and biological systems, as well as those aspects of social systems which arise without human intentionality. Other systems are denominated human systems and these are divided into a further three classes, resulting in a total of four classes:

1. Natural systems
2. Human designed systems (e.g. a telephone system)
3. Abstract systems (systems of ideas)
4. Human activity systems (purposeful systems: decision making systems and 'ways of doing things')

With regard to social systems, Checkland maintains that everyday social life should be considered as belonging to the natural system class. This corresponds to Lazlo's definition of a natural system as "any system which does not owe its existence to conscious human planning and execution ... including man himself and many of the multiperson systems in which he participates" (Lazlo, 1972, 23). Checkland further designates organized, purposeful human activities as a separate class of system: the human activity system (Checkland 1984 [1981], 119-20). It is beyond debate that humans exist both within and outside of the natural world. Checkland's framework provides the starting point for exploring this paradox of the human condition in systems terms.

Checkland presents his four classes as a 'systems map of the Universe' suggesting that all knowable systems must belong to one of the four classes or be a combination of more than one of them (Checkland 1984[1981]).

The scope of social-ecological systems

Halliday's four orders of complexity can be interpreted as an evolutionary account of the development of systems in the world. Thus, social-ecological systems are a real historical phenomenon, whose emergence coincides with that of human society; just as ecosystems could be said to date back to the origins of life on earth. The emergence of each new order of system complexity gives rise to a new class of system that fulfils the new potential for linkages, interaction and feedback within and between levels. Nevertheless in the study of systems one can choose to focus on linkages within one or more levels and, for the most part, ignore the linkages to other levels outside the area of interest. At the same time, of course, there should be a commitment to engage with the existing body of knowledge about the system level or levels selected for study. The situation is analogous to the way traditional branches of knowledge such as physics, chemistry, biology or sociology develop in relative isolation from each other. It is worth noting that, from a systems perspective, all these different branches of knowledge, which are also historical phenomena (cf. Enmerche et al., 1997, 145), can be considered components of a wider 'world system' of human knowledge, which has its own dynamic, and interacts in multiple ways with other phenomena in the world (cf. Popper, 1972).

In this sense, in terms of Halliday's model, the term social-ecological system simply describes a scope of interest — both of individual researchers and of a (still relatively new) branch of knowledge. It indicates the intention to consider social, biological and physical levels together. It does not — or should not — imply the imposition of any *a priori* structure on the situation. In a general sense, the terms social and ecological (ecological = biological + physical) describe levels of organization of the system. But there is no reason to start out by labeling them as subsystems except perhaps to facilitate the portioning out of work to specialists from different disciplines. But if the choice of SES as the focus of interest is motivated by a desire to break down boundaries between academic disciplines, the division into social and ecological subsystems might well be counter-productive.

This very broad scope of interest is a challenge which clearly presents difficulties for the development of an integrated systemic approach. But reference to Checkland's typology shows that our description is still not complete. Humans not only exist in social-ecological systems; they also manage them. Our management of the system will be influenced by our ideas about the system and our wider worldview. Moreover it will rely, to a greater or lesser extent on the application of technology; our choice of technology and how we apply it help determine the future of the system. Thus our conceptualization of a given SES, to be complete, should *also* include the corresponding management system or systems, as human activity systems, *plus* the systems of ideas which underpin the approach to management, *and* the human designed systems operating within the system, such as irrigation, power generation or waste disposal systems.

The inclusion of human activity systems and abstract systems within SES makes it clear — if it wasn't already — that our scope of interest also extends to Halliday's fourth order of complexity: that of meaning. Thus to describe a social-ecological system we need to consider all four orders of complexity identified by Halliday and all four system classes described by Checkland.

A generic system model

Figure 1a presents a generic system model of a SES as consisting of all four of Checkland's systems classes. It should be immediately clear that the model also covers all four of Halliday's orders of system complexity; this is shown in Figure 1b. (Figures 1a and 1b present a 'plan' and 'cross sectional' view of the model respectively. By mentally combining them one can obtain a 'three dimensional' view of the model and its relation to the two system typologies.)

In our generic model, we have changed some of the titles of the systems in Checkland's universe to make the correspondence to SES clearer, but without altering the underlying conceptions drawn from his work. Thus the four basic subsystems of a SES are:

1. The natural subsystem (N). The designation follows Checkland's terminology. It includes the natural ele-

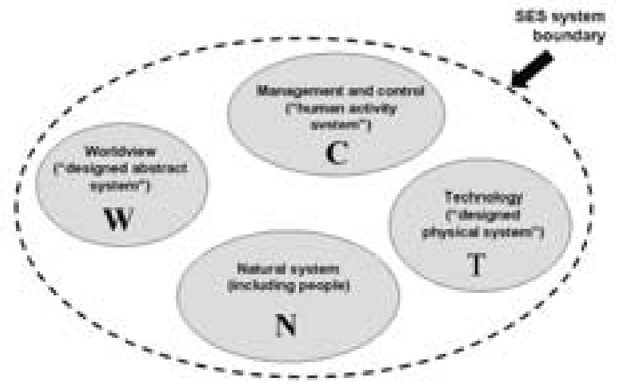

Figure 1a. Generic model of a social-ecological system.
Systems diagram after Checkland (1984 [1981])

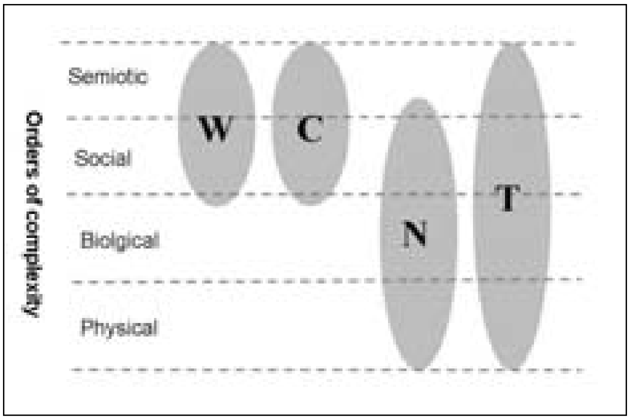

Figure 1b. Orders of complexity covered by subsystems in the generic model

ments and processes that make up the system, including humans in their daily interactions with their biogeophysical environment and with each other. In this sense it includes humans as 'part of nature' and extends across social, biological and physical orders of complexity as shown in Figure 1b.

2. The control / management subsystem (instead of human activity) (C). A possible alternative designation would be 'institutional subsystem'. This represents humans 'outside nature' as engaged in organized, purposeful activity to mould their biogeophysical and social environments. Here the principal orders of complexity involved are the systems of meaning that orient these interventions and the social systems that implement them.
3. The worldview subsystem (instead of abstract) (W). Checkland places great stress on the importance of Weltanschauung or worldview within his specification of human activity systems (Checkland 1984 [1981], 215ff). We underline its importance by giving it the status of a separate subsystem in our system description, roughly corresponding to the 'abstract systems' in his map of the systems universe. W includes the knowledge, belief and value systems that underpin and guide human activity. These are of course systems of meaning in Halliday's terminology, but always embedded in social systems such as academic societies and churches, as indicated in Figure 1b.
4. The technology subsystem (instead of human-designed) (T). Machine technology impacts directly on N across its three orders of complexity; information technology impacts directly on the meaning content of C and W. Moreover, as an expression of purposeful human activity, T embodies systems of meaning: human values and knowledge of the world. Thus it is shown as covering all four orders of complexity in Figure 1b.

This conceptual framework provides the basis for an integrated model that explicitly acknowledges the distinctions made in both Halliday's and Checkland's typologies of systems.

Application of the model

This model or any other model may be used to describe SES in general terms, as an approximate picture of an aspect of reality. It can be used as a heuristic tool for exploring the systemic properties of our social-ecological world. In this sense our model complements other general conceptual frameworks, such as the adaptive cycle, which focuses on system dynamics (Holling & Gunderson, 2002) or the 'linked system' model, which focuses of human-nature interactions (Berkes & Folke, 1998, Glaser et al., under review).

However, our generic system model is intended primarily as an analytical tool that can be used across a range of situations of interest to describe *a system* in the sense that this is generally understood by systems theory: as a bounded entity with certain properties and relations to its environment. Applying a model in this way involves an act of interpretation, which changes its ontological status. As Halliday notes, any *particular* system will always be constructed, or as he says 'built up' in some sense:

> *The property of 'being systemic' is a feature of the phenomena themselves. But the specific ... systems that we build up to represent and understand the phenomena are shaped by our point of view, our technical resources and our skills* (M.A.K. Halliday, pers. comm., 18 Oct 2008).

Thus, what Checkland says about the need to construct the description of any given human activity system turns out to be applicable to all classes of system. It is reasonable to assume that the difficulties involved in building up a system, as a bounded entity, will be proportional in a general sense to its complexity. Since SES are inherently complex, as discussed above, it is likely they will present exceptional difficulties to the system builder. The following section discusses some potential difficulties in more detail.

Determining system boundaries

What distinguishes a general discussion of systemic properties from work on a particular system is the fact that, in the latter case, the system boundaries are determined. So describing a system is essentially a boundary setting exercise, which the preceding discussion presents as an act of *construction*. Its might be suggested that the correct procedure is to *identify* the natural system boundaries, for example ecosystem boundaries, corresponding to our situation of interest. However, attempts to do so run into methodological difficulties, arising only in part from the absence of fit between the geographical boundaries of social and ecological systems (Roe, 1996; Folke et al., 1998; Cash et al., 2006). In fact, natural system boundaries in this sense do not exist.

We can illustrate this point by referring to the Manu Biosphere Reserve in Peru; this also sets the scene for the more detailed case study described later on. Of course, the act of referring to the area in this way already implies a boundary judgment. It declares a particular interest in the properties of the area that led it to be declared a biosphere reserve, especially the exceptional biodiversity that it contains. From an alternative perspective, it could described it as the area currently unavailable for oil and gas exploration bounded by Lots 56, 76, 88 and 110 (OSINERGMIN [Peruvian Ministry of Energy and Mines], online, accessed 21 April 2010). From an ecological perspective, the area has been zoned in numerous ways. At a global scale, the area is located in the 'southwest Andes moist forest ecoregion' within the global classification devised by the Worldwide Fund for Nature (WildWorld Ecosystem Profile, online, accessed 23 Aug 2010). It is also part of the 'Tropical Andes hotspot', within Conservation International's classification of critical areas for global biodiversity conservation (online, accessed 23 Aug 2010). Internally, the reserve can be divided into life zones using Holdridge's (1947) classification, based on physical characteristics such as latitude and rainfall; or topologically, into watersheds. Two separate maps can be drawn to divide the area by soil types, one using the classification of soil scientists, the other showing agronomists' classifications which indicate the suitability of soils for different types of land use (the latter were used to zone the family farm systems shown in Figure 3). Biologically, the area can be divided to show the ranges of key species of interest; ecologically into forest types, or to show the degree of human disturbance or threats to biodiversity; linguistically to show the territorial boundaries of the different ethno-linguistic groups in the reserve, and so on. It goes without saying that few, if any, of these boundaries coincide with any of the others.

This situation is typical; however our difficulties are only just beginning. We have not yet begun to consider the boundaries of the management and worldview subsystems of our model. These will relate, for example, to institutional and stakeholder participation in management (who is inside and outside the management system), and the conceptual basis for management (which concepts are inside and outside the worldview subsystem).

The conclusion is unavoidable: it is futile to attempt to identify the natural boundaries of a social-ecological system, in view of both the practical and the conceptual difficulties involved. The boundaries of any given SES must be determined by those with an interest in the system, according to criteria defined by them.

This point is of more than theoretical interest. How one sets the boundaries of a system will affect the future of the system. It follows that the description of a particular SES, rather than simply an act of interpretation, can more accurately be described as an act of intervention. This applies whether the system is defined for management or research purposes, since research itself can be understood as a class of intervention (Midgley, 2000), or indeed for any other purpose. A SES cannot be separated from the act of intervention that gives rise to its description.

This being the case, it would seem to make sense to recognize this explicitly by setting the boundaries of an SES to match those of the corresponding management system. However, although this simplifies the task, it is still unlikely that everyone involved will agree on where these boundaries should be set. People will disagree about the geographical administrative boundaries, on who should be involved in management, and about the goals and scope of management activities. In reality, boundary setting is nearly always a process of negotiation. The fate of the system may well hang on the outcome of these negotiations (Blackmore & Ison, 2007).

The process of giving meaning to the situation, by describing it as a system, thus provides normative as well as factual knowledge (Laszlo, 1972, 120). Meaning is "not limited to construing; [it] is also enacting" (M.A.K. Halliday, 2006, 70). We can acknowledge this by adopting an explicitly critical approach towards determining system boundaries, by asking boundary setting questions in two modes: *is* and *ought* (Ulrich, 2005). That is, we can ask: what are the boundaries of the system at present (in the multiple sense of the word boundary, as used in the preceding paragraphs); and what ought they to be?

However, this immediately raises further questions about power relations and participation in the management of the system. Who has the right to determine the system boundaries and who is excluded from the decision making process? This is also a boundary setting question. In this sense, a distinction can be made between two orders of boundary setting questions: first order questions, such as "what should be within the boundaries of the system?" and second order questions, such as "who should decide what is within the boundaries of the system?" (Midgley, 2000). Similar second order questions need to be asked about the worldview that underpins the system description: Which worldview should we adopt as the basis of our system description? Whose meaning counts? These approaches derived from Critical Systems Thinking (see Midgley, 2000) provide an explicitly political component to systems thinking, which is essential if the societal relevance of SES models is to be taken seriously.

This boundary setting process will lead to a system description that is considerably richer than if only processes occurring in the natural system had been considered. It is worth noting here that the inclusion of the three specifically human subsystems (C, W, and T) is conceptualized here not as a process of adding missing bits to the natural subsystem (N), but of stepping outside it. Figure 2 illustrates this. The description of any given aspect of the natural world (Figure 2a) as a system is itself a human construction; it represents the attempt to step outside a situation of interest to gain a view of the whole (Figure 2b). Nevertheless, such views view remain incomplete, not only because they are partial, but because "the knowledge of people inside an emergent structure affects the structure, and thus human knowledge becomes part of the system's relationships" (Trosper, 2005). Furthermore, this knowledge informs purposeful human activity for private ends or wider system management goals. Our generic system model is intended to facilitate the situation shown in Figure 2c; where one further step outside is taken to include this knowledge and these activities in the system description.

There is no reason for the process of 'stepping outside' to stop here and in theory an infinite expansion, involving multiple order boundary setting questions would be necessary to gain a complete view of the system. The fact that this is impossible in practice simply underscores the impossibility of ever gaining an objective view of the system as a whole. So, inevitably, the process ends up by the systems practitioners 'stepping back in', to build up the system of interest as part of the system from within; the participatory and critical aspects of the boundary setting process make this explicit.

Results of applying the generic system model

In the previous section we considered the process involved in applying the generic system model to construct a model of a particular social-ecological system of interest. While each model will be unique, it will naturally have much in common with others constructed following the same procedure. In this section we outline the principal structural and dynamic properties that can be expected in a model SES that is generated in the way suggested here.

Structural properties

Humans are present in all four subsystems. Three of the four subsystems are what Checkland calls 'human systems' and humans are also a driving force in the fourth subsystem (N). Thus the system as a whole can be considered as representing a purposeful human system; this corresponds to a focus on management, which is a human concern. And yet, of course, the system is full of non-human agents, all of them active within the system in pursuance of their own interests. This presents ethical, as well as methodological difficulties and gives rise to a 'second order' boundary setting question that has to be addressed and is specific to SES: to what extent can and should an attempt be made to give a voice to non-human agents in the process of constructing the system? The act of describing a social-ecological system seems inseparable from the notion of trusteeship.

The model system is cybernetic, in that it directs attention to the control and feedback mechanisms occurring between the four subsystems. These are functional components of the system. The inclusion of humans in all four subsystems highlights the multiple functions of humans in social-ecological systems. Any particular human individual is likely to be active to a greater or lesser extent within all four subsystems and in fact the role of people in SES could usefully be analyzed in these terms: for example with reference to individual access to and control of material resources (in N), access to technology (T), individual worldview and freedom to express it (W), and degree of autonomous decision-making capacity (C).

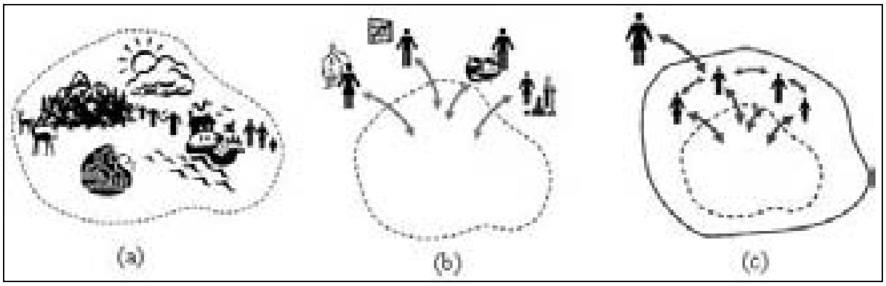

Figure 2. Different views of a social-ecological system.
After Ison, Blackmore & Morris (2006)
(a) A social-ecological situation of interest composed of humans and non-human species (plants and animals) acting and interacting with each other in a geophysical environment.
(b) People (such as a priest, a businessmen, a technician and a scientists) 'step outside' to get a view the whole situation, in order to better understand and manage it. But they are still part of the situation and in doing so, they change it.
(c) A systems practitioner steps outside to gain a more complete view. A systemic view includes the different perspectives that people have on the system; the actions they take to control it; and how ideas and actions interact to give rise to the emergent properties of the system.

Because the model shows functional system components, the four subsystems (N, C, W and T) will not correspond to the physical components of the system in any straightforward way. For example, beekeeping was a component of the farm systems described in more detail below. At the most basic level beekeeping could be considered simply as part of the technical specification of the system (in T). Nevertheless beekeeping was also present in W as the idea of beekeeping being a good thing, for various reasons; in C as the planning and management of beekeeping activities; and in N as the actual presence of beehive, bees and beekeeping activities on the farm, the production of honey for consumption and sale, and the effects of the bees on other components of the system though plant pollination, as well as unintended effects such as bee stings.

Thus system components can be considered as smaller scale structural subsystems (we use the term to distinguish them from the four functional subsystems in our model), possessing the same functional characteristics as those of the larger system. In the same manner, the environment (E) of any given SES will be formed by another, larger-scale SES, of which is it a component. Our social-ecological world can be visualized in this way as consisting of interacting nested SES that reproduce the same functional characteristics at different scales (cf. Holling, 2004).

Dynamic properties

Clearly, each of the four subsystems of a SES, and especially N, will be the site of complex 'internal' dynamic processes; the work of specialists in elucidating these will provide the foundations for exploring 'whole system' dynamics. In general terms, the dynamic processes occurring in a system can be investigated by looking at the network properties of a system, which can be conceptualized in terms of exchanges of matter and information (Janssen et al., 2006). Following Checkland and Halliday, we prefer 'meaning' to 'information', as a more precise description of what is exchanged, including qualitative as well as quantitative data. The structure of the generic model suggests a procedure for analyzing these exchanges. Thus, changes which are occurring (or managers want to promote) in a system can be analyzed as system-specific patterns of exchange of matter and meaning along different pathways within and between the functional system components, and between these components and the system environment (E).

With reference to Figure 1b, we suggest that in all cases full analysis of these exchanges in a model SES will show that they occur a 'horizontally' within layers, or 'vertically' within functional components. This conjecture directs attention to the need to analyze a statement like "an increase in environmental awareness will help protect biodiversity" more closely, in order to identify the 'paths of change' through the system which connect this change in W to the desired change in N. This analysis will reveal that the hypothesis in the statement is dependent on a number of assumptions and sub-hypotheses about the behavior of N, linkages to other system components (C and T), and the exchanges of matter and meaning which take place between the system and its environment. (Figure 7, discussed in the final section below, provides a more fully worked-out example.)

The above conjecture assigns a key role to linkages at the social level in system dynamics. This is a corollary of the structure of the model that includes human in all four subsystems. From Figure 1b it can be seen that exchanges of meaning will take place at the 'top', especially within and between W and C, while exchanges of matter take place at the 'bottom', especially between T and N. It is at the social level that matter and meaning interact with each other, providing pathways of communication between the four subsystems. For example, it is at this level that a conviction about the need to protect biodiversity in W is transformed into a decision to do so in C and actions taken by individuals that will impact on the matter content of N at biological and physical levels of the system. It is also at this level that information about the behavior of N (and T) is received and processed to provide inputs for the improvement of management systems and the advancement of knowledge. In all these processes, the technology subsystem, T, plays a key role by facilitating the exchange of matter (by machine technology) and meaning (by information technology) within and between systems.

Thus the structure of the model provides a framework for analyzing systems dynamics which, we suggest, is in accordance with an intuitive (and correct) understanding of how social-ecological change processes actually occur in the world.

An example: integrated family farm systems in the Manu Biosphere Reserve, Peru

This section further explores the application of the model as a heuristic tool by demonstrating how it can be used to build up a detailed system model of a particular set of real-world situations: the *Integrated Family Farm Systems* promoted by the project that the first author worked for in the Manu Biosphere Reserve in Peru (Figures 3, 4) (A.J. Halliday, 1998, 2001; A.J. Halliday and Bouroncle, 2000a, 2000b).

We are aware that by choosing this very small-scale example, we will not bring to light issues of power and institutional development which are key to understanding larger-scale SES. Our example is intended simply to illustrate how this system model can increase our understanding of a real-world situation.

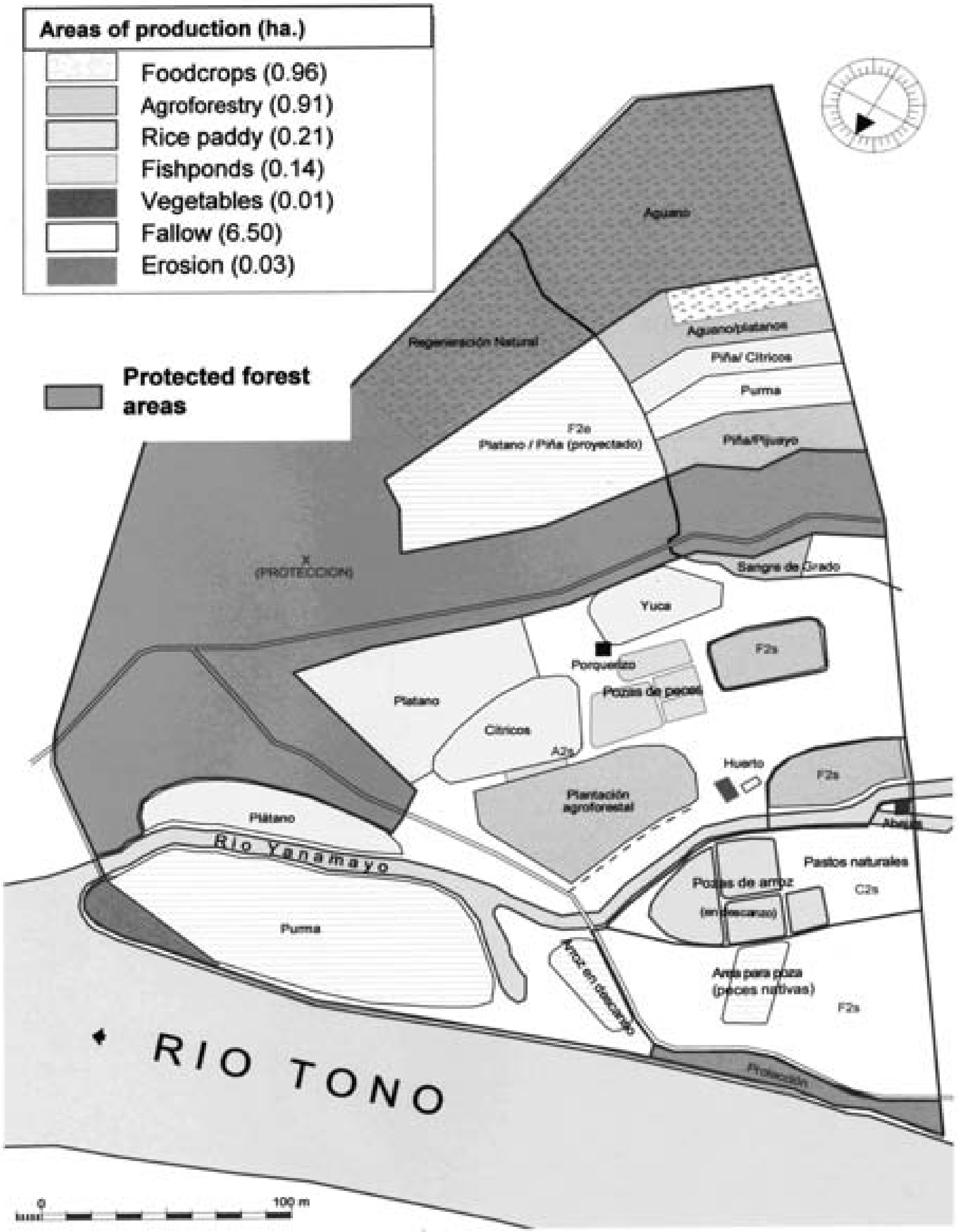

Figure 3. Integrated Family Farm: Amazon zone.
Source: Halliday, 2001.

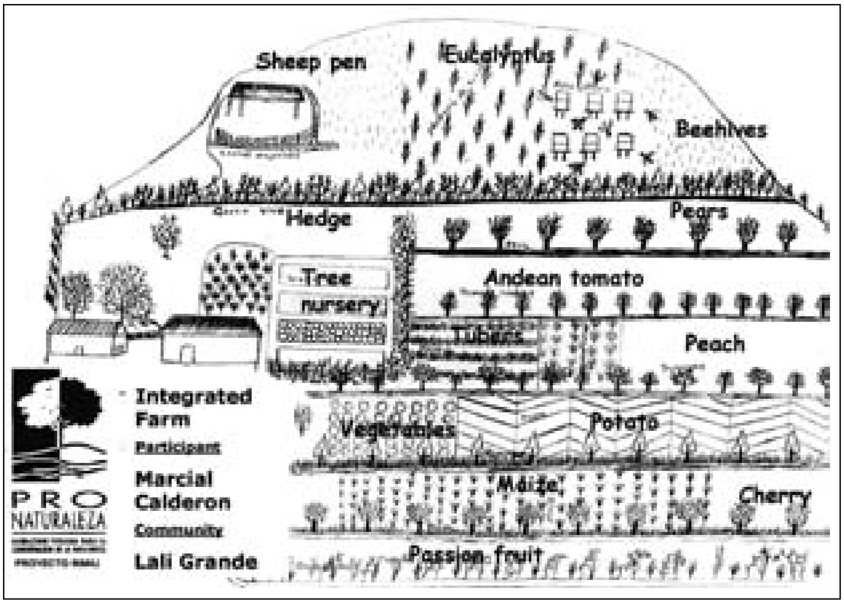

Figure 4. Integrated Family Farm — Andean zone.
Source: Halliday, 2001

The 'Manu Project' was undertaken between 1992-2000 by the Peruvian NGO, Pro Naturaleza (see www.pronatureleza.org for information about current work). The name *Sistema Integrado Productivo*, loosely translated in this paper as 'Integrated Family Farm System', was chosen by project field staff; at that time, none of the project staff (including the authors of this paper) had any particular knowledge of systems theory. Nevertheless, the name was chosen deliberately to indicate the intentions of the project team to promote a holistic vision of the family farm, in response to criticisms that previous activities undertaken with families had been too piece-meal, and to consider social and ecological aspects of the farm together. The term 'agroforestry system' was explicitly rejected by project staff as being too restrictive in this sense.

The other notably systemic element of the concept was the idea that the same system description could be applied to farms in very different geophysical and social environments. Thus Andean farm systems (Figure 4) were located on small plots (less that 0.5 ha) in a cold mountainous environment; Amazon systems (Figure 3) were much larger (up to 60 ha) and located in humid subtropical and tropical parts of the reserve. Doubts whether the same term could be used to describe situations which looked so different on the ground were part of the first author's initiation to the project. Project staff insisted that it could; the underlying concept and goals of the systems were the same, despite the differences in size and location, they said.

Figure 5 shows how this vision can be depicted using a systems diagram composed of the four subsystems in our model. The conceptual system boundary is the largest round-cornered rectangle, which contains the matter and meaning considered as part of the system, grouped into the four subsystems. The geographical boundary of the system is of course the land belonging to the family around the family home, as shown in Figures 3 and 4. Elements with-

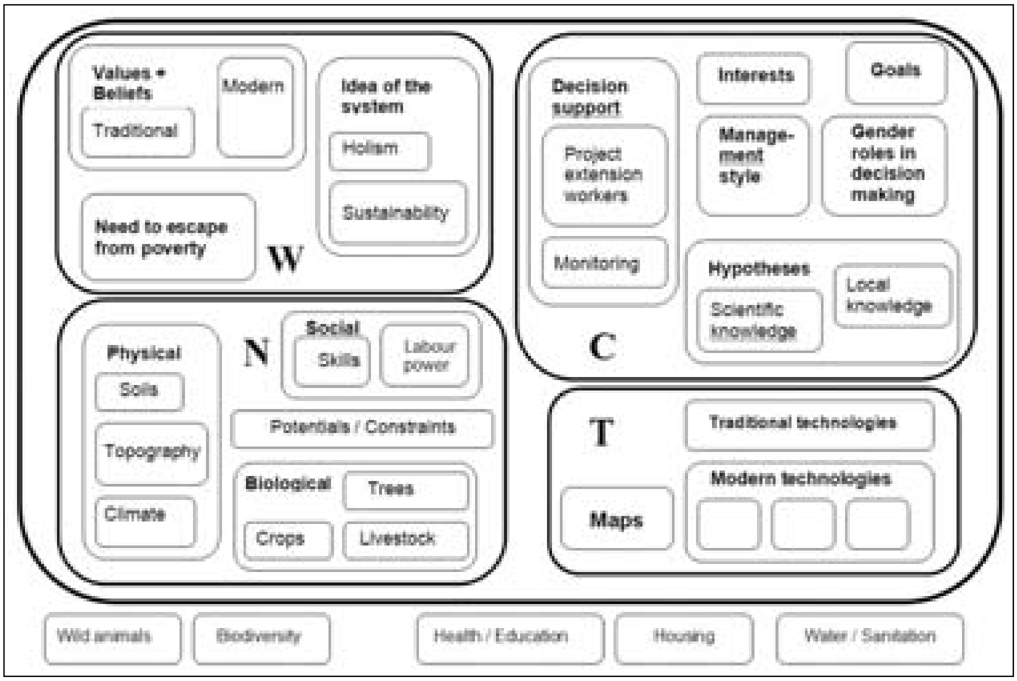

Figure 5. Systems diagrams of an Integrated Family Farm System

in the geographical boundary which were excluded from the system (for reasons discussed further below) are shown in Figure 5 by the row of small rectangles, outside the main rectangle, along the bottom of the diagram.

Considering the subsystems in turn, in W it can be seen that an important component of the system is the idea of the system itself — itself an abstract system in Checkland's terminology. The diagram highlights two further key ideas. Firstly the holistic vision of the system; the map of the farm (Figures 3, 4) communicates this vision, and is thus itself a functioning component of the system — it is meaning as enacting, and not just construing, in Halliday's terminology. The other key idea is sustainability, which as promoted by the project was most often expressed in terms of the well-being of people and their environment. But the idea of the system existed in and interacted with a wider 'worldview environment'. The daily struggle against poverty was possibly the principal motivating force among local people, but this was informed by an array of beliefs and values derived both from indigenous cosmology and modern ideas such as entrepreneurial capitalism and egalitarian socialism.

N includes the entire natural system of the farm and highlights elements of the physical, biological and social situation considered to be important components of the system vision. But it also indicates the importance given to a holistic vision of the entire natural system, which can be conceptualized (as shown in the diagram) as a set of potentials and constraints that need to inform decision making about the system.

C shows that even when the decision making unit is very simple — here just the farmer and his (or occasionally her) family — the structure of the decision making system is quite complex. Key elements here are the goals of the system and a set of hypotheses about the behavior of N that informed decisions. Examples of hypotheses were that soil and nutrient conservation maintained the productivity of biological components of the system, and that diversification of these components increased the overall resilience of the system. But the actual decisions taken were also influenced by more individual considerations, such as interests of different family members and their roles in the management process, and the style of management — whether, for example, it was motivated by risk avoidance or an experimental spirit.

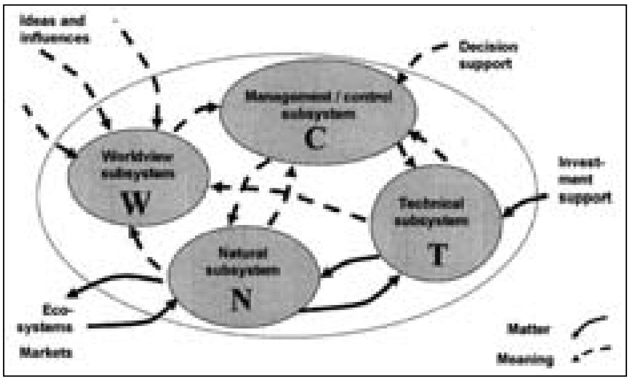

Figure 6. Framework for analysing the dynamics of an Integrated Family Farm System

Finally, T shows an outline of the technical specification of the system that can be represented as follows: firstly, traditional agricultural technologies, such as slash-and-burn agriculture (in the Amazon zone); secondly, novel technologies promoted by the project, and finally, the maps, which as mentioned above can be seen as a form of communications technology. Technologies were selected for promotion by the project in accordance with hypotheses about the behavior of the system in response to interventions; thus composting was expected to contribute to the conservation of soil nutrients, while bee-keeping was intended to contribute to system resilience through the diversification of livelihood strategies.

The systems diagram thus provides a fairly complete systemic view of an Integrated Family Farm System. It also shows what is left out of the system. The systems diagram does not show linkages between the farm system and the surrounding system environment, although these were obviously crucial to the functioning of the system. Some of these are shown in Figure 6 (which also provides a schematic overview of flows of matter and meaning within the system). For example, the success of bee-keeping depending on a set of social and technological linkages to the system environment that are summarized by the shorthand term 'access to markets'.

It is important to note that what is shown in Figure 5 is still an *abstract system*; that is, a depiction of the system concept developed by project staff. However it is informed, as the previous discussion makes clear, by the experience of applying the concept in practice on individual farms. From this abstract system, a systemic description of an individual farm could be built up by specifying the properties of each subsystem and its components: the individual worldviews of farmers and their families, management styles and practices, key features of the natural system (such as climate, vegetation and wild animals), and technological changes, both introduced by the project and other agencies and discovered by the farmers themselves, which combined to give rise to the unique emergent properties of each individual farm system.

Inputs to learning and decision making

The value of the proposed model will depend on the extent to which it provides useful inputs to learning and decision making. Since the conceptualization of the model postdates the case study being considered, this paper cannot report on a direct experience in this sense. Nor is there space for a full discussion of the wider issues involved, i.e. theories of learning and decision making, or the important question of how the model could be used promote participatory management of SES. It is intended to consider these issues in a forthcoming research paper. In this section, the model will be applied retrospectively to briefly outline its potential contribution to learning and relevance to decision making that actually took place during the implementation of the family farm systems. The kinds of inputs the model can provide include the following:

1) Boundary setting decisions: As can be seen from Figure 5, elements not included in the system description include wild fauna, health and education, housing, sanitation, and access to clean water. The exclusion of these elements from our system of interest was a conscious decision taken in response to operational considerations and (primarily) resource limitations. For example, the project would have liked to expand the system boundaries so as to be able to provide support for improved housing, water supplies and sanitation; but this was not allowed by the terms of the contract with the donor agency, and the farmers themselves had limited resources to improve these aspects without external support. This example illustrates how the model can be used not only to describe the system as it 'is', but also to initiate debate about how it 'ought to be'. On the other hand, the decision to exclude wild fauna from the system was taken deliberately, recognizing that the purpose of the farm systems was to enhance human livelihoods. However, a decision to develop farm ecotourism, an option several farmers were interested in, would have entailed resetting the system boundaries to bring wild animals 'inside'.

2) Stepping back to gain a systemic perspective. In fact, non-human agents (wild animals) showed no inclination to respect the system boundaries which had been drawn to exclude them, and domestic livestock was under constant threat from predation by jaguars, crocodiles and birds of prey. In most cases, these threats were met by improvements to T; for example sheep pens were built on stilts to prevent nocturnal attacks by jaguars. However, when on one occasion a marauding jaguar was shot by one of the farmers, this provoked a major row with the conservation agency that provided funding to the project. This problem can be understood in terms of interactions between different systems of interest. From the farmer's perspective, the jaguar represented a threat from the system environment (E). From the conservation agency perspective, the farm represented a malfunctioning structural component within a larger-scale system of interest (the buffer zone of the biosphere reserve). However both parties were understandably focused on very specific aspects of the situation. Project staff argued that more careful analysis would reveal that, in overall terms, the farm systems and other similar initiatives still made a positive contribution to larger-scale system goals (specifically in N), despite occasional unfortunate incidents.

3) Problem solving: This point of view could be appraised by drawing a systems map as in Figure 5 for the larger-scale system (the buffer zone) and then applying an integrative technique, such as the sign graph (a "soft systems" technique) shown in Figure 7 for the exploration of the problem situation, that is, focusing on dynamic linkages between populations of wild and domestic animals. Figure 7 depicts a conceptual model of flows of matter and meaning in a proposed solution to a problem that was identified in the farm systems: that of nutrient losses in slash-and-burn agriculture. This basic model could be the starting point for icon-based or agent-based modeling, which would require the definition the formal rules for linkages between system components that govern system behavior.

4) Measuring success: Clearly, verification in the field is necessary to determine whether interventions such as that shown in Figure 7 are having the desired effects. Our model provides a guide for the formulation of comprehensive indicator sets to define what we mean by success of the system intervention, and for the monitoring of progress in these terms: a minimum requirement would be one indicator for each of the four functional subsystems. A review of project indicators defined by the project team for the Integrated Family Farm Systems (Table 1) shows that all four subsystems were covered by the project logframe; although the list could be criticized for omitting key issues of soil fertility and farm

Table 1. Indicators of success from the Manu Project logframe.

Ind. No.	Indicator description	Sub-system
1.1	The participant implements the plan for his/her smallholding during the lifetime of the project	**C**
1.2	At least 75% of activities implemented by participants are in good condition during the lifetime of the project	**T**
1.3	Annual sales of products from project activities to the value of at least one Minimum Wage, from year 2 onwards	**N**
1.4	Incorporation in the diet or increased consumption of at least three foods of high nutritional value (proteins, fruit, vegetables and honey)	**N**
1.5	Incorporation in the farm of five additional native plant species by the end of the project	**N**
3.4	Recognition by men and women in the project area of the natural and cultural values of the Manu Biosphere Reserve	**W**

The first five indicators relate specifically to the Integrated Family Farm Systems, the final one to the results of environmental education work.
Source: Halliday 2001

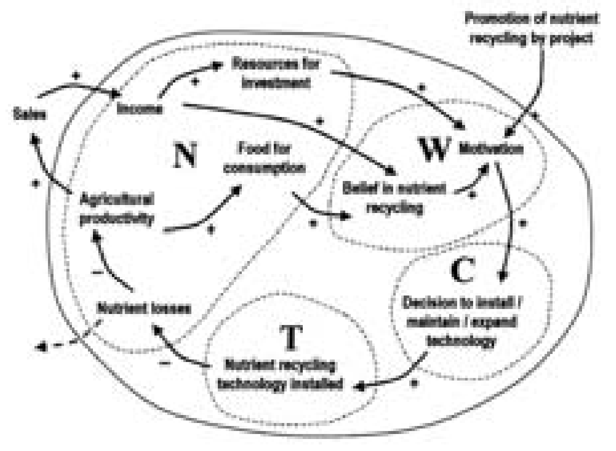

Figure 7. Sign graph showing interactions between subsystems in nutrient recycling technology
Arrows show causal linkages between variables. A plus sign indicates that an increase in the value of source variable leads to an increase in the target variable (e.g. more motivation lead to more decisions to install the technology). A negative sign indicates an inverse relationship (e.g. more nutrient recycling technology lead to fewer nutrient losses).

Benito Alata (Tono Bajo): "... first I had some conversations with the Engineer Percy and Miss Delfina, and then we made a series of drawings to define the area of the plot and to make better use of the nature's gifts, I mean pachamama's gifts, then later on we produced the definitive plan. We dug trial holes ... and determined the areas for protection, areas for reforestation and areas for permanent crops. Now I am developing my plot on the basis of this zoning plan and the results are very satisfactory, compared to what was achieved before. In the areas destined for reforestation I've planted "aguano" palms, and the trees are now 2.5 m high; in the areas zoned for permanent crops we continue to plant staple foods like banana, cassava and maize, and other crops as well. We've taken advantage of a water course to construct a fish pond, and this provides enough fish to feed the whole family. This is how I'm developing my plot together with my family."

Box 1. Integrated Family Farms in the Amazon — the experience of one participant. Source: Halliday 2001.

productivity explored in Figure 7. A compatible framework for the development of more comprehensive indicator sets is provided by Bossel's (2001) systems-based approach for deriving indicators of system viability (see below).

5) Telling the story of the system. Allen and Giampetro (2006) note that a narrative approach can make complex systems understandable and manageable. Their protocol for complex system narratives focuses attention on the interplay between changes in a 'material system' and changes in the 'idea of the system'. The structure of our generic model provides the basis for a similar approach, which could complement the more formal decision-making techniques outlined above. Box 1 is an extract from the story of the farm system shown in Figure 3.

From this rich narrative, in which all four subsystems can be identified, we would draw attention here to the references to 'nature' and 'pachamama' (Mother Earth); the latter is a core element of the Quechua worldview brought into the area by migrants from the Andean highlands. These references highlight the ideological content of the term 'nature' and show that nature's place in SES analysis is as a component of W (and not as a structural subsystem containing the 'natural' world). In fact, an understanding of the changing attitudes to nature in the area, under a variety of multicultural influences, is a key component of systemic knowledge about the biosphere reserve. The Project Director recalled that a key episode in this story had been the local screening of the BBC television series *Life on Earth*, which devoted a whole episode to Manu. People suddenly realized that the local biological diversity they had always taken for granted was regarded in other parts of the world as something very special. This awakened both local pride and a sense of potential business opportunities. It was, quite possibly, what stimulated the local government to add the words "world capital of biodiversity" to the road signs marking the provincial boundary. In terms of our system model, changes in T (television had only just arrived in the area) facilitated an exchange of meaning with the wider system environment (E) that had a (perceptible) impact on W.

6) Assessing sustainability: Table 1 illustrates the project's rudimentary, but nonetheless valid, conception of sustainability. The basic idea is that if all four subsystems are pursuing compatible goals and producing mutually reinforcing outcomes the system is likely to be operating sustainably. This concept can be further developed by adapting the procedures developed by Bossel for assessing system viability, using the criteria for the formulation of indicator sets shown in Table 2. The sustainability of the system can then be evaluated by applying the indicators to assess the viability of each subsystem plus the contribution of each subsystem to each aspect of whole system viability (see Bossel [2001] for more details and Fontalvo-Herazo et al. [2007] for a recent application). This operationalizes a multi-contextual definition of sustainability as "the changing ability of one or many [sub]systems to sustain the changing requirements of one or many systems over time" (Mandersen 2006, 96).

Longer-term sustainability will depend above all on the

Table 2. Criteria for defining indicators (sub)system viability.

- *Existence*. Is the (sub) system compatible with and able to exist in its environment?
- *Effectiveness*. Is it effective and efficient in its processes and operations?
- *Freedom of action*. Does it have the freedom and ability to respond to environmental variety?
- *Security*. Is it secure, safe, and stable despite a variable and unpredictable environment?
- *Adaptability*. Can it adapt to new challenges from its changing environment?
- *Coexistence*. Is it compatible with interacting systems?
- *Psychological needs*. Is it compatible with the psychological needs relevant to this system?

Indicators can be defined for each subsystem and to assess the contribution of the subsystems to overall system sustainability. Source: Bossel 2001

adaptability of each of the subsystems, separately and together, in response to changes of internal and external origin; many of which will be unforeseeable 'surprises' (Holling and Gunderson 2002). Scenario building is an appropriate systemic technique for envisaging future system behavior in response to different challenges and for evaluating possible future options (Walker et al. 2002, Carpenter et al. 2006). Our generic system model could provide a template for building alternative scenarios that would facilitate comparative appraisal.

Conclusion

The pervasive presence of humans in our generic SES model can serve as a metaphor for the situation of humanity as a whole vis-à-vis the 'natural' world in the era of the Anthropocene (Crutzen, 2002; Glaser et al. 2008). In this situation, systems thinking, and human knowledge in general, can make a key contribution to sustainability. As our account of the farm systems in Manu illustrates, any system model is itself an abstract system which, once established, augments the meaning content of the system. It becomes a component of W within the system and will affect the emergent properties of the system for better or for worse, and to a greater or lesser extent. This is why we cannot 'step outside' the system to *predict* future system sustainability. But we can become part of whole system sustainability by engaging in a process of critical systemic inquiry — or more accurately of *systemic intervention* (Midgley, 2000). In the broadest terms, this responds to an evolutionary imperative to develop the mental capacity of the global social-ecological system; in the sense that Bateson described *mind* as a "cybernetic system — the relevant total information-processing, trial-and-error completing unit [which is] immanent ... in the total interconnected social system and planetary ecology" (Bateson, 1970, 372-3). The aim of this paper has been to suggest a conceptual framework for systemic intervention that will facilitate collaborative contributions by specialists from different disciplines, and by non-academics, to enhance sustainability at scales that range from the local to the global level.

Acknowledgements

We would like to thank the two anonymous reviewers of the first draft of this paper for their detailed and helpful comments. Thanks are due to Milena Arias Schreiber, Michael Halliday, Polly Halliday and Dick Morris for their encouragement and feedback on previous versions of the paper. We benefited from stimulating discussions of ideas in the paper at meetings of the Social-Ecological Systems Analysis Group at Bremen University and of the Open University's Open Systems Research Group. The first author wishes to thank members of the project team of Pro Naturaleza's Manu Project for their friendship, insight, and stimulating collaboration, and acknowledge his debt to the Open University's post-graduate course *Environmental Decision Making — a Systems Approach*, which pointed the way towards the view of social-ecological systems outlined in this paper.

Endnotes

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