Linking Social and Ecological Systems: A Theoretical Perspective

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Social Ecological Structuration Model (SEStM)

The following framework was developed to evaluate the impacts of Costa Rica's payments for environmental services program on land use decisions and subsequent impacts on environmental services. To do this, an approach encompassing how structural factors (policy) influenced agents' (landowners) land use decision making was needed. Additionally, the framework had to incorporate how land use choices resulted in changes in the provision of environmental services. To date, no conceptual models adequately combine social and ecological theories that can account for micro-macro interactions necessary to address the processes that link the social and ecological systems (Lambin et al. 2003).

Elements of structuration theory from the social sciences (Giddens, 1984; Stones, 2005) and the theory of patch dynamics from the ecological sciences (Pickett and White, 1985; Wu and Loucks, 1995) were used to provide the heuristic framework for this study. Both social and ecological theories were used because the drivers of these systems function differently. For example, humans act with foresight, intent, reflexivity and can communicate these ideas into the future, which ecological systems do not (Walker et al., 2006). The theoretical frameworks mirror each other in that they together represent linked complex adaptive systems that are both the medium and outcome of interactions recursively organized across time and space.

Land Use and Land Cover

Land cover is the link between social and ecological systems and the key element for understanding the effect of policy and landowner livelihoods on the alteration of landscape patterns ultimately resulting in environmental services. In Figure 1, land use and land cover are identified as interaction element linking the social and ecological systems.

Structuration Theory

Structuration theory (Giddens, 1984; Stones, 2005) was used as the social theory for linking social and ecological systems. Structuration theory frames "the interaction of structure and agency across scales [that] must be the centerpiece of a dynamic understanding of people-environment interaction" (Scoones, 1999, p. 493).

Social Structuration

Structuration theory avoids both an overly objective structural approach and an exaggerated emphasis of subjectivist, agent-based approaches by focusing on their interaction (Stones, 2005). Human action is viewed as a continuous flow of conduct (Giddens, 1984). Structure is seen as both "the medium and outcome of the conduct it recursively organizes" (Giddens, 1984, p. 374). Structure enters into the constitution of the agent as a medium (internal structure) and from there into the practices that the agent produces as an outcome (external structure) (Stones, 2005). Structures that are the outcome of one period of conduct (actions, activities) become the medium for the next round of agents' conduct (Stones, 2005). Through recursive social conduct, structures influence the activity of individuals, who in turn, transform or reaffirm those same structures constantly producing and reproducing society (Kondrat, 2002).

Social Systems

Social systems (e.g. markets, governments) can be thought of as the patterns of social relations, or regularized social practices that stretch across time and space produced by the process of structuration. They are the "complex, entrenched, and powerful networks of relationships, behaviors, beliefs, interactions, rules, and resources" and are both temporally and spatially contingent (Kondrat, 2002, p. 446). Furthermore, they are integrated with other social systems hierarchically, across space and over time. Structures are considered to be both enabling and constraining of agents actions (Giddens, 1984).

Agency

Actors (e.g. landowners) are perceived to always have agency, to be able to "act otherwise," "make a difference" or otherwise intervene in the world (Giddens, 1984). This means that an actor has the power to make things change, and that whenever an actor acts; it is an assertion of that power. An actor's agency/capabilities in this regard also emanate from their ability to harness elements of structure and from the resources at their disposal (Sewell, 1992, Bebbington, 1999). Additionally, an actor's knowledge of and access to structural resources is likely to be geographically and historically contingent (Kondrat, 2002). Therefore agency should be seen on a continuum where all actors have some degree of agency, but no actor has completely unconstrained agency (Ritzer and Goodman, 2004).

Visualizing Social Structuration

To maintain the mutually constitutive formulation of the duality of structure and to heed cautions about using too simplistic and sequential pattern of causality (Stones, 2005, p. 20), we have adopted a cyclic model to present the four stages of structuration as a process visually similar to Gunderson and Holling's (2002) adaptive cycles.

The diagram presents the process of social structuration as a linked figure eight showing structure as both the medium and the outcome of actors' actions (Figure 1, left hand side). The arrows represent the flow of time, but also demonstrate the continual interaction of the structure and agency. This flow

of structuration is outlined with a hypothetical example of a landowner's (the actor) decision to change land use.

External Social Structure (1S). The first (though there is no correct order as the process is cyclic) aspect is external structures as conditions of action. This is the in situ "action horizon" structural context faced by the landowner at time 1 (Stones, 2005) and is diagramed as the top of the structure circle flowing into the landowner. External structures feature existing social systems such as the economic markets for goods and services, policies regulating trade, and the cultural norms related to marketing a product that are present at time one and currently exogenous to the landowner.

Internal structure (2S). External structures or social systems are diagramed to flow into the internal structures of landowner livelihood strategies. Internal structures would include landowner's knowledge of the resources at their disposal and how to apply those resources to accomplish their goals within the external structures. A landowner can look at price trends and supply and demand and consider their own costs and benefits and make a decision about whether to clear land or to plant a crop. They can also make use of their social assets and talk to their neighbors and extension agents to learn about what those individuals have to say about the market conditions.

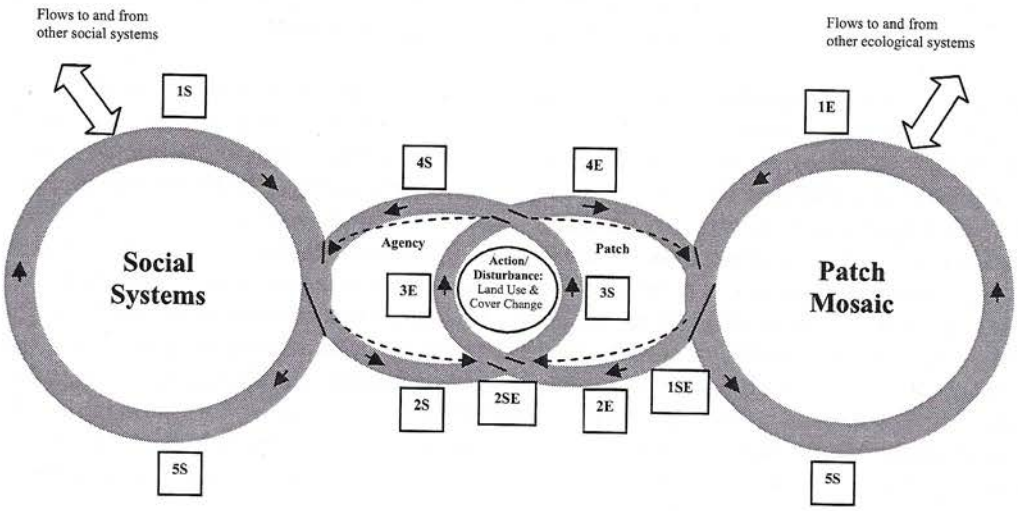
Unacknowledged Conditions (dashed line). The dashed line above the internal structures represents the unacknowledged conditions at time one (T1). This aspect of the model recognizes that knowledge of the external structures such as markets and policies is often incomplete, such as when landowners lack perfect information. Current investment in the same crop in another country is an example of a possible unacknowledged condition that might affect price at harvest time.

Action (3S). Action is considered active agency. This is the moment of structuration. This is where a landowner makes a decision applying their knowledge of the social systems and their capabilities and control over resources (e.g. financial assets for investment, physical assets such as a tractor) and takes an action that impacts land cover. For example, a landowner may clear a patch of forest or change a pasture into a crop. This is the "proximate" cause outlined in the land use change literature and is the result of the landowners action.

Outcomes (4S & 5S). There are multiple simultaneous outcomes of the action, internal and external outcomes. Results of the action may have pleased or frustrated the landowner changing or reinforcing internal structure as part of the whole structuration process (Stones, 2005). The planting of a crop may have been more difficult or costly than expected or the labor may have been unreliable. Each of these are lessons the landowner has learned and will consider in any subsequent land use decision and are part of their new internal structure. Additionally, the external social structure could be elaborated, reproduced or preserved by the outcome of landowner action. In the action of planting a crop, the landowner bought seeds from a local distributor and hired employees from local labor force, reinforcing the social systems that support the industry surrounding that crop.

Unintended Consequence (dashed line). The dashed line below the internal structures as outcomes represents the unintended consequences of the action that is both an input to external structures and internal structures for the next period. For example, landowner may not have expected that their own land use decision to influence migration patterns as part of future external structures, but their hiring of employees may have contributed to local demand for labor and immigration to the area.

Figure 1



Structuration of the Social System
1S: External structure as condition for action
1SE: Actor's knowledge of ecological systems
2S: Internal structure as capabilities of actor
2SE: Actors knowledge of the ecology of their land
3S: Action of land use change
4S: Internal structure as outcome of the action
5S: External structure as outcome of the action

Structuration of the Ecological System
1E: External patch mosaic as initial condition
2E: Internal patch structure as capabilities of patch
3E: Disturbance of patch from land use change
4E: Internal patch structure as outcome of the disturbance
5E: External patch mosaic as outcome of the disturbance

Theory of Patch Dynamics

Patch dynamics theory is used in this model to present the ecological "side" of the complex adaptive systems (Pickett and White, 1985). Hierarchical patch dynamics (Wu and David, 2002; Wu and Loucks, 1995) is incorporated because it focuses on both the structural and functional properties of patches across scales. Both patch dynamics and hierarchi-

cal patch dynamics have been used to explain ecological and social processes in urban ecosystems when combined with the Human Ecosystem Model (Grimm, Grove, Pickett, and Redman, 2000; Grove and Burch, 1997; Pickett et al., 1997).

Ecological Structuration

Modern ecological understanding of environments is that they are non-linear, hierarchically organized, have multiple equilibrium, and function as complex adaptive systems (Gunderson and Holling, 2002; Scoones, 1999). Quoting Levin (1999) (as cited in Gunderson and Holling 2002, p. 89), "The combined weight of multiple small scale processes can accumulate to help shape other patterns of interaction, and hence the structure and function of ecosystems, from small scales to the biosphere." For this model, we use patch dynamics as an ecological theoretical framework within a recursive structuration process that structures ecological relations across time and space.

Patches

Patches are defined as a discrete spatial pattern or homogeneous unit relative to an ecological system that can be characterized by their size, shape, content, structure, function or complexity (Wu and Loucks, 1995). Hierarchy theory was integrated with patch dynamics to extend the ability of the theory to address multi-scale issues with a "vertical" perspective (Wu and Loucks, 1995). In this way, it is possible to consider hierarchies of nested patch mosaics where at each level a patch is composed of its own dynamic patch mosaic (Wu and Loucks, 1995). This is an important feature for use in this model because it recognizes the internal structure of an individual patch at lower levels. As with the internal structure of the actors in social structuration where landowners have varied knowledge and resources under their control, the individual patch will have its own unique heterogeneity, function, and relationship to the external patch mosaic.

Patch Dynamics

Patch dynamics emphasizes change and heterogeneity which are driven by natural variation and disturbance. Disturbances are discrete events that change patches and are classified by size, shape, frequency, and intensity. Disturbances can be either naturally occurring such as a lightning fire or due to human intervention such as land use change. Multiple patches form a landscape or patch mosaic. A dynamic patch mosaic refers to the change in the mosaic over time including changes in structure and function (Pickett et al., 1997). We can therefore view the patch mosaic as both the medium and the outcome of recursive disturbances at the patch level. Disturbance corresponds to the actors' actions in structuration theory. Action and disturbance become synonymous when the action is one of land use change.

Visualizing Ecological Structuration

Figure 1 (right hand side) presents the process of ecological structuration as a linked figure eight. The flow is meant to show the progress of time, but also to demonstrate the continual interaction of the patch with the patch mosaic. It is suggested that this model represents the hierarchical patch dynamics model in terms of flows; "Thus, the dynamics of ecological systems are composed of the dynamics and interactions of constituent patches on different scales; this is an emergent property in that it is not simply the sum of the individual patch dynamics." (Wu and Loucks, 1995, p. 451).

External Structure (1E). The first (though there is no correct order as the process is cyclic) aspect is the patch mosaic as the existing condition at time one (external structure) and is diagramed as the top of the patch mosaic circle and flowing into the internal patch structure. This is the initial condition or template "for the subsequent structural development and dynamic interactions of the system" (White and Brown, 2005, p. 31). A landscape composed of a patch mosaic of forest and agricultural lands with all the attendant ecological functions and processes such as soil erosion rates into streams is an example of the external structure at time one.

Internal Patch Structure (2E). The internal structure of the patch prior to a disturbance is included to represent the internal patch mosaic of any given patch within the hierarchical patch mosaic at time1. The patch in this case might be a forest that a landowner is considering clearing to plant crops. The patch of forest has certain characteristics of its own such as riparian areas and fallen tree gaps signifying its own internal patch mosaic.

Disturbance (3E). The third aspect of the model represents the disturbance event on the patch. Disturbance (like action in the social system), is the catalyst of structuration of the ecological system, where the disturbance has the potential to transform, reproduce or maintain the structure and function of the patch and the patch mosaic. The disturbance could be caused by a farmer clearing part of the patch to plant a crop or could be a fire that runs through the patch of forest.

Outcomes (4E & 5E). A disturbance will impact both the internal structure of the patch, but also, and simultaneously, be an input to the dynamics in the patch mosaic. A disturbance may have impacts on some aspects of the internal patch mosaic, but not others. Therefore, *how* the patch has been impacted by the disturbance (disturbance to structure at the internal patch level) will impact how it will in turn influence the larger patch mosaic. The structure of the patch mosaic could be changed, reproduced or preserved by the outcome of the disturbance. As an example, forest clearing may significantly alter landscape connectivity and impact biodiversity at the landscape level, however, a ground fire may reinforce the patterns of vegetation that are dependent on fire and not significantly alter connectivity.

Social Knowledge of Ecological Systems

The combination of the two systems requires two additional elements. In structuration theory there is a distinction made between actions and intentions (Ritzer and Goodman, 2004). The distinction is made because of the limited nature of human

knowledgability and the possibility of unacknowledged conditions and unintended consequences of human action (Giddens, 1984). These conditions have already been addressed in relation to social structures, however, when combined with ecological systems; two new instances need to be added to the model.

Actor's Knowledge of Ecosystems (1SE). This process is labeled with the social element first, because it represents an interaction element of the social and ecological systems. This is the landowner's knowledge of "ecology in general" of the larger patch mosaic. It includes a landowner's general knowledge of the larger environment, about conditions, processes, feedbacks, and thresholds.

Actor's Unacknowledged Conditions of Ecosystems (dashed line). As noted regarding ecosystems, "knowledge of the system we deal with is always incomplete. Surprise is inevitable. Not only is the science incomplete, the system itself is a moving target" (Holling, 1993, p. 553 as cited in Scoones, 1999). There may be unacknowledged conditions about both general ecosystems and the landowners own land. Both of these unacknowledged conditions are indicated by the dashed line above 2E.

Actor's Knowledge Regarding Knowledge About Their Land (2SE). This is the specific knowledge that a landowner has about the ecological conditions specific to the action they are considering such as land use change on their farm. This "local knowledge" may be different than their general ecological knowledge due to direct interaction and feedbacks that they may have experienced and learned on their land. A landowner may be aware of variations of soil types across their land and how crops have fared in the past.

Unintended Consequences (dashed line). The land use decision by a landowner results in an action/disturbance that may be either intended or unintended. The dashed line under 4E is to indicate unintended ecological consequences of the landowner's action. An example of this is if the crop the landowner planted had led to the spread of a disease across the landscape.

Open Systems. The final elements on Figure 1 are the flows to and from other social and ecological systems. These are done in recognition that both social and ecological systems are open systems. Both systems represented are hierarchical across both space and time and therefore require acknowledgement of flows to and from other systems (Giddens, 1984).

Conclusion

The SEStM depicts the multiple scales of analysis that are necessary to analyze land use change. The conceptualization of land use and land cover change as both a medium and outcome of social and ecological structures recursively organized was used to provide a link between the systems. By explicitly outlining the dynamic process of Structuration (social and ecological), this model represents one way to overcome the macro - micro divide, remove problems encountered with static models (Leach et al., 1999) and avoid the mistakes of purely structure based or agent based analyses (Lambin et al., 2003).

Through the use of the concept of Structuration as a process, the model frames the linked systems in a manner that is consistent with theories from both ecology and sociology. This is a potentially significant advance on other linked human-ecological frameworks that are a-theoretical or try to incorporate social behavior under ecological theories.

Additionally, the SEStM addresses both unacknowledged conditions and unintended consequences of social action that is not found in other models.

Finally, this model can incorporate spatial heterogeneity in both social and ecological systems through the incorporation on hierarchical patch dynamics, which others have identified as critical for linked human environmental systems and the analysis of land use change (Pickett et al., 1997; Wu and Loucks, 1995).

A case study applying this model to Costa Rica's program of payments for environmental services can be found in Morse, 2007.

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