Connectivity and the Governance of Multilevel Social-Ecological Systems: The Role of Social Capital

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Abstract

We discuss the challenges confronting environmental governance caused by the increasing connectivity of resource-use systems and the growing functional interdependencies of ecological and social systems. We take as a point of departure the case of the Xingu Indigenous Park (PIX) in Brazil and its surrounding agro-industrial region. This case provides a basis for reviewing the literature on resource governance, including both points of consensus and contentious issues. We argue that no fixed spatial or temporal level is appropriate for governing ecosystems and their services sustainably, effectively, and equitably. We point to the need to recognize the multilevel nature of such problems and the role of institutions in facilitating cross-level environmental governance as an important form of social capital that is essential for the long-term protection of ecosystems and the well-being of different populations.

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1. INTRODUCTION

Most scholars and policy analysts are aware that the ecosystems that many want to protect are embedded in different levels of social organization. These ecosystems, which are diverse forms of natural capital, exist at multiple levels on a spatial scale ranging from very small to global. Furthermore, flows of positive services or negative externalities from an ecosystem tend to affect other ecosystems at smaller or larger scales. Humans who use or are affected by these ecosystems are also organized through diverse forms of social capital at multiple scales (1). Proposals to protect these ecosystems by changing the institutional rules of use and by the way these rules are monitored and enforced, however, frequently focus on a single level. Most often this is at the level of national governments. A major thesis of this article is that institutions at (and linking) multiple levels are essential for the long-term protection of ecosystems. Focusing only at a local, regional, national, or international level is itself a source of inadequate policy design.

Scales: dimensions (e.g., space, time) used in ranking various phenomena. Levels are specific positions on any given scale

The growth of interdependency within resource-use systems resulting from the twin forces of economic globalization and global environmental change amplifies the need to understand and address interlinkages that (1) expand global market chains competing for land and water resources; (2) increase overlaps of government jurisdictions, regional and local forms of use, rights, and ownership (created through development programs, export policies, and parks and production reserves); (3) increase interregional migratory flows and interconnections between social groups in different regions; (4) create regional trade blocks, multilateral infrastructure, and international/transboundary conservation areas; and (5) amplify changes in global climate patterns affecting the distribution and frequency of rainfall, drought, and temperature change.

The intersection between institutions and economic chains operating at different levels, and facilitated by the growing physical connectivity of resource-use systems, can produce distinct patterns of cross-level interaction. As argued elsewhere by one of us (2), such interrelated patterns of institutional interaction can take the form of dominance, separation, merger, negotiation, or system change with diverse consequences for social-environmental systems.

The vertical interplay of institutions representing groups competing or cooperating for authority over resources requires one to look at questions of subtractability (i.e., whether resource appropriation by one user reduces availability to others) and exclusion (i.e., how costly it is to keep potential beneficiaries out of the benefit stream) from an ecosystemic and multiscale perspective (3, 4). Local forms of use and regulation of a resource (e.g., based on customary rules of use and exclusion), although potentially effective at one level, are affected

and in some cases overwhelmed by resource use in a different part of the larger ecosystem, as illustrated in this article by the case of the Xingu Indigenous Park (PIX) in Brazil. The functional interdependency of resource systems poses an important question regarding social capital: How do different types of management arrangements help facilitate solutions to intricate cross-level problems? As expressed by Cash et al. (5) in the context of comanagement structures, the complex nature of cross-level resource-use systems requires institutional arrangements that facilitate the coproduction, mediation, translation, and negotiation of information and knowledge within and across levels.

Institutions facilitating cross-level environmental governance become an important form of social capital. A more detailed discussion is presented below, but we want to start with a working definition of social capital as referring to the value of trust generated by social networks to facilitate individual and group cooperation on shared interests and the organization of social institutions at different scales.

Considerable agreement exists on the usefulness of eight institutional design principles[1] (6, 7) to explain why some governance arrangements for environmental resources at local and subregional levels are robust (8, 9). Translating these principles for application to higher levels of social organization remains a challenge (10–15) and is the focus of the eighth institutional design principle, "nested enterprises," which is the importance of nesting local and larger institutional arrangements to accommodate the goals and interests of groups organized at different levels. Important challenges are involved in scaling up institutional design principles and building up social capital for linking governance systems across levels of social organization (5, 6, 16–20). These include the following:

a. Fit: the challenge of linking spatial scale and units of analysis created by mismatches between environmental and institutional boundaries;
b. Boundaries: the challenge of recognizing competing rules of subtractability and exclusion operating in different parts of the same ecosystem;
c. Authority: the challenge of recognizing shifts in jurisdiction and authority over resources, including overlaps, at different levels;
d. Sanctions: the challenge of accounting for [a potentially] inverted correlation between compliance with rules and scale (i.e., level of compliance decreases as you move from local to international levels); and
e. Knowledge and information: the challenge of understanding problems of credibility, saliency, and legitimacy resulting from differences in knowledge systems and access to information at different levels and by different groups.

We address these concerns in the following order. Section 2 provides an example of a successful local effort to govern PIX, which has one main local level of governance associated with it. Initially, the threat of invasion around park borders led indigenous groups to identify mechanisms and forms of internal organization to enhance and enforce exclusion rules for non-Indians. Over time, however, the lack of larger governance units, with appropriate incentives to buffer the pressure created by international commodity markets (e.g., beef, soybeans, and lumber), has allowed extensive deforestation all around the protected park. Nested within the larger Xingu River watershed, the park has become the sink and corridor for multiple pollutants derived from the clearing of vegetation around headwater springs, overuse of fertilizer, and extensive smoke from forest clearing. Now PIX itself is threatened by externalities from the surrounding agricultural areas, given the lack of effective institutions organized at that level and between the park and its surrounding agricultural and urban systems. Perception and

Comanagement: a method for supplying governance that features cooperative decision making among users and public authorities

Governance: a social function centered on steering human groups toward mutually beneficial outcomes and away from mutually harmful outcomes

[1] 1. Clearly defined boundaries; 2. congruence between local conditions, appropriation, and provision rules; 3. adaptability of collective choice arrangements; 4. appropriate monitoring; 5. graduated and implementable sanctions; 6. mechanisms for conflict resolution; 7. recognized rights to organize; and, 8. nested enterprises.

detection of ecosystem changes inside the park have led indigenous groups to consider different levels of institutional arrangements needed to face problems resulting from changes happening at different levels and outside their jurisdiction. We conclude this section with a brief outline of the lessons to be learned from the PIX case. Multiethnic indigenous associations, municipal governments and associations, national nongovernment organizations (NGOs) supported by international donors and groups of farmers, among other actors, have emerged and illustrate forms of social capital functioning to mediate the vertical interplay among institutional arrangements.

Section 3 provides a more general discussion of what we mean by institutions as a form of social capital and of how some forms of social capital at multiple levels are essential elements of the protection of ecosystems services for humans. Section 4 builds on the previous sections to identify the requirements for success in governing complex and dynamic systems that exhibit high connectivity across levels of social organization and to discuss various ways to meet these requirements in situations featuring rising functional interdependencies.

2. THE XINGU INDIGENOUS PARK

Originally created in 1964 and demarcated in 1991, PIX has an area of 2.6 million hectares (ha) occupied by 14 ethnic groups with a total population (in 2005) of 5020. PIX territory overlaps nine municipalities and is surrounded by one of the most active agropastoral economic regions of Brazil. The Xingu River, one of the main tributaries of the Amazon River, extends 2300 km, links the states of Mato Grosso and Pará, and discharges into the Amazon River just below Marajó Island in the Amazon estuary. As a whole, the Xingu watershed encompasses 51 million ha, cutting across 35 municipalities, with a population of approximately 450,000, and 27 indigenous groups, with a population of approximately 10,000 (21, 22). The region is considered a national and international priority for biodiversity conservation and cultural patrimony.

The initial demarcation of PIX in 1964 left out significant portions of indigenous territories and the headwaters of most tributaries of the Xingu River. Coinciding with the creation of PIX, the federal government created incentives for regional occupation and colonization through the expansion of cattle ranching and farming. The actual process of regional occupation started during the 1940s with Getulio Vargas' "March to the West" initiatives. This process intensified during the 1970s and 1980s to include colonization settlements and tax incentives for cattle ranching. The region became one of the first to experience the expansion of soybean cultivation during the late 1980s and sprinted ahead as one of the main producers during the 1990s (23, 24).

Deforestation for the full region of the Xingu watershed added up to 2 million ha by 1994, 4 million ha between 1994 and 2003, and 1.2 million ha between 2003 and 2005 (see **Figure 1**). In contrast to the high rates of deforestation during the 1980s and 1990s in the broader region, PIX maintained nearly intact forest cover. Indigenous groups began to confront the occupation around PIX during the 1980s. Protecting park borders from farming incursions, logging, hunting, and fishing became an important priority for political organization and negotiations (22, 25).

During the late 1980s and 1990s, alliances among individuals and organizations led to the creation of several kinds of associations within the park, with the overall goals of taking control of park management and of coping with the growing pressure on its borders. These alliances were with government officials [e.g., officers from the National Indian Foundation (FUNAI)], NGOs [e.g., Socioenvironmental Institute (ISA)], church-based movements, high-profile celebrities (e.g., singer Sting), anthropologists, and physicians working in the region. In 1994, alliances among all 14 ethnic groups led to the creation of the Association of the Indigenous Land of Xingu (ATIX).

The perception of the "unwanted hug," as assessment reports describe the deforestation surrounding the park, led the new ATIX to prioritize the monitoring of borders and the creation of 10 monitoring posts, mostly at the intersections of borders and riverways entering the park. Support from outside organizations (e.g., ISA) and external financing led to the creation of effective boundary controls. Furthermore, a program was established to restrict entrance to PIX, to clean and demarcate trails, to effectively use global positioning system units, and to cooperate with organizations using remote-sensing mapping (at three-year intervals), and geographic information systems (GIS) (21, 22).

Although effective in protecting PIX and its borders, these actions were limited in curbing the intensity and extent of the deforestation around the Xingu headwaters and their impacts on water and land resources. Early in the 1990s, indigenous groups began to see signs of environmental impact within the borders of the park. They observed lower water volumes in some tributaries (resulting from sedimentation and dried water springs), increasing loads of sediments, and decreasing water transparency (making arrow fishing difficult). Higher levels of smoke and air pollution during the burning season and an increasing risk of fire spreading during dry years also became concerns. Little information on pesticide pollution has been available to evaluate change in water quality (22).

The process and signs of environmental change affecting the region (**Figure 1**) illustrate the problem of functional interdependence as environmental and social processes transcend the space and levels of management of a resource system (26). The environmental and social connectivity of the resource-use system (e.g., interconnected vegetation biogeography and watershed, and overlapping authority over different parts of the watershed) renders the success of management at one level dependent on another. Indigenous populations within the park, and a network of supporting organizations and agencies, recognize the cross-level nature of the problem they face and are seeking new forms of horizontal and vertical linkages. One of the horizontal strategies under negotiation is an expansion of the indigenous territory through alliances and support to other ethnic groups claiming land rights and demarcation in areas contiguous to the park and related watershed tributaries (two watersheds are already demarcated, four have started the process) (21). In order to start building vertical linkages from the ground up, they are engaging in alliances with municipal governments and agencies to mediate agreements with economic sectors, educate the regional population about indigenous peoples, and create incentives for restoration. They also have engaged in extensive mapping and GIS-based surveying in collaboration with national NGOs, and to some extent with FUNAI, of all neighboring farms and properties bordering the park. Furthermore, they have created national and international public campaigns and celebrity alliances to spread the cause. Farmers also have been engaged in forest restoration, although only sparsely, along riverways, and some municipalities seem inclined to be involved in solving the problems (22).

At the same time, problems and uncertainties continue to exist, reminding us of the long-term consequences of development plans (e.g., national transportation networks and colonization schemes) and the strength of global commodity markets in shaping short-term land-use decisions. The federal government continues to invest significantly in programs to expand infrastructure and agro-industrial development in the larger region surrounding the park. There is slow but improving federal monitoring of deforestation in the region, and there is an interest in environmental zoning on the part of the state. But prospects for continuing intensive agropastoral use and expansion are high as are the costs of reverting environmental degradation. The growing complexity of resource-use systems in the region requires new ways of thinking about integrating economic development, conservation, indigenous rights, and national export goals as parts of the same equation.

2.1. A Key Lesson: The Need for Multiple Levels of Analysis and Organization

The case of PIX illustrates a puzzling phenomenon that is replicated all over the world wherever we try to identify an ecosystem and its services at a particular level to understand who is using it, what the consequences are, and what type of governance arrangement best fits its level. In this example, we see how indigenous peoples, who were long ago given formal rights to preserve a park, have done an amazing job of preservation. At first, it would appear that the governance system of PIX has been established at the appropriate level, given the control over deforestation achieved within its borders.

Many of the benefits of the park indeed have been obtained by the indigenous people, who organized themselves effectively to preserve it according to their views and forms of using the environment. When we look at the larger region and watershed, however, as illustrated in **Figure 1**, it becomes apparent that this ecosystem is not isolated. Protection inside PIX affects and is affected by larger ecosystems surrounding it. The region has experienced an exponential expansion of deforested area through large-scale clear-cutting and extensive use of fertilizers and machinery. As more and more farmers and corporations have moved into the region, they have engaged in massive deforestation to open lands for farming. Then, as farmers in the region have been able to sell products to the global market and support has grown through export policies of the federal government, they have become more and more interested in increasing yields. As a result, clear-cut deforestation of headwaters and streams, a strong rainy season, and limited soil conservation practices have increased proportionally surface runoff and the load of sediments into the basin. In addition, increased use of fertilizers and pesticides is leading to an increased runoff of nitrogen and pollutants. These runoffs are negative externalities that adversely affect the larger watersheds within and outside PIX. A single governance system at the park level is adequate to control many activities within PIX, but it is not broad enough to affect the ecosystem disservices from the surrounding region.

It is important to recognize significant differences in the ways indigenous groups within PIX and surrounding populations perceive and value the environment (26a). Different from the views of recently arrived farmers who may see the forest as a threat and the environment as sets of resources to be transformed, the environment as a whole is an intrinsic part of indigenous cosmology and an organic part of their economy. Detailed intergenerational knowledge about forest and water resources, cultural attachment to place, and customary rules of use and resource appropriation hinder indigenous groups from carrying out short-term and large-scale transformations that are characteristic of recent migrants, who are large- or small-scale farmers (24). The distribution of deforestation within and outside PIX represents, among other things, such a clash of perspectives. In looking for solutions, indigenous people were the first to acknowledge the need to search for meta-perspective, one that will eventually lead different social groups to reconcile their views and uses of natural resources with those of others in the larger ecosystem within which they live.

Stepping back to observe deforestation in the broader region, we can see that the spatial pattern itself is affected by the park. During the past four decades, the distribution of major road corridors and settlements on all sides of PIX has shaped the patterns of occupation and land cover of the larger central and north regions of Brazil, which in turn affect other sets of large and small watersheds. Settlement surrounding PIX expanded progressively as various cohorts of farmers moved into the region and responded to commodity prices and an active land market. The intersection of long-term colonization and agricultural expansion policies and globalization of markets has increased the market value of cleared land, and local and neighboring landowners are making decisions that are based on the opportunities available to them, leading to a swath of deforestation around the park.

The central message we wish to convey in this article is that no fixed spatial or temporal level is appropriate for governing ecosystems and their services effectively, efficiently, and equitably on a sustainable basis. This conclusion will drive some analysts to despair because everything is presented as being complex and multilevel. It is not our intention to broadcast a message of despair. Rather, our analysis leads us to recommend a different style of scholarship from the dominant orientation of many social and physical scientists who study social-ecological systems. Many social scientists and policy analysts believe that all analysis should follow the practice that is referred to as KISS—Keep It Simple Stupid. It is important to consider that when confronting complex, nested systems, efforts to keep it simple may themselves lead to undesirable outcomes.

We do not advocate making research and policy analysis complex for complexity's sake. We suggest the need for a multilevel diagnostic approach to examining relationships at each relevant level and the fit and interplay among levels (2, 13, 18, 26, 27). We need to recognize that most resources have horizontal impacts on other resources at a similar spatial level and vertical relationships upward and downward to systems that are larger or smaller. We should build social capital that enhances the long-term sustainability of natural capital at multiple levels on scales of relevance to particular ecological resources (28).

3. FORMS OF CAPITAL AND THE MANAGEMENT OF SOCIAL-ECOLOGICAL SYSTEMS

In our view, human-made capital, which we understand to include physical, human, and social forms of capital, is critical to addressing these complex governance problems.[2] We discuss, in particular, differences between social and other forms of capital and highlight the conditions that guide the formation of institutional arrangements for governing use and management of natural resource systems. All forms of human-made capital are created when individuals spend time and effort in transaction and transformation activities to build tools or assets today that will increase individual and social welfare in the future (see Reference 30 for a discussion of transformation and transaction costs in the provision and production of goods and services). In other words, "people form capital when they withhold resources from present consumption and use them instead to augment future consumption [or production] possibilities" (31, p. 153). The essential role of human-made capital in creating differential conditions for human well-being, including the management of ecosystems (e.g., References 32 and 33), is frequently acknowledged, but it is often poorly understood. Unfortunately, human-made capital is sometimes equated only with money, which is the means by which forms of physical, human, and social capital may be obtained. However, many types of capital can be created without money, or with very little money, based instead on the time and energy spent by individuals in building tools and facilities, learning skills, and establishing regularized patterns of relationships with others. Particularly contentious is the (pluralistic) understanding of social capital. The term social capital has a history that dates back to the nineteenth century as a reference to the value of social networks, but it was formally defined during the 1970s by the works of Bourdieu (34, 35) and Loury (36) and popularized by Coleman (37) and particularly Putnam (38, 39) and colleagues (40) during the 1990s. In its uses by Bourdieu, Loury, and Coleman, social capital tends to be defined at the level of individuals and their extrafamilial networks. Since its use and wide popularization by Putnam, however, it has been progressively adopted as a reference to the assets of larger systems of social institutions and organizations, a trajectory that has produced advantages and disadvantages with

Transaction activities: the relationships among involved individuals that take time and energy to accomplish the transformation activities

Transformation activities: physical inputs that are transformed into outputs, which may be used for further transformation activities or consumed

[2] As a consequence, we are not focusing on natural capital, defined as the inheritance that all humans receive from nature in the form of terrestrial, oceanic, and atmospheric resources that generate flows of services, called ecosystem services, and that are essential to human welfare (29).

regard to the heuristic value of the concept (e.g., Reference 41), an issue we will return to later.

Although frequently used by analogy with other forms of capital, the idea of social capital is controversial. Some theorists have even argued that social capital is not really a form of capital at all (see References 42 and 43). As is true of other forms of human-made capital, social capital involves creating new opportunities as well as exercising restraints, a risk that the investment will fail, and the possibility of using capital to produce harms rather than benefits (this section draws partially on Reference 44). Nevertheless, although apparently less tangible, it shares enough characteristics with the well-understood concepts of natural, physical, and human capital to make its treatment as such appropriate (see also Reference 45).

3.1. Physical Capital

Physical capital is the stock of human-made, material resources that can be used to produce a flow of future income (46). Physical capital exists in a wide variety of forms, including buildings, roads, waterworks, managed landscapes, tools, cattle and other animals, automobiles, trucks, and tractors, to name just a few. The origin of physical capital is the process of spending time and other resources constructing tools, plants, facilities, and other material resources that can, in turn, be used in producing other products or future income. Investments in physical capital are usually conscious decisions. When one builds a factory or a school, decisions have to be made regarding location, size, architectural design, parking facilities, and landscaping to mention some of the self-conscious decisions involved in building physical capital. Human and social capital are sometimes developed as by-products of other activities as well as self-consciously.

The construction of physical capital involves establishing physical restraints that (1) create the possibilities for some events to occur that would not otherwise occur (e.g., channeling water from a distant source to a farmer's field) and that (2) constrain physical events to a more restricted domain (e.g., water is held within a channel rather than allowed to spread out). Thus, physical capital opens up some possibilities while constraining others. The intention to construct useful physical capital is not always fulfilled. An investment in physical capital may not generate the improved flow of future services. A new but crumbling roadway or irrigation system or an empty building represents a failed investment decision, whereas in other cases, physical capital may lead to dominance and control of resources by particular groups with lasting effects on patterns of access and distribution.

Physical capital may have a dark side and generate more harms than benefits. Investment in a weapons facility increases the quantity of physical capital existing at a particular point in time, but the product of this form of physical capital is the threat of human destruction. Even investments in the production of consumer goods can generate substantial externalities as when production requires heavy use of a source of power emitting carbon into the atmosphere. Physical capital cannot operate over time without human capital in the form of the knowledge and skills needed to use and maintain physical assets to produce new products and generate income. If physical capital is to be used productively by more than one individual, social capital is also needed. A fair number of negative externalities and development failures have in common a functional unbalance within and among these different forms of capital.

3.2. Human Capital

Human capital is the acquired knowledge and skills that an individual brings to an activity (47–50), and forms of human capital can differ within each type. An education gained in college is a different type of human capital from an education acquired through apprenticeship training. Human capital is formed consciously through education and training as well as unconsciously as a side benefit of other activities. An individual who swims for pleasure, for example, is engaging in a pleasant activity and also

improving his/her physical health. Health is an asset that is drawn on to achieve other goals. Alternatively, some individuals dislike swimming or using stationary bicycles but do so because they know that aerobic exercise is essential for sustaining future capabilities. They exercise primarily to invest in human capital and then find ways to make this activity as pleasant as possible. Both self-conscious and relatively unconscious investment processes go on when building human capital.

Human capital consists of the acquisition of new capabilities as well as the learning of constraints. Learning a new language opens up different conceptions of the world. Many of the skills that individuals acquire involve the imposition of discipline on self. Like physical capital, human capital can be used for destructive purposes as well as productive ones. An individual knowledgeable in computer languages can use this skill to write programs today that help solve problems in the future. Those who write programs to function as viruses, which invade and destroy the records of others, use their human capital for destructive purposes. The relative value of human capital can vary significantly across social levels and among social groups. For instance, forms of knowledge valued at one level may not be recognized as legitimate at another level or by a different group. Effective cross-level interaction requires the buildup of social capital stocks to help facilitate knowledge coproduction, mediation, translation, and negotiation across levels (5).

3.3. Social Capital

The use of the term social capital by Bourdieu (35) and Coleman (51) has much in common as it refers to the way individuals and extrafamilial groups use social capital to facilitate social mobility or reproduce privileged access to certain kinds of resources, such as employment, education, and social positions. During the 1990s, however, Putman (38, 39) emphasized social capital as a feature of organization at a societal scale (e.g., municipalities, countries), in other words, as a civil asset of societies often framed in terms of its positive qualities. His application of the concept comes close to the way institutions and institutional arrangements have been conceptualized. In this sense, social capital refers to rules and norms underlying social behavior and order and representing particular forms of organization in society. The drawback, as put by Portes' competent review of the term (41, pp. 19–21), of stretching the term from local to larger scales is the potential for the "logical circularity" it creates, where the positive outcomes of social capital (e.g., a successful city) are also explained by its causes (e.g., successful civic communities).

Yet, the central problem discussed by this review—the intersection between horizontal and vertical interplay of institutional arrangements facilitating the management of natural resources—lies at the complementarities of both definitions of social capital. In other words, Bourdieu's (35) and Coleman's (37) small-group assets facilitate, in our case, the governance of local resource systems, and Putnam's (38) idea of civil assets of society recognizes, for the purpose of our argument, that local networks are embedded within larger social and ecological systems (e.g., a watershed) in ways that affect the success at both levels. At least in the case of resource management, the outcomes of shared interests within one level depend on the articulation of shared interests between levels. We call attention to the value of nesting these two dimensions of social capital to discuss the importance of articulating both levels of institutional arrangements in society. This is a requisite created by the increasing interconnectedness of ecosystems and resource-use systems. This approach is somewhat similar to Putnam's (39) characterization of the bonding (connections within a group's network) and bridging (connections between groups' networks) dimensions of social capital.

In this connection, we discuss the value of institutions as a form of social capital formed through diverse processes involving the development of trust, norms of reciprocity, and networks of civic engagement, including the rules and laws within and between levels of

organizations. Each condition affects the expectations that individuals have about patterns of interactions that groups of individuals bring to a recurrent activity at local or larger levels. Thus, we reassert the heuristic usefulness of the concept, not as defined within a single level, but representing the value of social networks in mediating shared interests at the levels of the individual, communities, and society as a whole.

There is a neutral quality to social capital because it can lead to both positive and negative outcomes of competing interests. When humans face social dilemmas or collective-action situations, such as those involved in regulating ecosystems, participants may easily follow short-term, maximizing strategies that leave them all worse off than other options available to them. Somehow participants must find ways of creating mutually reinforcing expectations and of trusting they will overcome the perverse short-run temptations they face (52). Agreements can be based on mutual learning about how to work better together. They can be based on one person's agreeing to follow someone else's commands regarding this activity. Or, they can be based on the evolution of a set of norms and/or the construction of a set of rules whereby an activity will be carried out repeatedly over time, commitments will be monitored, and sanctions will be imposed for nonperformance.

Like other forms of capital, social capital opens up some opportunities and closes down others. A decision to establish majority rule as the decision rule for making particular collective decisions, for example, opens opportunities that did not previously exist. Voting does not exist in nature. The opportunity to vote is created by rules. By contrast, new rules that limit the slope of land on which a farmer may plant or the width of the unplanted edge next to a river, for example, may restrain activities to a more limited set than previously available.

Social capital may also have a dark side. Gangs and the Mafia use social capital as the foundation for their organizational structures. Cartels also develop social capital in their efforts to maintain control over an industry to reap more profits than would otherwise be possible. Government corruption schemes and networks also illustrate a form of social capital used to manipulate power and public trust to divert physical capital to the detriment of the larger society. An authoritarian system of government, which is based on military command and uses instruments of force, destroys other forms of social capital while building its own. These commonalities are not shared with physical capital and are the source of substantial differences between these two forms of human-made capital.

3.4. Differences Between Social and Other Forms of Capital

Although all forms of human-made capital have some things in common, important differences also exist among physical, human, and social capital. Here, we focus on four key differences between social and physical capital.

- Social capital does not wear out with use but rather improves with proper use and deteriorates rapidly with disuse.
- Social capital is not easy to see and measure.
- Social capital is hard to construct through external interventions.
- Social capital operates most effectively when it is organized in complementary forms at multiple levels.

Many of these differences are due to the importance of shared cognitive understandings that are essential for social capital to emerge and to be transmitted from one generation to another (37, 51, 53).

First, social capital differs from physical capital in that it does not wear out with use but rather improves with proper use and deteriorates rapidly with disuse. Use of physical capital such as irrigation systems, highways, and buildings always involves wear and deterioration without extensive maintenance activities (54, 55). Social capital may, in fact, become more valuable the more it is used as long as participants continue to keep prior commitments and maintain reciprocity and trust (56–58).

Trust grows with repeated interactions where participants show each other that they are trustworthy. Using social capital for an initial purpose creates mutual understandings and ways of relating that can frequently be used to accomplish entirely different joint activities at much lower start-up costs (38, 59). It is not that learning curves for new activities disappear entirely. Rather, one of the steepest sections of a learning curve—learning to make commitments and to trust one another in a joint undertaking—has already been surmounted once a group has solved this problem for at least one joint task. A group that has learned to work effectively together in one task can take on other similar tasks at a cost in time and effort that is far less than bringing an entirely new group together who must learn everything from scratch. For instance, although it took significant effort to form a multiethnic indigenous association for PIX (e.g., ATIX), achieving a similar level of cooperation and trust between Indians and neighboring farmers has been far more challenging. The ease of transferring the social capital acquired in relationship to one activity is more limited than the ease of using physical or human capital across activities. No tool is useful for all tasks. Instead, different tools are needed to address different patterns of expectation, authority, and distribution of rewards and costs across groups.

If unused, social capital deteriorates rapidly. Individuals who do not exercise their own skills also lose human capital rapidly. As time goes on, some individuals enter and others leave social groups. If newcomers are not introduced to an established pattern of interaction as they enter (through job training, initiation, alliances, or any of the myriad ways that social capital is passed from one generation to the next), social capital dissipates through turnover in group membership. Eventually, no one is quite sure how a particular joint activity used to be done. Either the group has to pay most of the start-up costs all over again or forgo the joint gains they had achieved at an earlier time. The same is true when distinct social groups aim at cooperating under conditions of competing economic and political interests, as in the case of Indians and farmers around the park. The social capital necessary for cooperation will require consistent and sustained levels of trust and reciprocity. Even so, these relationships can be dismantled by surprisingly small triggers (e.g., a gossip, an individual disagreement, an accidental fire).

Second, social capital is not as easy to find, see, and measure as physical capital. The presence of physical capital is usually obvious to external onlookers. Health centers, schools, and roads are easy to see. Social capital, by contrast, may be almost invisible unless serious efforts are made to inquire about the ways in which individuals organize themselves and the rights and duties that guide their behavior, sometimes with little conscious thought (60). Even when asked, local residents may not fully describe the rules they use. Yoder (61) warns those interested in helping farmers that they must probe deeply and in nonthreatening ways to get adequate information on the rules used to allocate water and maintenance duties within irrigation systems. "Intimidated by the higher status of officials, they may fail to communicate the details of the rules and procedures they use to operate and maintain their system" (61, p. 39). Common understanding is frequently hard to articulate in precise language, particularly when status differentials make communication difficult in the first place. If external agents of change do not expect that villagers have developed some ways of relating to one another that are productive in the setting in which they live, they may easily destroy social capital without knowing what they have done. If past social capital is destroyed and if nothing takes its place, the well-being of those involved can be harmed rather than improved by external "help."

Researchers or project workers interested in social capital cannot assume from the outside that a group has (or has not) established common understandings that enable its members to rely on each other to behave in ways that are predictable and mutually productive (62). The presence of words on paper or a building with a name on the outside is not the equivalent of the common understandings that are

shared among participants. The self-organizing processes that social capital facilitates generate outcomes that are visible, tangible, and measurable. The processes themselves are much harder to see, understand, and measure. It is not surprising that, in the "war of numbers" and gross domestic products, political investments tend to prioritize physical capital as a development mechanism to the detriment of social and human capital that in fact are necessary to sustain and distribute the benefits generated by the physical assets.

Third, social capital is harder than physical capital to construct through external interventions. A national government or a donor can provide the funds to hire contractors to build a road or line an irrigation canal or to support a local agricultural mechanization project, but building sufficient social capital to make an infrastructure operate efficiently requires knowledge of local practices that may differ radically from place to place (63). Organizational structures that facilitate the operation of physical capital in one setting may be counterproductive in another. Local knowledge and respect of local forms of organization are essential to building effective social capital able to promote cumulative improvements in local conditions beyond the influx of external subsidies usually associated with development projects (64, 65).

Creating social capital that makes physical capital operational over the long run or protects natural capital from being overharvested is not as well understood as the technology of constructing physical capital. For private-sector activities, important aspects of entrepreneurship are bringing relevant factors of production together and effectively integrating them. Aspects of these skills are taught in schools of management and learned in the workplace through experience. The incentive to create social capital related to private enterprise is attributed to the profit motive. A great deal of what private entrepreneurs do is to create networks of relationships that increase the profits that can be obtained (66). The private entrepreneur then keeps the residuals from creating and sustaining social capital. For Commons (67), the "going concern" (social capital) includes the informal rules that members of a firm develop to relate to one another in a productive fashion when using a physical "plant" (physical capital).

The incentives and motivation of public entrepreneurs, who provide public goods and services, are not as well understood as those of private entrepreneurs (68, 69). In an earlier era, the theory of bureaucracy posited public officials who ascertained the public interest and were motivated to achieve it. More recent analyses of public bureaucracies are less optimistic about the capacity of public officials to know the public interests or to undertake the least costly ways of providing and producing collective goods. Instead of being viewed as if they were automata who do what they are told to do in the most efficient way, public employees are viewed in much of the recent public-choice literature (and as much in the eyes of the people) as individual actors pursuing their own interests (70, 71). This may or may not generate net public goods, depending on how well the rules affecting their incentives help induce high performance. Simply turning over the task of creating social capital to make physical and human capital more effective to a public bureaucracy may not generate the intended results unless officials are strongly motivated to facilitate the growth and empowerment of others (72, 73). Instead, the social capital created may be the organization of limited networks of individuals or cliques that engage in mutual reciprocity at the expense of the larger group they are supposed to be serving (74, 75).

Fourth, social capital operates most effectively when it is organized in complementary forms at multiple levels (16, 76). An important attribute of social capital, and one that is essential to understand in analyzing and designing appropriate governance arrangements related to human-environment interactions, is that the social capital present or absent at one level may enhance or retard the effective development of social capital at other levels (77). When social capital is based on common values held across groups operating at diverse levels, it is a valuable resource for solving multilevel problems.

A major problem arises when different groups within a society, whether interacting at the same or different levels, are advocates of different uses of physical and human capital and thus create competing forms of social capital. Under such circumstances, social capital can have a negative value by becoming a barrier to collective improvement and a source of conflict. Returning to our example of PIX, a local organization of indigenous peoples was able to draw on horizontal linkages with other organizations to establish a very effective protected park. Because of vertical linkages with national NGOs using GIS and remotely sensed data, the PIX population has also become more aware of the impacts on PIX of deforestation and farming practices in areas surrounding the park. The absence of any effective governance system, however, to coordinate conflicting goals of farmers and Indians renders efforts on one side (park border protection) inadequate to deal with land-use activities on the other side (e.g., deforesting the watershed and using fertilizers outside the park to maximize economic return).

Some analysts might contend that what we have shown with this example is that PIX is too small and should be replaced by a government-owned and -managed forest at a larger scale. That is not the conclusion we draw from this example. Nor would we recommend that the boundaries of PIX itself be extended as the main solution to the problem. PIX has been remarkably successful in protecting the area under its jurisdiction—more successful than many national forests in Brazil and other Latin American countries (see, for example, the discussion of the Maya Biosphere Reserve in Guatemala in the Supporting Online Material for Reference 6). What is missing is social capital—institutionalized rules that are considered legitimate, monitored, and followed—at a larger scale that is focused on the extent of deforestation and the agricultural activities of farmers responding rapidly to the global market.

In other words, linked governance arrangements that deal effectively with the functional interdependence of the ecosystems in this region of Brazil are missing. Young (26) has outlined some of the key elements of linked governance systems to cope with small, medium, and very large ecosystems and their interties.

4. CONNECTIVITY AND THE SUPPLY OF GOVERNANCE

We have learned a lot over the past several decades about the performance and robustness and resilience of governance systems, construed as a form of social capital, that communities establish and rely on to guide human-environment interactions in a variety of settings. Here, we draw on the discussion of various forms of capital in the preceding section to evaluate recent work on environmental governance and to consider the application of this work to situations characterized by rising levels of horizontal and vertical connectivity.

Work on small-scale societies has demonstrated that the tragedy of the commons is not inevitable. Substantial variation in outcomes occurs from one setting to another. Nevertheless, many small-scale societies have managed to develop systems of rights and rules governing human uses of natural resources, and they have done so in a wide range of settings without resorting to either privatization or the creation of governments or public authorities to do the job (6, 78–80). A complementary literature has developed that addresses similar issues at the macrolevel. It analyzes efforts to create governance systems to manage human-environment interactions at the international level and often at the global level (81–83). This literature, too, seeks to account for variation in the successes of individual regimes and to examine the causal mechanisms that make some arrangements more effective than others. Of course, this situation leads to questions regarding the extent to which findings about the performance and robustness and resilience of governance systems derived from the study of small-scale societies can be scaled up to apply to similar systems operating at the macrolevel and vice versa. Although good reasons exist to be cautious in this endeavor, there is no doubt

that comparing findings developed at different levels is a fruitful enterprise (2, 5, 84–88; 13, Chapter 6).

For the most part, these studies have treated human-environment interactions occurring in specific settings as isolated or self-contained in the sense that links to the outside world are weak enough to allow them to be set aside for purposes of analysis. The analytic attractions of this strategy are apparent. The study of governance systems dealing with human-environment interactions in discrete settings is complex enough, especially when the systems in question are dynamic. Yet, we now know that the assumption that individual settings are self-contained is at best a naive one (64). As the case of PIX demonstrates, rising connectivity is increasing both horizontal and vertical links between settings and making it increasingly risky to abstract away the role of outside forces by assumption. Many specific forces are at work in moving us toward a world of increased connectivity (89). But the twin forces generally labeled global environmental change and globalization have pushed connectivity to unprecedented levels; we can no longer afford to ignore the impacts of connectivity in thinking about the governance of human-environment interactions (90).

4.1. Functional Interdependencies

As our example of PIX makes clear, connectivity can take a number of forms. Functional interdependencies can involve both biophysical and socioeconomic links. Land-cover changes in areas adjacent to the park have major consequences for the status of PIX's ecosystems. Land-cover changes are affected in turn by a variety of socioeconomic factors, such as the prevailing systems of land tenure, the operation of global markets, the development of infrastructure (e.g., transportation systems), and policy initiatives on the part of Brazil's federal government. Similarly, actions taken in one setting can produce major impacts in areas that are far removed from the site of the actions. Agricultural practices in the U.S. Midwest play a critical role in producing the "dead zone" in the Gulf of Mexico. The use of pesticides, e.g., DDT, produces impacts thousands of kilometers away from the locations in which they are applied.

The resultant interdependencies can involve, often simultaneously, connections that are horizontal and vertical in nature. Clearing land in the Amazon for the purpose of cattle ranching and building dams on major river systems to generate hydroelectricity have far-reaching consequences for ecosystems located in adjacent areas, but cross-level impacts are prominent as well. The biophysical consequences of clearing forested areas in Honduras (60) to grow coffee are determined in part by the dynamics of the global coffee market. Because of the endemic nature of many species within the so-called biodiversity hot spots, local actions in ecological hot spots make a difference in efforts to conserve biological diversity through global efforts under the provisions of the Convention on Biological Diversity (**http://www.cbd.int/convention/convention.shtml**).

Underlying and intensifying all these links is the fact that we now live in a world of human-dominated ecosystems in which it is essential to focus on the dynamics of social-ecological systems rather than on biophysical or socioeconomic systems treated as separate or distinct entities (91–94). Under many circumstances, the dynamics of these coupled systems generate nonlinear changes, tipping points, and emergent properties that have far-reaching consequences for human-environment interactions. A practical implication of this development for an area like PIX is that efforts to govern these interactions must begin with the realization that levels of uncertainty will always be high and that surprises or unexpected developments must be treated as the norm rather than the exception (95–98).

Rising connectivity can cut both ways in terms of its implications for the robustness and resilience of social-ecological systems. Connectivity makes it possible for disturbing forces, such as diseases and financial crises, to spread throughout a system at a rapid pace. Yet, it also

can accelerate learning processes, as those responsible for dealing with problems in particular areas find it easier to compare notes and learn from each other's experiences (27, 33). An especially serious concern develops when the rise of connectivity is a random process in contrast to a process characterized by coevolution and mutual adjustment through time (89). Random connectivity is more likely to give rise to tipping points that trigger system flips or regime changes, shifting social-ecological systems from desirable to less desirable domains of attraction that are difficult to escape once the relevant systems settle into them (99–101).

4.2. Implications for Governance

The overall implications of the rise in connectivity for governance are clear. Arrangements that seem to work well in more-or-less isolated settings are often ineffective or even counterproductive when adopted in settings featuring high levels of functional interdependence (102). Systems of locally generated and enforced rules that work well in governing the activities of subsistence fishers, traditional reindeer herders, or gatherers of uncultivated plants, for instance, experience extreme stress and even collapse when commercial fishers become active, reindeer products are exported to distant markets, or commercial timber harvesting disturbs the habitat for various plants (103–104a).

As the concept of "roving bandits" suggests, these impacts may be largely horizontal in nature (105, 106). That is, commercial harvesters of fish or timber may simply move from one area to another when local supplies are exhausted rather than making a commitment to stay in one location and develop incentives to manage the consumptive uses of the relevant resources on a long-term and sustainable basis. Often, this leads to ownership or control of harvesting operations by distant decision makers who have little or no knowledge of local conditions, strong incentives to think in terms of commoditized products, and little interest in the maintenance of ecosystem services that are important to local users. The differing perspectives of the permanent residents of PIX and the newcomers in surrounding areas illustrate this problem clearly.

Connectivity also means that users of ecosystem services can be expected to take actions that have profound impacts on users located far away from their areas of operation. The use of atmospheric or riverine systems as repositories for wastes provides particularly dramatic examples. As long as the atmosphere is available free of charge as a repository for emissions of greenhouse gases, it is predictable that producers of such emissions will use this "factor of production" to the maximum extent possible. Because Earth's climate system is planetary in scale, the impacts of climate change will be felt throughout the system. Changes now occurring in the Arctic, an area whose contribution to greenhouse gas emissions is negligible, provide a variety of dramatic examples ranging from beach erosion in coastal communities to the melting of permafrost and infestations of destructive insects in subarctic forests (107).

As a result, governance systems arising in one area (e.g., spatially defined fisheries' regimes) can affect the operation of similar regimes in other areas (e.g., by driving fishers from one location to another, making it attractive for polluters to move their operations to new locations), and arrangements developed at one level of social organization (e.g., the state or regional level) can have major impacts on arrangements operating at other levels (e.g., traditional rules pertaining to the harvest of living resources at the local level) (108, 109). As long as the effects of the resultant institutional interplay are of a limited nature, it may make sense to avoid the complexities arising in such situations. Nevertheless, when these interaction effects become important determinants of the success of governance systems, we can no longer afford to ignore them. As our case study of PIX suggests, the impacts of global environmental change and globalization have now created conditions in which institutional interplay of a de facto or unintended nature has become a major factor in many social-ecological systems (110). This situation suggests that it is time to

think about these interaction effects systematically and to devise ways to address them that at least minimize interference and that may even turn up opportunities for synergistic interactions among governance systems operating in different settings and at various levels of social organization (111).

4.3. Limits to Mainstream Responses

So far, those responsible for managing human-environment interactions have developed two main strategies in their efforts to adapt governance systems to the functional interdependencies associated with increased connectivity. One moves management responsibility to higher levels of public authority. The other, often associated with the idea of subsidiarity, takes the opposite track, shifting management responsibility to lower levels. Although the rationale behind each response is easy to understand and persuasive to a point, neither response is adequate to address problems of governing human-environment interactions in situations featuring high levels of connectivity, such as PIX (112–114).

The first strategy is well illustrated by the history of fisheries and wildlife management as well as the governance of river basins. Starting in the nineteenth century and extending through much of the twentieth century, prevailing practices featured an expansion of the role of higher levels of authority (115). The growing role of the U.S. federal government in managing fisheries through the assumption of authority over the Exclusive Economic Zone (see Part V, *United Nations Convention on the Law of the Sea*, **http://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf**), in managing wildlife through the exercise of the interstate commerce clause of the *Constitution of the United States of America* (see Article I, Section 8, clause 3, **http://www.archives.gov/exhibits/charters/constitution_transcript.html**), and in exercising its authority over international affairs (in the case of highly migratory species) is a familiar story. So also are the stories of the development of interstate compacts and the expanded role of the federal government in managing uses of the waters of the Colorado River and other major rivers of the West (116).

This strategy certainly has merit. It does not, however, constitute an effective means of dealing with a number of major issues arising from human-environment interactions in distinctive areas like PIX. These interactions are to a significant degree place based. Naturally, some commonalities exist among distinct places. Yet, the differences are sufficiently large to produce serious unintended and unforeseen results when uniform policies and management strategies are articulated and implemented at higher levels of social organization. Managers operating at the national level are often out of touch with local users, who understand the character of spatially defined social-ecological systems better than distant managers and have an intense interest in the governance of specific places. As a result, national management can easily slip into a mode featuring ignorance or even incompetence on the part of distant managers, producing feelings of illegitimacy and resistance on the part of local stakeholders. This makes it easy to understand the occurrence of protracted battles over proposals to shift management authority back to the people who know and live with the social-ecological systems in question.

The idea of subsidiarity, featured most prominently in recent European practice, takes the opposite track (117, 118). Just as advocates of national or central authority point to linkages of various sorts, those who advocate subsidiarity are sensitive to the propositions that local users will have the best understanding of smaller social-ecological systems and the greatest incentives to find ways to use the relevant resources sustainably. They propose to shift management authority to the lowest level capable of managing the relevant social-ecological system effectively. The recognition of use rights and devolution of partial authority over resources given to so-called traditional populations in Brazil since the mid-1990s illustrates an approach reflecting the idea of subsidiarity

(119). In fact, similar devolution policies have become widespread in Latin America and other regions during the past two decades.

This is, however, exactly where the problem is exacerbated. Given the rising levels of functional interdependence and systemic connectivity we have described, the idea that we can safely turn management authority over to local or even regional officials is untenable. Just as distant managers are apt to be ignorant of and insensitive to local considerations, local managers tend to know little about linkages to larger systems and the interests of those who are not physically present at the local level but exert economic pressures involving land use and the production of commodities. In addition, local managers are often not provided with financial means to achieve proposed goals of decentralized authority. Although a more sophisticated form of place-based management might work in such cases, the simple, and in many ways appealing, idea of subsidiarity cannot by itself provide the basis for solutions to the problems under consideration here. Andersson's (120, 121) research on governance outcomes in Bolivia illustrates the importance of using multilevel analyses to explain governance outcomes. Andersson measures processes and outcomes in 32 Bolivian municipal governance systems. His measures of outcomes include forest-user ratings of public services related to forestry and the number of formal property rights issued to formerly illegal forest users. He finds that the extent of vertical and horizontal connectivity among actors at the community, municipal, and national levels is systematically and positively linked with outcomes related to local forest practices (see also References 122–124).

4.4. Alternative Approaches

If mainstream responses are insufficient to solve problems of governance arising in areas like PIX in a world featuring increased institutional interplay resulting from the rise in connectivity within and among social-ecological systems, what are the alternatives? We are not now in a position to answer this question authoritatively; the subject of institutional interplay constitutes an important research frontier among those interested in the supply of governance in a wide variety of settings (10, 125). The result is a dynamic environment in which a number of ideas are under consideration, but no clear paradigm has achieved dominance. Among the ideas that figure in current discussions of such matters are multilevel governance, panarchy, polycentric governance, comanagement, and place-based management.

Place-based management: a form of governance that integrates many functionally distinct activities within a spatially delimited area

Multilevel governance: a form of governance involving distinct but interlinked components at two or more levels of social organization

Multilevel governance is a phrase meant to signal clearly that we need to address human-environment interactions at a number of levels from local to global (126). The case of biodiversity offers a clear example. There is no substitute for devising management practices that local residents are willing to accept as compatible with their own needs, whether they involve protecting crops from elephants in southern Africa or maintaining cultural traditions centered on the hunting of whales in the Arctic. The creation of sound local practices, however, will do little good if the relevant species (e.g., migratory animals and birds) are affected by severe pollution, the destruction of critical habits, or poaching along their migratory routes. And, of course, overall measures of biological diversity involve adding up the fate of species located in distinct regions throughout the world. So far, however, the idea of multilevel governance has been most successful in alerting us to the need to create governance systems that are compatible with distinct systems above and below and that include mechanisms for alleviating tensions arising from the special needs and circumstances of individual levels (5, 84, 109). This is an important achievement, but it does not provide a clear answer to the problem we are addressing here.

Panarchy is a term reformulated in the twentieth century by systems theorists who think about the resilience, vulnerability, and adaptability of complex systems as an alternative to hierarchy to facilitate thinking about nested adaptive cycles (99–101, 127). Systems operating at different levels in spatial terms are often linked to one another in terms of the

connectivity of their adaptive cycles. The general assumption is that the dynamics of larger systems are slower than those of smaller systems, so we can understand the operation of smaller systems treating the existence of the larger systems as a set of background conditions. It is certainly true that lower levels of governance are nested into higher levels. Municipal governments, for example, operate within frameworks established by state governments, which, in turn, operate within the frameworks of national governments. Yet, we have not developed a clear understanding of the applicability of the concept of adaptive cycles to governance systems, and it is not clear that high-level systems always change more slowly than lower-level systems in this realm. One of the effects of globalization, in fact, is a tendency to accelerate the dynamics of larger systems in ways that have important consequences for smaller systems (2). This potentially fruitful mode of thinking requires further development in order to provide a useful framework for guiding our thinking about institutional interplay relating to human-environment interactions.

The concept of polycentric governance systems rests on the idea that "autonomous, self-organized resource governance systems may be more effective in learning from experimentation than a single central authority" (128, p. 281). The argument here is straightforward. Smaller systems are easier to manipulate than larger ones. And the existence of many smaller systems (e.g., state or municipal governments) opens up opportunities to make use of natural or quasi experiments to explore the consequences of different governance arrangements (e.g., different policy instruments that can be put in place to guide the behavior of users of ecosystem services in areas like PIX). Under appropriate circumstances, these individual systems can be linked to form dynamic networks capable of addressing macrolevel issues (129). Extensive empirical research in complex metropolitan areas and linked water systems have shown that when local governments have considerable autonomy to seek out ways of achieving economies of scale in the production of some public goods and avoiding diseconomies of scale in other public goods higher levels of performance are achieved (130, 131). The rise of connectivity, however, may introduce complications affecting this strategy. The stronger the links between and among different resource governance systems, the harder it will be to separate out the effects of individual, self-contained arrangements.

Comanagement is an idea that has received considerable attention among managers of human-environment interactions in a variety of settings (10, 84, 132). Comanagement is a response to situations in which public officials have the authority to make decisions about the use of natural resources and ecosystem services but lack the capacity to ensure compliance with their decisions in the absence of voluntary conformance on the part of members of the relevant user groups. Effective governance, under the circumstances, requires cooperation between those with the authority to make decisions and important users or representatives of user groups. The idea of comanagement has become fashionable. The term is now used to describe a variety of arrangements that are diverse, although they all share the commitment to an alliance or working relationship between formal decision makers and users. Most applications involve the harvesting of living resources (e.g., caribou, birds) in relatively well-defined areas. The outcomes vary; we are just beginning to assemble a picture of the major factors that determine the results of comanagement as a way of addressing social-ecological systems featuring a high level of connectivity (17, 65, 133).

The idea of place-based management is emerging with particular clarity in the growing debate about responding to the crisis in marine systems caused by the fragmentation of authority together with spatial and temporal mismatches between biophysical systems and the governance systems responsible for managing human-environment interactions in such settings (134, 135). This approach differs from the idea of subsidiarity in two important ways. Although the focus is on integrative governance

addressing numerous activities in spatially demarcated places, place-based management is sensitive to outside forces and involves a concerted effort to view places as complex and dynamic systems that are open rather than closed in character (136). This approach to governance also features active participation on the part of officials located at different levels of social organization as well as representatives of major stakeholder groups (79, 137). Efforts to apply this approach to specific places are just getting underway, so it is premature to draw inferences about the effectiveness of place-based management. Nonetheless, this approach appears to have promise.

5. DETERMINANTS OF SUCCESS AND FUTURE CHALLENGES

As the previous section makes clear, thinking about the governance of human-environment interactions under conditions of high systemic connectivity is at an early stage. What we have is a collection of suggestive approaches, none of which has been applied often enough and long enough to produce a track record that we can evaluate systematically. The problem is clear. We must devise effective governance systems to manage situations, such as PIX and the surrounding areas, in which it is not sufficient to treat individual cases as self-contained or effectively closed systems, but we have begun to develop strategies for meeting this challenge.

We have made some progress in identifying determinants of success with regard to governance systems that deal with human-environment interactions in more-or-less self-contained or isolated situations (4, 54, 138). Some have pointed to features of the problem at hand and argued that we are more successful in cases where problems are relatively benign rather than malign (82). Others have pointed to attributes of the governance systems we create to address problems. They emphasize features such as monitoring the use of an ecosystem and the availability of graduated sanctions to deter violators (7, 139, 140). A debate over the feasibility of translating these findings into design principles of interest to those endeavoring to (re)form governance systems has engaged many participants in this field of study (125). Building up the social capital needed to deal with these problems will require, among other things, the academic and policy communities to recognize, as described by Cash et al. (5), forms of mediation, translation, knowledge coproduction, and negotiation that are capable of managing complex interlinked systems.

When we come to the management of specific systems, for example, PIX and its environs, in which functional interdependencies and institutional interplay loom large, it is clear that we need to pay attention to scope conditions in thinking about the determinants of success in the creation and administration of governance systems. We know that institutions play some role in guiding human-environment interactions in a variety of settings. The importance of this role, however, clearly varies from one situation to another. Other major drivers (e.g., population, consumption patterns, technology, different views of the environment) are always at work in such situations. An important task, under the circumstances, is to devise methods of separating out the signal of governance systems from the influence of numerous other factors in specific situations before we can generalize about the roles that this form of social capital plays.

Even so, we can begin to see the outlines of a theory of governance applying to systems characterized by high levels of functional interdependence. These social-ecological systems are highly dynamic, a condition that puts a premium on the development of monitoring procedures capable of providing continuous and timely feedback regarding changes (e.g., shifts from one domain of attraction to another) and on making use of adaptive processes that can help maintain resilience in the face of change (141, 142). Such systems often feature tipping points. Crossing a specific threshold may trigger nonlinear and rapid changes, so it is important to anticipate these disproportionate changes and to respond quickly whenever possible (143).

As in the example of PIX, indigenous populations and, more recently, surrounding farmers, municipalities, and the state are beginning to make the efforts needed to build institutional interlinkages from the bottom up. However, these attempts are clearly not enough to address problems at larger scales shaped by national policies and global markets. Although the natural boundaries of the Xingu River watershed facilitate some actions and forms of institutional cooperation, the international dimension of the regional economy requires other frameworks to be at play.

Such situations call for a diagnostic approach to institutional design (13, 18, 125). We are unlikely to be able to formulate uniform design principles that can be applied with good success under a wide range of circumstances. We can, however, engage in careful diagnoses, profiling the major attributes of individual social-ecological systems and devising institutional arrangements tailored to maximize resilience and satisfy appropriate performance standards on a case-by-case basis. This will not lead to the development of simple recipes to be used with little variation under a wide range of circumstances. There is ample scope for the development of expertise in bringing general knowledge about governing complex and dynamic systems to bear in the interests of achieving sustainable results in specific cases.

SUMMARY POINTS

In the context of globalization and global climate change, we discuss the challenges of environmental governance created by the increasing functional connectivity of resource-use systems and ecosystems. Using the example of the Xingu Indigenous Park and its surrounding agribusiness complex in Brazil, we speak to cases and similar problems worldwide, particularly in areas experiencing fast expansion of agropastoral systems, intensive resource exploitation, and increasing overlap of diverse institutional arrangements regulating resource ownership and use. Although indigenous groups within the park have developed strong institutions to monitor its border successfully, rampant deforestation outside the park, and around the headwaters of the massive Xingu River watershed which cuts it, has systemically undermined the park's environment causing water pollution, soil erosion, and forest fire. We discuss the limitations of conserving "islands of resources" and consider the growing need for institutional connectivity and resource governance systems to function at multiple levels.

FUTURE ISSUES

1. This article raises new questions about institutional arrangements as a form of social capital, mediating local and regional levels of environmental governance. We call attention to the challenges involved in scaling up institutional design principles and building up social capital to link governance systems across levels of social organization. These include understanding the interplay of institutional fit, boundaries, authority, sanctions, and dissemination of knowledge and information across levels and social groups.
2. We hope this article will motivate studies of the coevolution of institutional arrangements and resource-use systems, the formation of complex adaptive systems, and their implications for sustainable governance of resources and adaptation to global climate change.

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Earth System Governance. **http://www.earthsystemgovernance.org/**

Ostrom E, Janssen MA, Anderies JM. 2007. Going beyond panaceas. *Proc. Natl. Acad. Sci. USA* 104:15176–78

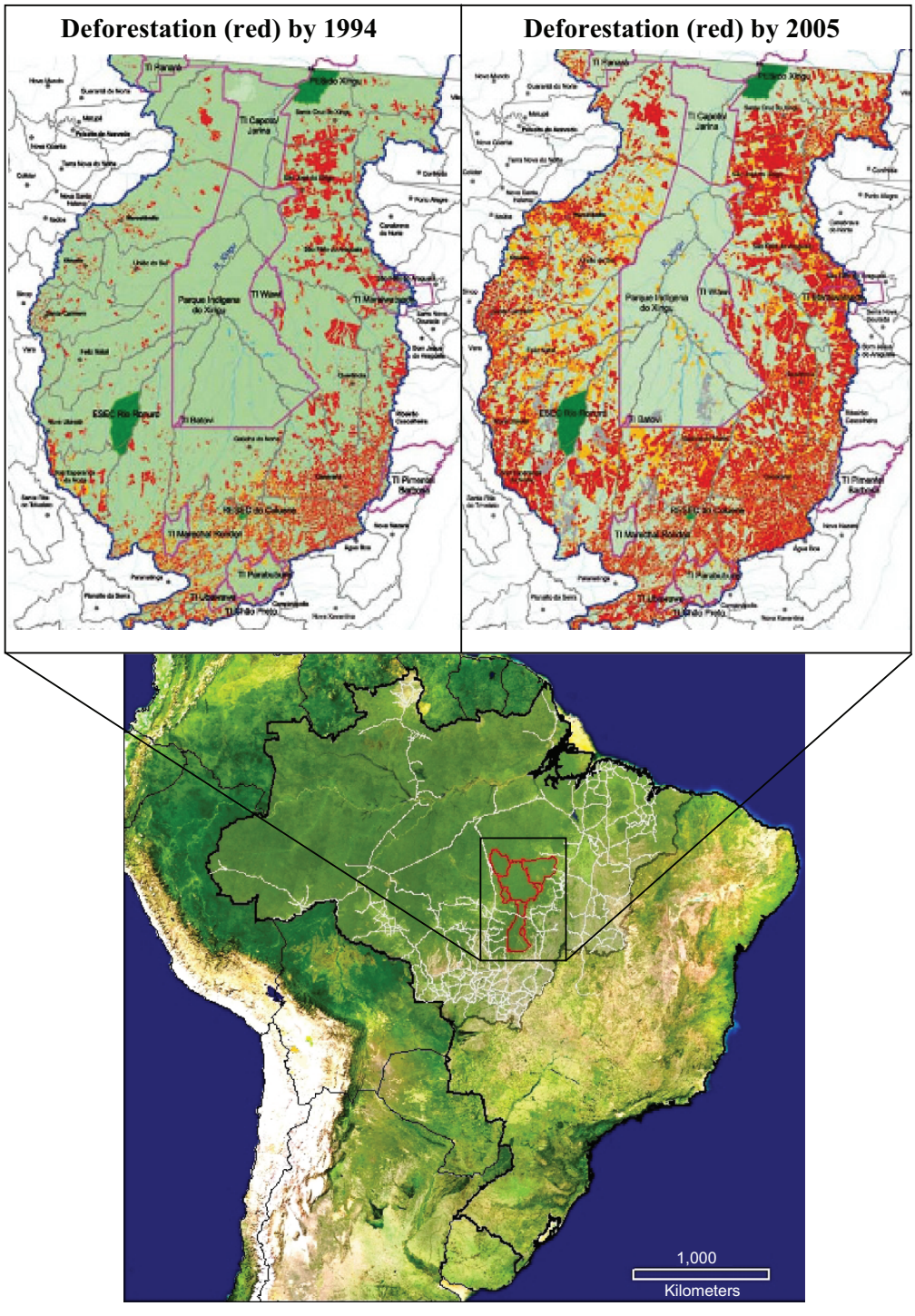

Figure 1

The Xingu River watershed and the Xingu Indigenous Park, deforestation 1994–2005. Source: Deforestation 1994–2005 maps prepared by the Instituto Socioambiental and adapted from References 21–23.