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Article *in* Urban Ecosystems · March 2013
DOI: 10.1007/s11252-011-0178-3

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Urban Ecosyst (2013) 16:53–77
DOI 10.1007/s11252-011-0178-3

Social ecological complex adaptive systems: a framework for research on payments for ecosystem services

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Published online: 3 May 2011

Abstract The environment is both a setting for and a product of human interactions. Understanding the dynamic nature of human-environment interactions is critical for mitigating the impacts of human induced environmental change and understanding how the environment shapes social systems. Current research has focused on the reduced ability of many natural systems to provide ecosystem services and the subsequent impact on human well-being. Furthermore, there has been a proliferation of cases analyzing the impacts of payment programs designed to enhance ecosystem services. However, analyses that link environmental policies through to their ecological results are not common and methods to do so are not thoroughly developed. To better analyze these interactions, a theory or framework is necessary. This article presents a framework of social ecological complex adaptive systems (SECAS). The framework links structuration theory from social science with the theories of complex adaptive systems from ecology to provide an enhanced understanding of the human drivers and responses to environmental change. The framework is presented as a recursive process where social and ecological systems are

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both the medium for and product of social action and ecological disturbance. A case study of Costa Rica's ecosystem service payment program is presented as a demonstration of empirical applicability. This framework is proposed as a method to evaluate payments for ecosystem services, conservation policies, urban ecosystems, and for land use change in general.

Keywords Social ecological systems · Structuration · Ecosystem services · Theory

Introduction

The environment is both a setting for and a product of dynamic human interactions (Scoones 1999). It provides the foundation on which human societies have developed and is implicated in their collapse (Diamond 1999, 2005). Land uses designed to provide ecosystem goods such as food, fiber, and water to a growing global population are converting or altering large extents of natural systems on the planet's surface and diminishing their functional capacity (Foley et al. 2005). Over the last half century, human impacts on natural systems have been faster and more extensive than in any time in human history putting at risk many of the ecosystem services on which we depend (MEA 2005).

In general terms, ecosystem services is a concept used to describe the ways that functioning ecosystems contribute to human well-being (MEA 2005). For example, ecosystem services provide benefits such as drinking water, property protection, good health and aesthetic value (Boyd and Banzhaf 2007). In this context, ecosystem structures such as surface water, wetlands, air quality and natural land cover represent some of the corresponding ecosystem services that provide these benefits (Boyd and Banzhaf 2007; Fisher et al. 2009). Under this definition, ecosystem structure "is a service to the extent that it provides the platform from which ecosystem processes occur" (Fisher et al. 2009 p. 646). More recently this notion of ecosystem structure as a platform to provide services has been advanced as an ecosystem fund; or the "particular configuration of ecosystem structural components (water, minerals, soil, plants, animals, and so on) that generate a flux of services of value to humans and other species" (Farley et al. 2010). The physical characteristics expressed as ecosystem structure and its configuration, the fund, can also be described in terms of land use and land cover (Farley and Costanza 2010). Therefore, land use and land cover can be related to, or as is often the case, assumed to have a relationship with the provision of a flux of services (Muradian et al. 2010).

There are a number of critical reasons for the continued degradation of ecosystem services including; their nature as public goods, the lack of ecological knowledge or feasibility for quantification of many ecosystem services, and the complexities of scale issues (Kroeger and Casey 2007; Hein et al. 2006; Norgaard 2010). While ecosystem goods can often be found and traded in markets, many ecosystem services are considered public goods which are not conducive to establishing market exchanges (Brown et al. 2007). Furthermore, while many ecosystem services are public goods, "the physical structure that provides them is often privately owned" (Kemkes et al. 2010). The lack of a market means that private landowners will have little incentive to provide the socially optimal amount of ecosystem services (Kroeger and Casey 2007). This has led to an interest in developing market-based or economic incentive programs of payments for ecosystem services (PES) to alter the incentives for landowners (Pagiola et al. 2002).

When developing a market, it is important to identify and quantify what it is that is being sold. Unfortunately, knowledge of the ecological relationships between a particular configuration of ecosystem structures and their linkages to their flux of services is not often thoroughly understood (Kremen 2005; Kosoy et al. 2007). The linkages are often highly complex, specific to a particular local context, depend on the specific service of interest, and are subject to change over time (Norgaard 2010). Faced with the lack of understanding in a given context and the potentially high cost of obtaining it, many of the PES programs applied in the field base their program decisions on an assumed relationship between land use and land cover (configuration of ecosystem structures) and the provision of a flux of services associated with certain social benefits (Muradian et al. 2010; Porras et al. 2008). According to Farley and Costanza (2010), "PES schemes actually pay for land uses associated with generating the service" (p. 2062). A definition of PES in this regard is perhaps best not described as a formal market, but "a transfer of resources between social actors, which aims to create incentives to align individual and/or collective land use decisions with the social interest in the management of natural resources" (Muradian et al. 2010; p. 1205).

Subsequently, it becomes imperative to identify which social actors will be involved in the transfer of resources. Ecosystem services provide benefits at a variety of scales and different stakeholders will often attach different values to these benefits across the scales (Hein et al. 2006). Some ecosystem services provide benefits at global levels such as biodiversity and climate regulation, some are directional such as water provision, and others are site specific such as aesthetic benefits from natural land cover. The spatial separation of providers and beneficiaries, the high numbers of actors involved, spatial specificity of some services and the different perspectives on benefits that different stakeholders can have all have implications for PES programs.

One of the highest profile case study or PES programs is the New York City watershed protection program in the distant Catskill Mountains and Delaware River watersheds (Postel and Thompson 2005). In this case where nearly three-quarters of the watershed is privately held, a memorandum of agreement (MOA) was developed between "the City and State of New York, the EPA, 73 local municipalities and eight counties in the watersheds, and five environmental organizations" (Pires 2004, p. 168). The MOA outlines a three-pronged approach to upland rural watershed conservation that included land acquisition, water supply regulations and watershed protection partnerships (Pires 2004). Many of these actions such as land acquisitions, conservation easements, setbacks and stream buffers and agricultural best management practices were designed to specifically regulate or encourage rural land uses, or particular configurations of ecosystem structures, which are associated with the improved provision of hydrological services to the urban areas (Pires 2004). New York urban beneficiaries recognized that "compensation to rural communities for the opportunity costs associated with implementing more stringent watershed regulations is imperative if it seeks long-term water supply protection" (Pires 2004). As noted for the New York case, but applicable in most cases where the beneficiaries are urban residents, "various stakeholders in upstate watershed communities are rediscovering the inextricable linkages that bind rural and urban regions together in mutually dependent, although not always mutually beneficial, relationships" (Pires 2004).

While there has been a proliferation of PES programs around the world (Porras et al. 2008), analyses that link environmental policies through to their ecological results are not common and methods to do so are not thoroughly developed (Ferraro and Pattanayak 2006). New integrated and interdisciplinary approaches that are focused on the interdependencies and complexities of social and ecological systems are required (Berkes et al. 2003; Geist and Lambin 2002; Muradian et al. 2010; Norberg and Cumming 2008; Rammel et al. 2007). As indicated in Lambin et al. (2003, pg. 217)

> What has been lacking so far is the development of an integrative framework that would provide a unifying theory for these insights and pathways to land use change and a more process oriented understanding of how multiple macro-structural variables interact to affect micro agency with respect to land.

This paper is a presentation of such an integrative framework. It details a social ecological complex adaptive systems framework and applies it to study a program of payments for ecosystem services. The goal is to help understand how social and ecological systems interact so that we can continually adapt and improve our management of them. Adaptations of structuration theory from the social sciences (Giddens 1984; Stones 2005) and theories of complex adaptive systems (Gunderson and Holling 2002; Levin 1998) and hierarchical patch dynamics (Wu and Loucks 1995) from the ecological sciences were integrated to develop this heuristic framework. A primary contribution of this framework is the application of social theory to social ecological complex adaptive systems to better explain human intent, learning and adaptation within and across the systems and, importantly, scales. Its emphasis is on recursive processes, individual actions/interactions with the environment that create (elaborate, reproduce or change) both social and ecological systems during one cycle, and then respond to feedbacks from both systems for subsequent actions/interactions. We believe that a detailed theoretical understanding of human micro level individual actions/interactions and both purposeful and emergent structural development are critical; "because human actions dominate in SESs, adaptability of the system is mainly a function of the social component—the individuals and groups acting to manage the system" (Walker et al. 2004, p. 3).

The paper begins with an overview of key background assumptions regarding social and ecological systems that were used for this framework. Structuration theory and how it can be applied to the social complex adaptive systems is then explained in detail. Subsequently, hierarchical patch dynamics from ecology is used to frame the ecological complex adaptive systems for the ecological side of the framework. Presentation of the integrated framework is demonstrated with a brief case study from Costa Rica's environmental service payment program for which it was developed. The case presentation provides a brief example for each component of the conceptual map that was developed to provide a guide for empirical analysis across linked social ecological CAS. Finally, a discussion and conclusion are offered identifying what we believe are the main contributions of this framework.

Social Ecological Complex Adaptive Systems (SECAS)

Fundamental framework assumptions

A widely held premise, and fundamental assumption here, is that both social and ecological systems are dynamic and change over time. Furthermore, the systems are inextricably linked forming integrated social ecological systems (Berkes et al. 2003). As linked social and ecological systems co-evolve they display characteristics of what have been described as complex adaptive systems (Berkes et al. 2003). Complex adaptive systems (CAS) are systems in which lower level components interact in ways that result in emergent patterns at higher levels during one period; subsequently, these emergent higher level patterns then feedback to influence future lower level interactions for the next round of interactions

(Levin 1998). Through a process of emergence and feedback CAS self-organize, often into nested hierarchies (Levin 1999). These systems can also display self-reinforcing of self-moderating processes where the components of the systems don't change, but the dominance of different processes can alter how a system functions (Norberg and Cumming 2008). Other characteristics of CAS are high levels of uncertainty, non-linearity, multiple equilibria and cross scale interactions (Berkes et al. 2003). The attributes of CAS have been identified in both social and ecological systems (Norberg and Cumming 2008).

Due to the dynamic nature and inherent uncertainty of social ecological CAS, management to maintain a flux of ecosystem services is necessarily an adaptive endeavor. Adaptive management, developed to address change and uncertainty in resource management, is a process of active learning where managers iteratively monitor ecological feedbacks from policy actions and treat policies as opportunities to learn (Gunderson 1999; Walters 1986). This same principal can be applied to individual actors. The focus of adaptive management is on individual and social learning while "emphasizing the importance of feedbacks from the environment in shaping policy" (Berkes et al. 2003 p. 9). Following others (Berkes et al. 2003; Gunderson and Holling; 2002; Norberg and Cumming 2008) we utilize the concepts of CAS and adaptive management to act as interdisciplinary unifying principals that have application in both social and ecological systems.

The premise that social ecological systems are thoroughly integrated is also accepted. However, as others have identified, the mechanisms that drive self-organization are different for social and ecological systems (Scheffer et al. 2002; Westley et al. 2002). For example, humans are reflective and act with foresight and intent (Walker et al. 2006) and can and do purposefully develop institutions to manage resources and mitigate impacts and can communicate these ideas into the future (Ostrom 2005; Weisbuch 2000). Further differences that have been identified are the ability of humans to abstract from a situation in time and space, to be reflexive and evaluative, to generate expectations, to create technology, and the scale of human influence (Westley et al. 2002).

In accordance with this dynamic perspective, the configuration of ecosystem structures found across a landscape can be viewed as the result of complex adaptive systems where multiple rural household conservation and production decisions are made within a particular social and environmental context over time (Lambin et al. 2003). In this framework, individual land use and land cover actions are a primary link between social and ecological systems and a key element for understanding how PES programs may influence the eventual provision of final ecosystem services.

All of these fundamental assumptions warrant use of a conceptual framework that can both integrate *and* differentiate social and ecological systems. We suggest that the application of social theory is a valuable and necessary component for any framework used to analyze human shaped natural environments. Social theory is necessary to conceptualize how individuals and social systems respond to changes in the environment. Additionally, when human motivations and actions are imposed on ecological CAS through intentional (and unintentional) disturbances, a social theory is necessary to explain changes to the ecological systems. We believe that structuration theory (Giddens 1984; Stones 2005) is a useful compliment to ecological theories of CAS (Levin 1999) and the best suited to frame feedbacks within social systems and across social ecological systems. To emphasize the uniqueness of self-organizing principals in both the social and ecological (SE) systems, but also to identify both systems as linked complex adaptive systems (CAS), this framework is titled the social ecological complex adaptive systems

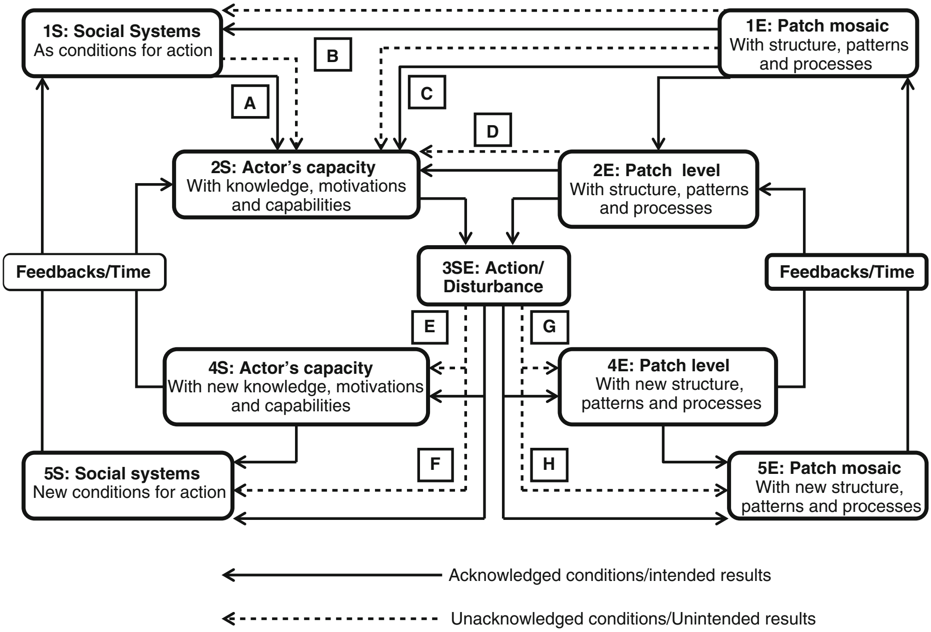


Fig. 1 Structuration of social ecological complex adaptive systems. **a** Social systems constrain and enable actor's actions; **b** Institutions in social systems have knowledge of ecological systems; **c** Actors have knowledge of ecological systems; **d** Actors have knowledge of ecological patches over which they have control; **e** There are outcomes of actions that will influence the actor; **f** There are outcomes of actions that will simultaneously influence social systems; **g** There are outcomes of disturbances that will influence the patch; **h** There are outcomes of disturbances that will simultaneously influence the patch mosaic

(SECAS). The two components interact and mirror each other in this conceptual framework (Fig. 1).

Social complex adaptive systems

Structuration theory (Giddens 1984; Stones 2005) frames the interactions of individuals and social systems. A defining characteristic of structuration theory is that through recursive social practice or action, social systems (structures) influence the activity of individuals, who in turn, produce, transform, or otherwise reaffirm those same structures constantly producing and reproducing society. Structuration theory has been identified as a useful social theory for linking social and ecological systems (Bebbington 1999; de Haan and Zoomers 2005; Leach et al. 1999; Scheffer et al. 2002; Scoones 1999; Westley et al. 2002) but was never fully developed and applied to SECAS. Strong structuration theory is a revision of Giddens' work that was developed to address previous critiques and refinements to the theory and to establish a foundation for empirical research from an otherwise abstract theory (Stones 2005). While remaining consistent with the core of structuration theory, Stones (2005) describes an inter-linked four part formulation of structuration that frames the recursive or cyclic nature of structuration over time that we have found beneficial for our framework and for conducting empirical analysis. In addition to the organizing concept of the duality of structure, the four parts are; external structures, internal structures, active agency (action) and outcomes (Stones 2005).

Duality of structure: How the system operates

By focusing on the interaction of structures and agents Structuration theory avoids the oversimplification of purely objective or subjectivist approaches (Stones 2005). Human action is described in terms of flows of conduct (Giddens 1984). Based on this procession of human social action, Giddens identifies a concept termed duality of structure. It is a duality because agents and structures (social systems) are not considered independent of one another (Ritzer and Goodman 2004). Structure is defined in temporal and dynamic terms as "the medium and outcome of the conduct it recursively organizes" (Giddens 1984, p. 374).In other words, structures that are the outcome of one period of conduct become the context and medium for the next round. Actions taken at any given time have been conducted under conditions provided by the social structures such as market conditions, government regulations or social norms that were present at that time. If these new actions result in outcomes that reaffirm those same social structures, conditions will likely be similar for the next time they take an action. However, the outcomes of actions may either intentionally or unintentionally change the social structures for the next round of actions. For example, if a participant views a situation as unfair they may intentionally set out to change the social structures (Ostrom 2005). Furthermore, if there are high levels of uncertainty or lack of perfect information in a situation, actions may result in outcomes that unintentionally change the social structures. Feedbacks occur between actions and social structures in a temporal sequence of relations (Stones 2005).Thus, the duality of structure is a recursive process, continually recreating and "structuring of social relations across time and space" (Giddens 1984, p. 376).

External social structures/social systems

Stones (2005) has conceptualized two types of social structures; external and internal. External social structures are the patterns or organization of social relations (Kaspersen 1995). They include social systems and institutions (e.g. markets, governments), power and authority relations and constraints that are the context or condition for action (Stones 2005). Social systems also include the beliefs, behaviors, networks and relationships, and rules and resources that can be found in a specific location at a given time (Kondrat 2002). In the temporal flow of the process of structuration, *external* structures are those structures that are autonomous to the decision agent at the time they choose to act—or the immediate 'action horizon' (Stones 2005). This is the structured terrain that constrains or enables an agent's actions. Social systems are also perceived to be hierarchically nested over space and time; "all societies both are social systems and at the same time are constituted by the intersection of multiple social systems" (Giddens 1984, p. 164). However, while social systems and institutions are external to the agent at any given decision-making point in time, it is the actions taken by agents over time that reproduce, create and/or change the social systems.

Structure can be further broken down into 'rules and resources' that are involved in the reproduction of social systems (Giddens 1984). Rules (or schemas) are the formula or procedures to action that tell us 'how to get on' in the world (Kaspersen 1995; Sewell 1992). Rules can be codified and formal, as with laws and regulations or informal, such as how close one should stand when talking (Kondrat 2002). Resources, in structuration theory, refer to the 'structures of domination' and include both allocative and authoritative resources (Giddens 1984). Allocative resources are the "material resources involved in the generation of power, including the natural environment and physical artifacts" (Giddens 1984, p. 373). Authoritative resources involve domination or control over people and their activities (Giddens 1984).

Internal social structures: Power and capabilities

Internal structures include the actors' knowledgability or understanding of external structural rules, personal capabilities and control over allocative and authoritative resources, motivations and desires. Under Giddens theory, agents are perceived to have power or agency, to be able to "act otherwise' or 'make a difference' in the world (Giddens 1984).To 'make a difference' means that an agent's actions are not predetermined by the social structures, but that they have the power to make things change (Munch 1994). An agent's capabilities, in part, come from their ability to utilize elements of structure (rules and resources) to achieve their goals (Bebbington 1999; Stones 2005). Understanding and using the rules to their advantage and having control over allocative and authoritative resources can increase an agent's power and transformative capabilities (Sewell 1992).

Therefore, all agents are not situated equally in their power, or knowledge of rules and access to or control over resources. An agent's power can also be limited by others who have sanctioning power. As indicated by Kondrat (2002, p. 441)

> Actors may be located at varying positions along structuring dimensions of social life such as class, status, gender, and cultural or religious marginality. An individual's social location influences access to resources (including technological resources), power, opportunity, and information, all of which enter into the determination of what one knows, does not know, or is prevented from knowing.

In this way an agent's capabilities are constrained or enabled by the structural social order in which they are found. This indicates that their power is culturally, geographically and historically contingent (Kondrat 2002). Therefore agency should be seen on a continuum where all agents have at least some power, but that their capabilities and their social context matters (Ritzer and Goodman 2004).

Agency: Taking action

Active agency is the action that an agent conducts; this is their expression of power (Stones 2005). Structuration presents agents as both powerful and knowledgeable; "all social actors know a great deal about the conditions and consequences of what they do in their day to day lives" (Giddens 1984, p. 281). A key to understanding the capability of actors to use structural resources in their decision to act is outlined in the conception of the agent in structuration theory. The agent is conceptualized to have: 1) motivation to action; 2) the rationalization of action and knowledgeability; and 3) reflexive monitoring of action (Giddens 1984). Motivation to action includes the wants and desires that prompt individuals to engage in action and their overall objectives and livelihood strategies. Rationalization of action includes the agent's knowledgeability of social structures and schemas and their ability to purposefully act to obtain their intended outcomes (Stones 2005). However, while agents are seen as knowledgeable, it is not a perfect knowledge; "the agent's knowledgeability is always limited by the unacknowledged conditions of and the unintended consequences of action" (Kaspersen 1995, p. 40). Reflexive monitoring of action is the basis of the agent's learning through the continual monitoring of the outcomes of their actions, of the actions of others, and of their context (Giddens 1984).

Outcomes and feedbacks

Finally, outcomes occur for both the agent's internal structures and for external structures (Stones 2005). For example, an agent's internal structures will be influenced by any new knowledge or understanding of external structures, changes in their capabilities or control over allocative or authoritative resources, or changes in their motivations as a result of their action. As part of an agent's reflexive monitoring of action they learn from the outcomes of their actions to adapt and improve their situation for the future. Additionally, agents actions will elaborate, reproduce or change external structures. However, it is not in every, or even most, cases that agents can directly change external structures. Stones (2005) identifies a spectrum of external structures where some are completely independent and external to an agent's conduct to those where an agent does have the power, knowledge and "critical distance in order to take up a strategic stance in relation to a particular external structure and its 'situational pressures'" (Stones 2005, p. 115). The outcomes of an agent's actions, and those of all other agents, continually feedback over time to create the structures that will be considered external for the next decision context. As we shall see in the next section, outcomes of land use actions have simultaneous outcomes for ecological systems as well.

Complex adaptive systems & hierarchical patch dynamics

Patch dynamics

The theory of patch dynamics is widely used in landscape ecology and conservation biology (Turner et al. 2001) and is effectively and commonly applied to land use change studies with remote sensing and GIS technologies because of its landscape perspective (Wu and David 2002). A "hierarchical patch dynamics paradigm has emerged as a result of recent linkages between the patch dynamics perspective and hierarchy theory that emphasizes multiple-scale properties of pattern and process dynamics in ecological systems" (Wu and Loucks 1995, p. 450). Hierarchical patch dynamics (HPD) provides the framework for analysis of spatial heterogeneity and to represent the structural and functional properties and dynamics of patches across scales (Alberti 2008). These frameworks make it particularly useful for assessing land use cover and change that are frequently used as indicators for the provision of ecosystem services (Farley and Costanza 2010).

Patches

Patches are discrete spatial patterns within ecological systems and can be defined by their size, shape, content, structure, function or spatial configuration (Pickett and White 1985). HPD presents complex adaptive systems as vertically nested and nearly decomposable meaning that patches at different scales form a nested hierarchy (Wu and Loucks 1995). This framework results in nested patch mosaics where at each level a patch also contains its own dynamic patch mosaic (Wu and Loucks 1995). A particular emphasis for understanding the functional attributes of patches regarding ecosystem services is that patch content, or the particular configuration of ecosystem structures, matters (Franklin 2005). As with the internal structure of the actors in structuration theory who have a variety of capabilities, each patch level will have its own unique function and relationship to the external patch mosaic. However, the drivers *within* an ecological system will follow ecological principals in contrast to human motivations and intent.

Patch mosaic

Multiple patches form a landscape or patch mosaic at all levels. This implies that patches have unique spatial locations and that mosaics have distinct patterns or configurations. The patterns of patches have implications for ecosystem flows and processes so understanding both composition and configuration of patches is critical to evaluate ecosystem function (Turner and Chapin III 2005) and consequently, their potential to provide a flux of ecosystem services. Patch mosaics are dynamic and change in pattern, structure and function (Pickett et al. 1999). Changes and heterogeneity are driven by natural variation and by disturbance. Disturbances are discrete events that can alter a patch's size, shape, structure and vary by frequency and intensity (Turner et al. 2001). Presented in this way, it is possible to envision a duality of ecological systems where the patch mosaic is both the outcome of previous disturbances and the medium providing future system potential in a process described in CAS.

Fire, a tree fall and a landslide would all be examples of natural disturbances. However, each of these disturbances could also be caused by human intervention. Therefore, we can understand disturbance and action as inputs to the SECAS that are both socially and ecologically driven and associated with outcomes for each system. Our use of HPD is consistent with other research (Alberti 2008; Grimm et al. 2000; Pickett et al. 1997; Redman et al. 2004; Wu and David 2002) but elaborates on its use through the application of principals of structuration theory for direct linkages with human land use and land cover actions, agents intentions and knowledgeability, and to the constraining and enabling conditions provided by social systems.

Empirical analysis: Applying methodological bracketing

We have developed a diagram that depicts the stages of structuration of SECAS in Fig. 1. This figure presents the nested hierarchical framework at only the base level of these systems, the individual and the patch, because that is the level where action is taken and structures are first elaborated, reproduced or changed. The figure presents the process of structuration of SECAS linked through action/disturbance with structures as both the medium and the outcome of actions and disturbances in continual feedback loops. We have included the concepts of unacknowledged conditions and unintended consequences from Giddens' conception of the agent as explicit elements in the diagram because of the significant role that knowledge and intent play in the adaptive human responses to changes in the SECAS (Berkes and Turner 2006; Ostrom 2005). The arrows represent the temporal order and are used to demonstrate the continual interaction and cyclic feedbacks. Consistent with current research and theories of social ecological systems and as a defining characteristic of CAS, this framework is also hierarchically nested to include multiple structural levels that expand from local to global levels and allow for cross scale interactions (Berkes et al. 2003; Giddens 1984; Gunderson and Holling 2002; Ostrom 2005; Wu and Loucks 1995).

Depending on the research question, analysis could be aimed at any portion of the framework. However, to gain an understanding of the process of social ecological structuration that would provide insight to how structures are changed in response to feedbacks between and among systems, one would need to analyze the "intermediate temporality of historical processes" (Stones 2005, p. 81). For the social system, an intermediate time period would allow the researcher to empirically analyze changes in structures (slower variables), while also analyzing how those structures influenced (enabled or constrained) agents actions and motivations and how agents' actions reproduced or changed those same structures. In the context of examining a policy of payments for ecosystem services, this means that it would need to be long enough to observe changes in policy or other external structures, but not so long as landowners could not remember their motivations, rationalizations, and understanding of the external structures at the time of their land use change actions. A parallel argument can be made for the ecological systems, enough time must necessarily pass to see changes in configuration of ecosystem structures in the patch mosaic, but not so much time that understanding the process that influenced those changes are unidentifiable.

Methodological bracketing is a tool designed by Giddens (1984) to focus the researcher on certain aspects or dimensions of the structuration process. Stones (2005) reformulated Giddens' methodological brackets to include actors' conduct analysis and actor context analysis. The actor's conduct analysis looks 'in' at the actor to focus on the conjuncturally specific internal structures in a way that addresses the knowledgeability, motivations, reflexive monitoring, and desires and capabilities of the actors themselves and how those are negotiated through to action (Stones 2005). Actor's context analysis is intended to examine the terrain the actor faces as the enabling and constraining external context (Stones 2005). There are two parts to the context analysis mentioned by Stones (2005), one is from the actor's perspective and the other is the researcher's perspective. The actor's perspective also focuses on the conjuncturally specific internal structures, but on how the actor looks 'out' at the external context. This is the actor's perspective on the external possibilities and constraints, power relations and norms, and consequences of action (Stones 2005). The actor's "context analysis also allows the social researcher a perspective from which to identify and assess the range of relevant casual influences, the potential courses of action, and the probable consequences of both, and to judge these assessments against those of the agent" (Stones 2005, p. 122). The researcher's perspective of the context analysis can then be linked with the actor's perspectives (both conduct and context analysis) to identify unacknowledged conditions and unintended consequences. The two bracketed methods are intended to provide an outside-looking-in (the researcher's perspective) and inside-looking-out (the agent's perspective) analysis of the process of structuration in social systems. A similar type of bracketing that helps reduce complexity can be found in the use of 'enveloping' in hierarchy theory for ecological systems and applied in hierarchical patch dynamics (Wu and Loucks 1995).

Case study: Costa Rica's environmental service payment program

Background

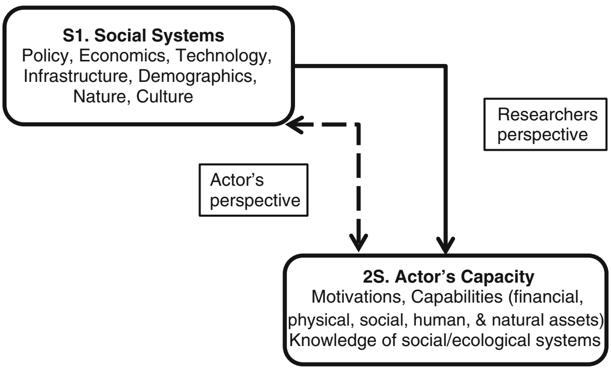
An interdisciplinary study of the PES program was conducted in the San Juan–La Selva Biological Corridor in the northeast of Costa Rica that was heavily targeted for conservation payments. A detailed presentation of the program, methodologies used, and interdisciplinary results can be found elsewhere (Morse et al. 2009). The small portion of the case presented here will focus heavily on the social analysis to draw attention to this portion of the model. Social analysis was focused at several levels to understand both the external structural influences (focused on the PES) and the individual decision making process within that context. Eighteen expert interviews and focus groups with regional natural resource agency personnel and environmental groups and a meta-analysis of literature on the drivers of tropical deforestation in Costa Rica were used to understand external structures for the researcher's perspective of the context analysis (Morse 2007a) (Fig. 2). Additionally, in-person surveys were conducted with 207 spatially paired PES participants and non-participants to understand the external structures as enabling and constraining factors influencing land use decisions from the landowner perspectives (internal context analysis). Questions were also asked regarding their motivations for land use choices for the agent's conduct analysis. A livelihoods analysis was conducted as part of the conduct analysis to help understand landowner capabilities (Bebbington 1999) (Fig. 2). Land use change results were conducted through remote sensing using 3 Landsat images that bookended the 1996 Forestry Law; 1986, 1996–97, and 2001 (Morse et al. 2009). Brief results related specifically to the reforestation portion of Costa Rica's payment program will be reported here as an example of how the framework can be applied (Morse 2007b). The case study will be presented following Fig. 1 as a guide.

External social structures: Social systems (1S)

The first (though the process is cyclic) social aspect on the upper left side of the figures presents external structures as conditions of action. This is the 'action horizon' or the initial given structural context encountered by the landowner at time 1 (T1) (Stones 2005) and is shown at the top left of the diagram (1S). External structures feature existing social systems that are present at time one and currently exogenous to the landowner.

From a researcher's perspective, a number of periods of change in forest policies and other external structures were identified to have influenced land use over the last several decades (Fig. 3) (See Morse 2007a for a complete review). Costa Rica currently has a reputation for its protected areas and promoting conservation and ecotourism originating from its first Forestry Law in 1969 which established the foundations for its world class national parks system (de Camino et al. 2000). However, throughout the 1970s and 80s Costa Rica had one of the world's highest deforestation rates (de Camino et al. 2000). These rates were reported to be in large part enabled by land tenure laws granting title for developing land (forest into agriculture) and cattle subsidies which provided strong incentives to clear forest in the Corridor region (Butterfield 1994). By 1979, the government first attempted to counter forest loss on private lands with incentives for

Fig. 2 Variables used in agent context/conduct analysis



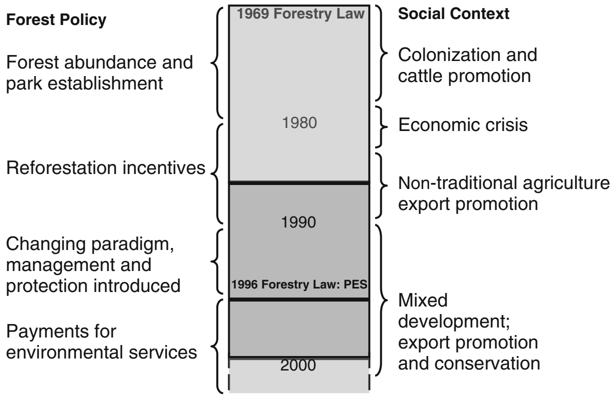


Fig. 3 Intermediate time period analysis of social systems

reforestation of forest plantations. Other social factors influencing land use also continued to change during this period. An economic crisis in the early 1980s forced the government to agree to a Structural Adjustment Loan (SAL) with the World Bank, International Monetary Fund, and U. S. Agency for International Development for assistance (Montanye et al. 2000). As part of the SAL, cattle subsidies were reduced by mid-1980s decreasing some incentives for expansion, but governmental infrastructure development and colonization influenced by geopolitical concerns continued to promote regional land conversion during this period (Watson et al. 1998). The logic of cattle of low labor, low input, proof of land utilization against squatters, and easy marketability meant that cattle remained a dominant use in the landscape and many landowners were investing in land and not trying to establish highly profitable farms (Schelhas 1996). Throughout the 1980s forest incentives continued to evolve and were modified to allow for increased participation and improve payment mechanisms (Thacher et al. 1997) and reforestation projects became more widespread across the research area. By 1994–6 continued growth along semi-urban road corridors and relatively low prices for cattle provided incentive for pasture abandonment and subsequent migration away from the frontier as the region shifted toward a more wage and service oriented economy (Schelhas and Sanchez-Azofeifa 2006). Forest policies also continued to adapt with modifications in 1990 to provide incentives for sustainable management and by 1995 incentives for forest protection were developed (Miranda et al. 2004). Each new law was an adaptation to new circumstances and an attempt to improve on previous regulations and address evolving goals (Pagiola 2008; Grieg-Gran et al. 2005). As external structural incentives for forest conversion were pointedly waning, significant change in the evolution of Costa Rica's forest policies occurred with the 1996 Forestry Law (No. 7575). Under this Law a voluntary program of payments for ecosystem services (PES) was established (to replace previous subsidy type incentive programs) alongside firm restrictions on deforestation (Pagiola 2008). The payments are for forest protection and reforestation activities and are designed to compensate rural landowners for providing four ecosystem services including; watershed, biodiversity, carbon sequestration and aesthetic services (Pagiola 2008). The program provides incentives that are based on type of land use and land cover (forest protection and reforestation/forest plantations) on a per acre basis for a bundle of services regardless of the amount of services provided (Muradian et al. 2010; Daniels et al. 2010). The price for the services are based on the opportunity cost of low-value pasture land use currently equal to approximately $64/ha per year for forest protection and $816/ha per 10 year reforestation period (Daniels et al. 2010). These services provide benefits from local (hydrological services, aesthetics) to global (biodiversity, carbon sequestration) scales. Though primarily funded through a national fuel tax and global partners (World Bank Global Environmental Facility, German aid agency KfW), there have been an increasing number of contracts with private hydropower, municipalities and a newly instituted water tariff used to provide the financial incentives to landowners (Pagiola 2008).

The solid line (A) represents this full suite of social structures that potentially enable or constrain landowner actions (researchers perspective), whether or not they are known by or influenced the actor (dashed line A). Costa Rica's policy of incentive payments for ecosystem services and restrictions on deforestation are some of the known enabling external structures that landowners considered and the focus of the case study (Morse et al. 2009). The Corridor was selected for this case because of the high number of PES contracts in the area. According to agency interviews, the high percentage of remaining natural forest, altitudinal gradient, and ability to connect protected areas were reasons for designating the area as a biological corridor and for targeting PES in the area. The solid line (B) demonstrates this ecological rationale used at the policy formation level. The parallel dashed line (B) represents the uncertainty in the ecological knowledge at this system level about the provision of ecosystem services (Kremen 2005).[1]

Internal social structures: Actor's knowledge of social systems

External structures or social systems lead to the internal structures of landowners where they make decisions regarding their livelihood strategies which in turn determine land use and cover (A). Internal structures include both the knowledge of external social systems (context analysis, landowner's perspective) and the motivations and capabilities to harness external structures to achieve livelihood goals (conduct analysis) (Fig. 2). Internal structures regarding the external social structure of the reforestation portion of the PES program (Solid line A) would include knowledge of how to subscribe to the program and how the payments and the adoption of forest plantations and subsequent marketing of the wood might influence their land use choices and help them accomplish their livelihood goals.

Results from the survey indicate that of the majority of survey respondents had heard of the incentives program and very generally understood how to participate in the program, even if they were not enrolled. Furthermore, there were a few external factors influencing the decision to reforest including poor returns on cattle (8%) and time limitations due to opportunities for off-farm employment (13%) that were also identified in the researcher's context analysis. However, the PES (and previous subsidies) incentive programs had an overwhelming influence enabling reforestation in the region with over two-thirds (68%) of landowners in the program indicating that they would not have reforested without the incentives.

A key factor of the knowledge of social structures is there are often *unacknowledged conditions*. This dashed line (A) reminds us that for any given agent, knowledge of external structures is often incomplete. Actors lack perfect information at any given time regarding markets or policies, and different actors have access to different knowledge. In Costa Rica, a critical factor adding uncertainty to the adoption of reforestation practices is the length of time until harvest (Miranda et al. 2004). This is because unknowns such as new market opportunities can open up during the lengthy reforestation contract that could significantly

[1] Note: A specific focus on the decision making process at the level of the agency developing and adapting policy is also possible using this framework and could be a part of an extended context analysis.

alter landowner opportunity costs, such as had more recently happened with the widespread adoption of high value pineapple plantations in the research area.

Internal social structures: Actor's capabilities and motivations (2S)

The conduct analysis part of the survey demonstrated that economic factors were shown to be primary motivators for enabling participation in regard to payments, but were also seen to be a constraint for others in terms of farm dependence. Primary motivations for reforestation adoption by PES program participants were economic including; the value of the wood at harvest (68%) and the incentives (32%). Specific motivations that were frequently mentioned for participation in the PES program were the financial incentives (83%) and technical assistance offered through the program (20%). Finally, the majority (76%) of landowners participating in the PES reforestation program were not dependent on their farm as a primary source of income indicating that financial constraints (and opportunity cost of converting land to forest) were factors reducing adoption. External social systems, motivations and internal capabilities, however, are not the only factors that an actor must consider when making a decision about taking an action. Landowners must also consider the ecological attributes of their patch of land as part of the allocative resources that they control. Landowners may also consider larger scale ecological characteristics if they believe they are relevant to their land use decision.

External ecological structures: Patch mosaic (1E)

The upper right hand corner of the ecological side of the figure is the patch mosaic. It represents the existing ecological condition at time one (T1) (external structure) and flows into the internal patch structure. This is the base or initial condition "for the subsequent structural development and dynamic interactions of the system" (White and Brown 2005, p. 31). This external mosaic establishes both the enabling and constraining ecological conditions for the individual patches. The configuration of ecological structures will be associated with certain flux levels of ecosystem services such as biodiversity, hydrological services and carbon sequestration.

In 1986 in the San Juan–La Selva Biological Corridor Costa Rica only a very small percentage of the land was in reforestation (.8%) while the rest of the Corridor was primarily natural forest (>55%), with pasture (>20%), forest regeneration and a small portion in crops (Morse et al. 2009). Spatial distribution of patches of different forest and agricultural types, their connectivity and aggregation, and other indicators of forest fragmentation are indicators of the ecosystem structure of the landscape patch mosaic. While the patch mosaic is the template for ecological patch interactions, it is also part of the larger ecological external structures for social systems and for the actor. It is the object of ecological knowledge and provides context for landowners' decisions. The attempt to understand ecological services at this scale is akin to the researcher's perspective of the context analysis where attempts to estimate or quantify the baseline flux of services based on land structures and configurations are done prior to policy (PES) implementation (Solid line C).

Internal social structures (2S):Actor's general ecological knowledge and beliefs

Actors may have some knowledge or beliefs about ecology at the level of the landscape, or larger patch mosaic, even if it is very basic (Solid line C). For example, landowners may believe that if there is less forest across the landscape it is bad for many animals that need those forests for food and cover; or that deforestation of steep slopes and areas adjacent rivers and springs will negatively affect water quality. These beliefs, and potential concern, regarding ecology at this level may be directly self-interested such as when the water quality reductions happen up-stream from their own water supply (and now has to be treated) or if the loss of animals happens to be ones they hunt or enjoy seeing. Knowledge, beliefs and concerns at this level may also be influenced by social norms and other-regarding preferences (Ostrom 2005) and part of a more complex set of motivations. This knowledge is akin to the agent's general knowledge of social structures and social systems.

According to the survey results, landowner beliefs about improved conservation at the patch mosaic level including watershed, biodiversity and aesthetic services are part of the larger ecological structures that were identified as primary motivations for reforestation by a third of participants (34%). This means that, whether their reforestation actions actually contributed to the additional provision of these services or not, landowner beliefs that they would contribute was part of their motivation to take that action. Additionally, as an ecological structural enabling and constraining factor, landowners had beliefs about the biophysical possibilities and limitations of the landscape for growing trees in the region.

There are also *unacknowledged conditions* about the general ecological context as represented by the dashed line (C). Is has been stated that, "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, evolving because of the impacts of management and the progressive expansion of the scale of human influences on the planet" (Holling 1993, p. 553; and see Norgaard 2010). Future effects of climate change on conditions for regionally growing trees, and insect or disease outbreaks are examples of macro level ecological unacknowledged conditions that could potentially impact reforestation systems.

Internal ecological patch structure (2E): Patch structure

The external patch mosaic is diagramed to flow into the internal patch structure to indicate the configuration of ecological structures and ecosystem flows and processes of which a patch is a nested component. This is simply recognition of the hierarchical patch mosaic. The internal ecological structure of a patch represents the internal patch mosaic of any given patch within this hierarchical patch mosaic at time 1 (2E). A patch of forest may have certain internal characteristics such as riparian areas and fallen tree gaps. As with the heterogeneous actors with different capabilities in the social structuration process, these internal characteristics represent the internal potential and capabilities of each patch in its relation to the larger context. Each patch will be associated with its own potential to provide different ecosystem services by itself *and* as part of the larger patch mosaic.

In the Costa Rica case study, landowner's had a variety of land uses on the farm. The landowners' farms were composed of fields of pasture, fields dedicated to crops and other portions remaining in forest. While they may be called by different names, the different land covers are the patch mosaic of resources over which they have control. To be eligible for the reforestation program, the minimum requirements for participation were for 1 ha of land to be reforested with a maximum of 300 ha (Grieg-Gran et al. 2005). To receive incentives for reforestation the land must come from pasture (cleared before 1990), crops, or previous forest plantation meaning that landowners not meeting these requirements were not eligible.

Internal social structure (2S):Actor's specific ecological knowledge and control of natural resources

The landowner's land (patch mosaic) will have certain configurations of ecological structures and the landowner will have ecological knowledge or beliefs specific to their land (Solid line D). They would be expected to have some idea about the ecological patch conditions that are specific to the actions they are considering on their farm. For example, they would likely have specific knowledge about how past crops or reforestation efforts have fared in the area and likely reasons for their success or failure such as flooding or soil quality. Actors may have knowledge of how changes to the landscape outside their farm may impact their land. Knowledge of their own patch would be expected to be more detailed than that of the patch mosaic due to the direct interaction and feedbacks (tighter coupling) that they may have experienced on their land. Additionally, this is the natural resource base that a landowner controls and combines with other assets to achieve their livelihood goals.

Results in the case study indicated that landowners recognized that there were biophysical limits to areas of their land for other production systems (cattle and crops) that they believed would still be suitable for forest plantations. This belief was a motivation for a number (16%) of participants to adopt reforestation. However, many participants selected sites on their land for reforestation based on access to roads and not biophysical limits, indicating that these limitations were not an overriding consideration for adopting reforestation.

However, there may be *unacknowledged conditions* about the specific ecological patch changes a landowner may be considering on their farm (Dashed line D). For instance, early adopters of reforestation in the region had to experiment to identify which tree species grew better in the different soils, which were least susceptible to diseases, spacing of trees, and which species would produce the most marketable wood (Miranda et al. 2004).

Action/disturbance: Active agency and patch disturbance (3SE)

The third aspect of the duality of structure is that of active agency where the landowner initiates action. Actors make land use and land cover decisions by applying knowledge of social and ecological systems taking into account their motivations, capabilities and control over resources. These actions impact land cover and cause an ecological disturbance to the patch (3SE). Disturbances are the catalyst of change in ecological systems and they simultaneously reproduce, maintain or transform ecosystem structures and functions of the patch and the patch mosaic across all levels.

Results for the reforestation portion of the PES program indicated that the majority (88%) of land that was reforested came from pasture while the remaining (12%) was planted on land that was previously crops. These were the specific action/disturbances that occurred on the patch. Once the action of reforestation was taken there were simultaneous social and ecological outcomes across multiple levels.

Outcomes: Internal social structures (4S)

There are multiple outcomes of landowners' actions including reinforcement or change in internal structures. Results of the action may have been what the landowner had expected (i.e. success with the planting) and reinforced their desire to continue with that action in the future (Solid line E). However, the action may have had *unintended consequences* (Dashed line E) that frustrated the landowner into changing their views, creating new contradictory (to previous assumptions) knowledge, or altered their capabilities as part of the internal structuration process.

Results indicated that the majority of participants (59%) in the PES reforestation program planned to reforest after their current crop was harvested indicating that their original motivations for reforestation were being met. A sizeable number (17%) were holding off making a decision until after they harvested to know more about the process of and results of harvesting and sale. However, nearly one quarter (24%) had already decided not to replant, primarily due to biophysical issues with plantation establishment and growth (or failure). Additional consequences that were often unintended (unexpected) but positive were the social capital (increased network of individual associations) developed through participation in the program and the new forestry knowledge necessary to be successful (Miranda et al. 2004).

Outcomes: External social structures (5S)

External social structures are also the outcomes of actions and can be elaborated, reproduced or changed by the event. If society benefitted from the provision of ecosystem services that were the result of a land cover action taken by the landowner, these benefits could be identified here. Some of these outcomes would likely be directly intended, or at least expected, while others were likely unintended. In the action of reforesting, landowners purchase seedlings and hire labor to help with plantation establishment. Results indicated that two-thirds (66%) of reforestation participants hired additional labor for planting which has some regional economic impact. Others have identified the establishment of additional mills and furniture factories and stores as direct external outcomes of reforestation establishment (Miranda et al. 2004) (Solid line F).

The manner in which the PES program has adapted and changed over time to include Global Contracts and working around lack of land title to include more small landowners are outcomes of landholders actions that were likely unintended (Pagiola et al. 2002). A landowner may not have expected that their own land use decision and involvement in the PES program would support the establishment of for-profit and not for-profit non-governmental organizations dedicated to providing forest plans, technical assistance, and monitoring compliance with PES contracts (Miranda et al. 2006). These would be examples of *unintended consequences* to external social structures as a result of landowner actions (Dashed line F). The final arrow from 4S to 5S indicates that the individual, changed or otherwise, still remains nested in the social system but with the potential to have a different role in a potentially changed system.

Outcomes: Internal ecological patch structure (4E)

The internal ecological structure of the patch will be maintained or changed by the disturbance. This will in turn alter or stabilize the dynamics in the patch mosaic. Therefore, it is critical to understand *how* the patch has been impacted by the disturbance as that will have consequences for the larger patch mosaic. Ecosystem structures and configurations have implications for the services that the land can provide. A natural forest will have a different ecosystem structure than a forest plantation or secondary forest regrowth or pasture and each will have its own capabilities in terms of providing services. Comparing baseline conditions to this outcome is where additional ecosystem services could be quantified ecologically and associated with land use actions that resulted in the 'new' patch ecosystem structure.

Land cover actions by a landowner result in a disturbance that may be either intended or unintended, however, ecological consequences will result regardless of intent (Solid and dashed lines G). Unintended ecological consequences of the landowner's action are critical for linked complex adaptive systems such as this where the ecological implications of our actions are not always known and highly uncertain.

In Costa Rica, the patch transition addressed here was largely from pasture to forest plantation. Early forest plantations were of non-native species and planted in monocultures including melina, teak, and pine among others while more recent efforts have been to establish native species. The mean forest plantation plot of PES program participants was 53.5 ha with a median size of 28 ha. These were the intended consequences of landowner actions and progress will be monitored by the actor during the next time period (Solid line D).

Likely unforeseen site consequences included forest plantations that had trouble with insects and disease, and the impacts non-native species plantations such as pine had on the soil (Miranda et al. 2006). Each of these was an unintended ecological consequence that monitoring could identify and could provide information for improved future management (Solid line D during next time period).

Outcomes: External ecological patch mosaic structures (5E)

As indicated, changes in the patch are at once changes in the patch mosaic because of their nested nature. At the landscape level, the type of change (size, shape, intensity) and the spatial location of change will be determinants of its impact on the larger mosaic (Solid line H). This level of analysis where additional ecosystem services could be quantified ecologically and associated with PES enabled land use actions that resulted in the 'new' patch mosaic and configuration of ecosystem structures. In the Corridor in Costa Rica, the Landsat images show an increasing amount and new arrangement of reforestation on the landscape throughout the study period (1986 to 2001) with the fastest rate of increase in reforestation from 1986 to 1996 when the incentives were first offered on a wide basis (Morse et al. 2009). Large increases in reforestation led to changes in forest connectivity (Morse et al. 2009). As the overall increase in reforestation across the landscape would be expected and was the intent of the incentive program and of some individual agents (Solid line H), the spatial arrangement was an emergent characteristic that was driven by individual agent decision processes. This emergent pattern would be considered and unintended consequence (Dashed line H). Additionally, the benefit of increased forest cover and connectivity for biodiversity and likely improved watershed services were benefits that were identified in landowner motivations, and therefore intended. However, this intent does not imply that the landowners knew the specific ecological process or had a specific idea of the amount of services they would contribute. Therefore, while intentionally targeted within the Corridor, the patterns and amount of benefits were unintended emergent phenomenon from the many individual landowner actions. The line from 4E to 5E is included to indicate that the new patch continues to be a nested component of the larger patch mosaic.

Feedbacks over time

Outcomes of actions are the original feedback to structures. However, in a continuous recursive process (of everyone's land use decisions occurring frequently over time) the feedbacks of one period become the structural context for the next time period. Feedbacks are indicated within each element of the system consistent with structuration theory and CAS which argue that local level actions/interactions continually re-create (or change) the structures for the next time period. These are the components that are actively monitored by the actor (or by the policymakers at the higher level) as part of the learning process of adaptive management. The inclusion of the latter part of the moniker—Feedback/time, in the label is a reminder that the temporal response within and across systems may vary. Some responses at the structural level may be immediate, but others may have a significant lag.

Some examples of feedbacks that have initiated changes in social structures include the continual adaptive evolution of Costa Rica's incentive program to improve access for small poor landholders (Grieg-Gran et al. 2005) and to better target the provision of ecosystem services (Wunscher et al. 2008). However, the Costa Rican government will likely be interested in continued monitoring of the impacts of these outcomes at the site (for compliance), regional, and national levels to identify their effectiveness at promoting changes to land use/ecosystem structure are successful.

Discussion and conclusion

The framework presented here was designed to comprehensively analyze conservation policy in the form of Costa Rica's program of payments for ecosystem services (PES) from policy implementation through actions/disturbance to ecological and social outcomes and feedbacks (Morse 2007b).While the framework outlines how it is possible to make the connection from land use decisions to ecosystem services provided, it is unclear if the ecosystem structures and configurations that are being promoted in the PES program actually provide particular amounts of the ecosystem services that are sought. This connection is an area of ongoing research and debate (Kremen 2005; Kosoy et al. 2007; Norgaard 2010).

A number of integrative frameworks and theories were consulted to help frame the social-ecological interactions for the original model (Giddens 1984; Grimm et al. 2000; Gunderson and Holling 2002; Levin, 1998; Machlis et al. 1997; Pickett et al. 1997; Wu and Loucks 1995). Each of these frameworks and theories identifies social and/or ecological variables and outlines connections among them. However, our framework is unique in that it outlines the temporal process of structuration to explain actor's action in context and how those actions, in turn, influence the external structures of linked SECAS. We believe that this framework, while building on and acknowledging those other research projects, provides an improved conception and/or explicit recognition of the following factors:

1) Application of social theory
2) Focus on the interactions of structure and action/disturbance; the duality of structure
3) The role of social and ecological structures as both enablers and constraints of action/disturbance
4) Decision-making processes of heterogeneous individual actors with different capabilities
5) Recognition of unacknowledged conditions and unintended consequences of actions
6) Conceptualization and visualization of the process of structural changes and feedback within and across social and ecological systems and across scales.

Addressing the first of these factors, social theory, has in turn rectified many of the remaining issues. While others have used pieces or concepts from structuration theory (in particular: Scoones 1999; Scheffer et al. 2002; Westley et al. 2002), we believe that our more inclusive application of the central tenets of the theory, and use of strong structuration in particular (Stones 2005), is a potentially significant advance on other linked human-ecological frameworks. Structuration is a theory of human complex adaptive systems and provides a theoretical framework for understanding human intent that CAS alone does not. Our framework then outlines the interactions among and across these linked social and ecological systems.

Within a social analysis, use of structuration theory shifts the focus from structural variables to the interaction of structure and agency, the duality of structure. The purposeful development of social structures and then responses to these structures by individual actors is missing from most social-ecological frameworks (Asah 2008; Pritchard Jr. and Sanderson 2002). Actors' actions create the structures which in turn enable and constrain actions in the next period in a recursive manner. Some of these are emergent structural factors while others are an intentional effort to design structures to achieve a desired result (Ostrom 2005). Understanding how these emerge or are created is critical to adaptively manage a resource.

In this framework, individual actors are the creators of social systems, but are also constrained or enabled by the social, cultural, economic, political and ecological structures that exist at any given time. Social order and social differentiation have been identified as key components modifying human capabilities (Grove and Burch 1997; Machlis et al. 1997; Pickett et al. 2001) and have an influence on how powerful an actor is and how irresistible social structures are (Stones 2005). However, it is the actions of individual actors who occupy levels of power that give relevance to that structural social order. Therefore, it is necessary to identify how these structures influences actions at the level of the individual actor to understand how agents with different capabilities behave under similar structural conditions. This will help to answer "why and how landowners do what they do on their property" (Grove et al. 2006, p. 579).

This framework also recognizes that individual actors are not uniform in their knowledge of social or ecological systems. The inherent 'unknowability' and unpredictability of linked social and ecological systems necessitates the consideration of these elements (Holling 1993). The explicit inclusion of *unacknowledged conditions* and *unintended consequences* as explicit areas for analysis is unique to this framework. Its inclusion is largely due to structuration theory's conception of the actor (individual, but also household, business, government agency) as varying in their access to and ability to harness knowledge of social and ecological structures and resources and the implicit understanding that this knowledge is often incomplete. Actors, in this imperfectly known world, are also reflective and capable of monitoring results and learning from their actions. The improvement of this knowledge over time is one of the critical elements of adaptive management (Berkes and Turner 2006).

The study of feedback loops and how structures come to exist and change has been identified as a key element for integrated social ecological systems research (Pickett et al. 2001) and for adaptive management (Scheffer et al. 2002). Many social ecological frameworks have not addressed how structures (i.e. policies, regulations, behavioral norms) are reinforced or changed by continual individual human responses to ecological and social conditions (emergent behavior), and fail to capture human reflexivity and intent to change or adapt structures when the results of actions are not desired (Ostrom 2005; Parker et al. 2003). This is the essence of Giddens (1984) duality of structure and essential for understanding adaptive management. The recursive feedback loop within ecological structuration remains consistent with the disturbance driven process as presented by complex adaptive systems (Levin 1998) and hierarchical patch dynamics (Wu and Loucks

1995), but now is linked in a coherent and meaningful way to individual actors and social systems.

What results is a framework for SECAS that compliments analysis of CAS with social theory to explain human actions and social structures that modify the environment and impact the ecosystem structures that provide ecosystem services. Application of this framework necessitates an understanding of actors that includes their motivations, knowledge and capabilities (actors looking in) and their knowledge of external social and ecological structures (actors looking out). This is the perspective of the situated actor. It also requires a broader investigation of the external social and ecological contexts since it is understood that there are both unacknowledged conditions and unintended consequences (the researcher looking at the context). It is suggested here that the framework is applicable to the study of SECAS in general, programs of payments for ecosystem services, conservation policy, land use change, and to urban ecosystems. It is hoped that the framework will be the subject of further elaboration in both design and application and of further empirical testing.

Acknowledgments This research was supported in part by NSF-IGERT grant no. 0114304.

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