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Understanding protected area resilience: a multi-scale, social-ecological approach

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Abstract. Protected areas (PAs) remain central to the conservation of biodiversity. Classical PAs were conceived as areas that would be set aside to maintain a natural state with minimal human influence. However, global environmental change and growing cross-scale anthropogenic influences mean that PAs can no longer be thought of as ecological islands that function independently of the broader social-ecological system in which they are located. For PAs to be resilient (and to contribute to broader social-ecological resilience), they must be able to adapt to changing social and ecological conditions over time in a way that supports the long-term persistence of populations, communities, and ecosystems of conservation concern. We extend Ostrom's social-ecological systems framework to consider the long-term persistence of PAs, as a form of land use embedded in social-ecological systems, with important cross-scale feedbacks. Most notably, we highlight the cross-scale influences and feedbacks on PAs that exist from the local to the global scale, contextualizing PAs within multi-scale social-ecological functional landscapes. Such functional landscapes are integral to understand and manage individual PAs for long-term sustainability. We illustrate our conceptual contribution with three case studies that highlight cross-scale feedbacks and social-ecological interactions in the functioning of PAs and in relation to regional resilience. Our analysis suggests that while ecological, economic, and social processes are often directly relevant to PAs at finer scales, at broader scales, the dominant processes that shape and alter PA resilience are primarily social and economic.

Key words: *biosphere reserve; conservation; cross-scale; national park; nature reserve; protected areas; resilience; social-ecological system; socioecological system; spatial resilience.*

Introduction

Protected areas (PAs) remain one of conservation biology's most important approaches for ensuring that representative examples of ecological populations, communities, and ecosystems are maintained for current and future generations. Historically, most PAs were created as places that would remain natural (Brandon et al. 1998). Over time, as the original focus of conservation biology on rare and endangered species has expanded into a more general awareness of the relevance of

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TABLE 1. International Union for Conservation of Nature and Natural Resources (IUCN) protected area categories.

IUCN category	Description
Ia) strict nature reserve	Category Ia are strictly protected areas set aside to protect biodiversity and, also, possibly geological or geomorphic features, where human visitation, use, and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.
Ib) wilderness area	Category Ib protected areas are usually large, unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.
II) national park	Category II protected areas are large natural or near-natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational, and visitor opportunities.
III) natural monument or feature	Category III protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature, such as a cave, or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.
IV) habitat or species management area	Category IV protected areas aim to protect particular species or habitats, and management reflects this priority. Many category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.
V) protected landscape or seascape	A protected area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural, and scenic value, and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI) protected area with sustainable use of natural resources	Category VI protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management, and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.

Note: The source for the IUCN categories is http://www.iucn.org/about/work/programmes/gpap_home/gpap_quality/gpap_pacategories/

ecosystems (and the services they provide) for human well-being, our understanding of PAs and their objectives has changed. PAs now range from strict PAs, in which no harvesting of fauna or flora occurs and human visitation is restricted, to multiple-use areas in which sustainable use of natural resources is the norm (Table 1; Dudley 2008). PAs can no longer be viewed as purely ecological islands (Janzen 1983). Instead, as we come to better understand the driving roles of regional processes (i.e., those that occur over broader extents than most PAs) in the composition of ecological communities and their spatial and temporal population dynamics; the complex political and economic influences that underpin PA establishment and maintenance; the role of PAs as providers of benefits for local communities and society within a broader landscape context; and the potential costs of PAs, including opportunity costs, it is becoming increasingly clear that PAs are social-ecological systems (note that we use the term "social-ecological," following conventional Resilience Alliance usage)[12] that both respond to and influence a wide range of ecological, social, and political processes.

[12] http://www.resalliance.org

PAs are human constructs in which institutions are used to try to achieve ecological and social goals. Human activities in most PAs are limited so that recognized natural, ecological, and/or cultural values for some social groups are maintained (Table 1; Dudley 2008). In order to meet ecological goals, conservationists have strived to influence PA location, pattern, management, and governance. The creation of state-owned or public conservation areas is usually driven by the ecological consciousness and political will of the participants (Mathevet and Mauchamp 2005) but must also confront a variety of ecological and political constraints. Defining the formal boundaries of protected areas is impossible without support from external institutions such as national and international policies, laws, and agreements. This means that the creation and maintenance of PAs is heavily dependent on their compatibility with institutions in the broader social and economic system. Each PA has social and ecosystem characteristics, often including stated management goals, that influence (and are influenced by) governance, affecting economic outputs and social outcomes in the social-ecological system (Ostrom 2009).

PAs are vulnerable to political change (Agrawal 2005, Clement 2010), economic fluctuations, and ecological change. Understanding what makes PAs resilient to both ecological and socioeconomic change is, therefore, important for conservation. We view resilience as being comprised of the ability of a system to remain within the same regime (system state characterized by key processes) following a perturbation, and the capacity of a system to adapt to change and persist through times of change (Carpenter et al. 2001, Lundy and Montgomery 2010). Resilience may also be viewed as the maintenance by a system of a continuous identity in space and time (Cumming and Collier 2005). Resilience itself is not a normative concept, and the resilience of some social-ecological states (e.g., poverty traps) may be negative from a conservation perspective; we focus here on positive resilience, in the sense of resilience that helps PAs to achieve conservation goals. PAs must change and adapt to changing environmental conditions through time (Lee and Jetz 2008), while seeking to maintain their cultural and social roles as important elements of their identity. The core of their identity, however, lies in the fact that they support, or at least are intended to support, the long-term persistence of populations, species, and communities of a wide range of organisms, as well as related abiotic ecosystem elements and processes (Jax 2010) and ecosystem services. If PAs are to be resilient in social, economic and ecological terms, their physical location and boundaries, as well as their management and governance, must be politically viable well into the future (Folke et al. 1996, Adger et al. 2005), lest they become paper parks, are made smaller (e.g., the extent of Etosha National Park, in Namibia, is currently about a quarter of what it was in 1907), or are de-gazetted altogether. Management of decision-making processes is, therefore, at least as important for PA resilience as management of the biophysical system, suggesting that conservation science is necessarily interdisciplinary (Mathevet and Mauchamp 2005). Furthermore, PAs influence the regions in which they are embedded, and are, in turn, influenced by the broader context of those regions. Clearly, the maintenance and possibly enhancement of PA resilience, in a social-ecological context, is a key goal for conservation biology.

The social-ecological nature of PAs has already received considerable recognition within both the peer-reviewed literature and cutting-edge conservation practice (Berkes et al. 2003, Fischer et al. 2009, Strickland-Munro et al. 2010, Ban et al. 2013). Despite the existence of a solid body of inter- and trans-disciplinary work on PAs, however, many gaps remain. Here, we focus on three particular areas that require further development, the relationships between a social-ecological perspective on PAs and research from other fields on social-ecological systems and their resilience; scale and the analysis of cross-scale influences and feedbacks on PAs; and assessment of the resilience of PAs. Although many scholars have also argued for greater attention to issues of power in studies of environmental governance (Blaikie 2006, Jentoft 2007, Clement and Amezaga 2013), we do not explicitly focus on this topic in this paper. Nonetheless, the close relationship between power and the rules, norms, and conventions (i.e., institutions) of human societies means that power is rarely far removed from the discussion.

PAs and Social-Ecological Systems Frameworks

The study of social-ecological systems (SESs) has led to a wide range of frameworks, theories, and models that aim to structure inquiry and explain or predict the dynamic outputs of complex adaptive systems. We use system to refer to a cohesive, temporally continuous entity that consists of key elements, interactions, and a local environment (Cumming and Collier 2005). SESs are systems that include social, economic, and ecological elements as well as the interactions between them. The concept of an SES is useful for PA management because it explicitly implies that the manager, other stakeholders, and related institutions are part of a cohesive whole, the system. This, in turn, suggests that approaches that incorporate these elements into dynamic models of system interactions, rather than treating them as immutable external influences on ecosystems, may identify opportunities to enhance the resilience of systems that would otherwise be overlooked. Moreover, PAs do not exist in a vacuum and interact with, contain, and/or are nested within other SESs.

Frameworks are underlying sets of ideas that serve to connect and make sense of different concepts (Pickett et al. 2007). They are used to aid the investigation of complex phenomena by identifying, organizing, and simplifying relevant factors, and are generally compatible with multiple theories and models (Pickett et al. 2007, Schlager 2007, McGinnis 2011). Frameworks that have been explicitly developed for understanding social-ecological systems include, among many others, resilience (Holling 1973, Resilience Alliance 2007*a*, *b*), robustness (Anderies et al. 2004), vulnerability (Turner et al. 2003, Adger 2006), self-organized holarchic open systems (SOHO; Kay and Boyle 2008, Waltner-Toews et al. 2008), and sustainability science (Kates et al. 2001). All of these approaches have the potential to provide a unified approach for the study of SESs across multiple methods and disciplines (Ostrom 2007, 2009, Poteete et al. 2010); and all are potentially relevant as a platform to better understand the dynamics of PAs. Different frameworks have, however, tended to focus on different elements of the same problem, and no single existing framework can be considered fully comprehensive (Cumming 2011). In the context of PAs, there is a strong need to bring key ideas from different frameworks together into a more comprehensive body of theory.

We propose an approach that combines elements of resilience analysis (e.g., Holling 1973, Resilience Alliance 2007*b*) and the closely related SES framework of Ostrom (2007, 2009), while extending them in several directions. Before we consider how these frameworks can be applied to PAs, a brief summary of each set of

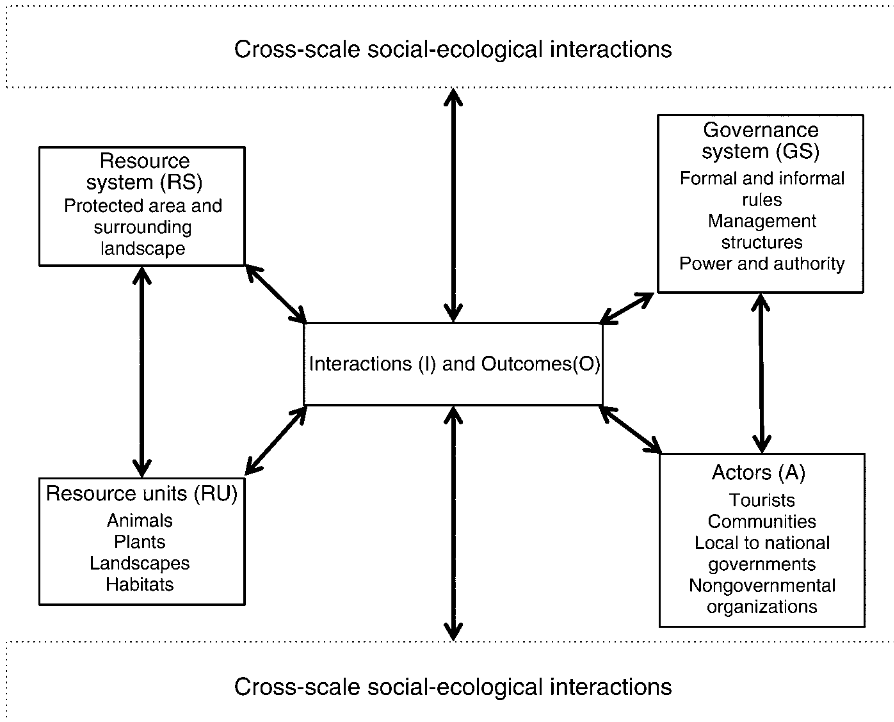

FIG. 1. A summary depiction of Ostrom's social-ecological system (SES) framework. Different components of social-ecological systems (characterized as resource units, resource systems, governance systems, and actors) interact to produce outcomes. Each component is composed of numerous different elements. Although the framework indicates a role for cross-scale dynamics, this aspect of it has not been well developed in most applications. We note also that interactions and outcomes include interactions among the ecological components of the system (e.g., predator–prey dynamics); the social components of the system (e.g., rulemaking); and the social and ecological components of the system (e.g., harvesting).

ideas and their main strengths and weaknesses is necessary.

The Resilience Alliance workbooks (Resilience Alliance 2007*a*, *b*, 2010) attempt to operationalize key resilience concepts by posing a series of questions to strategically define and assess SESs. Within this broader framework, a nested framework (adapted from Chapin et al. 2006) offers a protocol to structure interacting, cross-scale social-ecological components, processes, institutions, and feedbacks. The workbooks use the adaptive cycle and panarchy models (Kenward et al. 2001, Gunderson and Holling 2002) and the adaptive governance and social-network literatures to facilitate an understanding of system dynamics and interactions, assess governance, and offer insights about potential actions. What they lack in a unified underpinning theory (Cumming 2011) is compensated for by their firm grounding in a rich empirical literature, spanning many case studies and multiple disciplines (reviewed in Haider et al. 2012). In providing a practical way to structure multiple resilience perspectives in complex, dynamic SESs, the framework offers an approach to understand issues of scale in SESs, including PAs, and proposes a novel approach to natural resource management (Walker et al. 2009, Strickland-Munro et al. 2010, Haider et al. 2012).

The resilience approach has, however, been criticized for being difficult to operationalize (Strickland-Munro et al. 2010, Cumming 2011, Holt et al. 2012). Practical problems in applying resilience thinking have resulted in a relatively low number of directly comparable case study examples. Practitioners have also lamented its lack of guidance for delineating system boundaries, developing tools to navigate a transition to desirable futures, and describing governance structures (Strickland-Munro et al. 2010, Haider et al. 2012, Holt et al. 2012). These criticisms are particularly relevant for PAs, where implicit geographic or ecologically relevant boundaries (e.g., catchment edges) may not line up with PA boundaries (Mitchell 2011), and where identifying social thresholds and variables, articulating governance choices, and incorporating relations of power (Strickland-Munro et al. 2010, Armitage et al. 2012) may be particularly important in defining elements that may contribute to or erode a system's resilience (Walker et al. 2009).

Ostrom's SES framework (Fig. 1) provides a useful complement to resilience approaches. It has its origins in institutional studies of the commons that made significant contributions towards a game theoretic understanding of environmental governance (Ostrom 1990, Ostrom et al. 1994). It provides researchers an analytical tool with which to capture, organize, and analyze a diverse set of social and ecological variables that are considered relevant for a particular aspect of a system (Ostrom 2007, Poteete et al. 2009). In total, Ostrom's SES framework includes over 50 potentially influential classes of variables that are ordered within a multilevel classificatory system. The four core components (resource systems, resource units, actors, and governance systems) are organized as a partially decomposable system (Simon 1991) where each of the potentially influential variables can be further unpacked to capture subclasses and cumulatively integrate knowledge concerning their effects on sustainability. There are two additional components that allow for linkages across levels of governance, or between systems, and an additional two components that are used to evaluate SES interactions and outcomes.

Ostrom's SES framework has been criticized on several fronts that generally point to two main issues. First, its origin in institutional analysis neglects alternative social scientific perspectives. Most notable among these omissions are the power-laden theories of political ecology that view environmental degradation as a direct consequence of imbalances of power between influential policymakers (e.g., national governments) and their associates (e.g., local elites and businesses) and marginalized small-scale users (e.g., subsistence farmers and pastoralists; Peet and Watts 1993, Robbins 2004). Second, the ecological aspects of the framework and their interactions remain underdeveloped (Berkes and Ross 2013). A particularly problematic issue for ecologists seeking to apply Ostrom's SES framework is its lack of clear definitions concerning resource units and resource systems. For example, resource units have been operationalized at multiple levels of biological organization, including species and communities (Gutierrez et al. 2011), water and land (Ostrom 2011), and even landscapes for tourism (Blanco 2011). While it could be argued that each of these studies presents an internally consistent application of the framework, it is unclear whether syntheses between such disparate case studies are feasible or if the findings necessarily apply to the broader population of SESs. Third, while dynamic and multi-scale analysis is technically possible, nearly all applications of the framework and its institutional analysis precursor focus on a single focal action situation (e.g., resolution of a natural resource management problem by multiple stakeholders) that occurs once only and in a single location (McGinnis 2011). Moreover, until recent modifications to the SES framework were introduced by Epstein et al. (2013), the framework was poorly equipped to analyze biophysical processes and diagnose ecological contributions to social-ecological outcomes. However, even with these changes, Epstein et al.'s (2013) analysis of the successful remediation of Lake Washington simply transforms inherently dynamic internal phosphorus loading processes into several static one-way relationships with the dependent variable. Although sufficient for their analysis, the failure to account for dynamic linkages within and across scales remains a major weakness of the SES framework. In fact most applications of the framework have a general tendency to focus on a single scale or level of governance, on a single resource, and to treat the problem as if all resources and actors were at the same focal scale.

As analytical approaches for understanding (and hence, better managing) PAs, both resilience approaches and Ostrom's SES framework have much to recommend them. Our objective in this article is to extend them to better integrate social-ecological feedbacks and cross-scale effects that often dominate the dynamics of PAs and other social-ecological systems.

Extending Existing Frameworks to Include Scale and Cross-scale Feedbacks

The obvious tension between ecological and social demands in many PAs suggests that analysis of the resilience of PAs requires a hierarchical, cross-scale and multilevel framework in which different scales and institutional levels are connected by a set of interactions between different actors, resources, and processes. Examples of interactions include the movements of actors and resources (e.g., tourism and water flows out of PAs to downstream communities) as well as the interplay of rules and information across scales. Holling (2001) suggested that complex system behaviors, such as those that we observe in PAs, arise from the interactions of processes that occur at a minimum of three different spatial and temporal extents, and, furthermore, that, in many cases, shifts between different system states are driven by changes in the slower variables (e.g., buildup of phosphorus in a shallow lake or loss of trust in human society) rather than the faster variables (e.g., trophic interactions or law enforcement).

It is important to recognize that PAs, which are institutions (in Ostrom's sense) rather than biophysical entities, have been created at a variety of different spatial scales and institutional levels. While PAs in the International Union for Conservation of Nature and Natural Resources (IUCN) categories I–IV are often single tenure units, those in categories V and VI (such as biosphere reserves and transfrontier conservation areas) usually include multiple, nested tenure units that are governed by different rules (Table 1). For example, the current rules in use in the Great Limpopo Transfrontier Conservation Area or the Causse Méjan (both of which are discussed in more detail in *Understanding the resilience of protected areas*) differ between farms, core conservation areas, hunting areas, and designated buffer zones. Similarly, while larger areas may be expected to change more slowly because of the buffering effect of larger ecological populations, this is not inevitable; political change that has an influence at a national extent, for example, can happen swiftly. In heterogeneous landscapes, different tenure units at the same

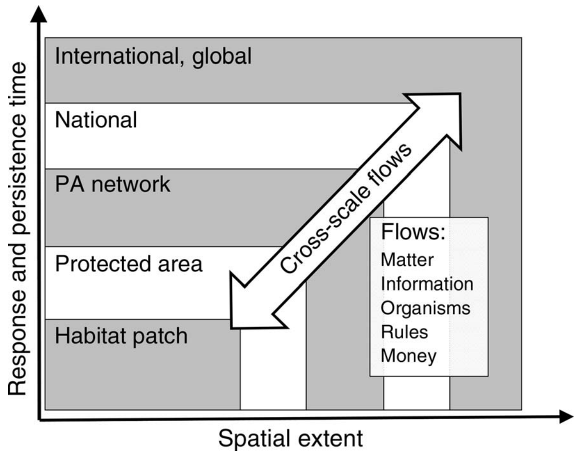

FIG. 2. A multi-scale perspective of protected areas (PAs) as social-ecological systems, showing the relationships between the sizes, response times, and persistence times of different system elements. Note that individual elements in this figure are nested within each other. At each scale, Ostrom's SES framework captures some of the complexity of interactions between and across different subsystems.

spatial scale may also interact (e.g., mines and conservation areas).

We propose a system description that includes five hierarchical levels of institutional organization. These, in turn, are related to five hierarchical spatial scales of analysis, with some flexibility, depending on the system that is under analysis (Fig. 2). The first institutional level is defined as the sub-tenure unit. It refers to patches of habitat (or any other fine-scale, discrete ecological units that are managed differently), and/or specific human use areas that fall within a single tenure unit, have a single management policy, and exist at smaller spatial extents than the boundaries of the tenure unit. For example, different rules about making fires or leaving your vehicle may apply at picnic sites or bird hides (blinds) within a PA; and, different habitats in a PA may have different management needs. Sub-tenure units will always, by definition, have a smaller spatial extent than a PA. They relate most closely to the patch scale of analysis, which reflects the grain and extent of habitat heterogeneity within the PA.

The second institutional level is that of a single tenure unit. Single tenure units belong to a single owner or organization. They may have the same extent or a smaller extent than that of a PA, depending on the diversity of tenure types and human use zones occurring within the PA. Single tenure units define one or several scales of analysis that might, for example, correspond to the extent of a traditional game park or to those of core ecological and farming areas respectively within a biosphere reserve.

The third institutional level, the proximate institutional context, includes multiple tenure units as well as the institutions and organizations that are responsible for coordinating the interactions (where these occur) between tenure units. Depending on the nature of the study system, the proximate context might define a spatial scale that is only slightly larger than the PA, or a larger region that contains a network of PAs that are managed with a shared objective. For example, provincial parks in the Western Cape of South Africa form a network that is overseen by a regional conservation organization, Cape Nature; the proximate institutional context for any single provincial park includes Cape Nature, and related ecological scales of analysis include surrounding PAs and unprotected dispersal corridors that connect PAs. The proximate institutional context also includes institutions that relate to the governance of resources around PAs, particularly where (as in the case of water laws, for example) they relate directly to ecological flows (e.g., water and invasive species) that might enter the PA from surrounding areas.

Proximate institutions, in turn, sit within (or sometimes straddle) a national institutional context, the fourth level, which typically consists of the institutions of a single nation-state (e.g., its constitution and related governance structures). This institutional level aligns with a national extent of analysis. However, sometimes, as in the case of trans-boundary conservation areas, PAs may include as many as three or four nations, creating an international institutional context that is the fifth and final institutional level.

This fifth level includes international power relations and the global economy. International contexts are aligned with the broadest scales of spatial analysis, ranging from multiple countries to global. While the fifth level may seem ecologically far removed from the majority of established PAs, it has particular relevance for migratory species and related resources, such as wetlands that are important for migratory waterbirds and are supposedly covered by international conventions and agreements (e.g., Convention on Biological Diversity [CBD], Ramsar, African-Eurasian Migratory Waterbird Agreement [AEWA]; see United Nations 1992, Matthews 1993, Lenten 2001). Similarly, international conventions and agreements (or lack thereof) can have a strong influence at the level of a single tenure unit, as in the case of the management of species that are listed in Appendix I of the Convention in Trade and Endangered Species (CITES).

At each different scale and level, different temporal dynamics occur. The temporal scales that are relevant to the ecology of PAs range from short-term processes, such as predation and competition that occur on a daily scale, through seasonal processes, such as breeding or wintering seasons for birds, to long-term processes, such as atmospheric oscillations, ocean acidification, and climate change that take place at decadal and centennial scales. Similarly, the temporal scales within the social realm also vary from short-term initiatives to establish PAs to long-standing national assets such as Yellowstone National Park in the United States. Social history and pre-PA politics may also affect the resilience and social-ecological context of a PA. Both ecological and social processes act synergistically to produce outcomes and thus neither can be considered in isolation (Hughes et al. 2005).

The boundaries of a PA can span multiple nested institutional and ecological levels and scales. Each PA interacts directly with its immediate context (i.e., defined by scale and level), which becomes the main source of both inputs and outputs (e.g., information and finances) for any given PA. Since the number and diversity of people involved in SESs at different levels affects both ecological and social processes and the temporal periods over which they occur (Westley et al. 2002), it is crucial to take these interactions into consideration. Practitioners often speak of getting the different levels of governance aligned. For example, a decision made internationally, at, say, Ramsar Convention-level, may or may not promote wetland sustainability, depending on whether the national government(s) that are involved take action and are supported by local communities. In other cases, local communities may seek support at the international level for initiatives that lacked support from their own national governments. Alternatively, some of the policies funded and promoted by international donors and organizations may contribute to systematic disenfranchisement of local communities despite a supporting rhetoric of social justice (Blaikie 2006). Positive synergies among scale-dependent institutions, therefore, usually depend upon brokering organizations that facilitate (even make possible) the interactions between the various levels, including in the reverse direction, so that the national governments and Ramsar Convention receive the necessary confirmation or other feedback to assist future policy formulation. Worldviews, values, attitudes, and power are key factors that shape PA design and governance and shape the behaviors and practices of social groups operating at different spatial levels that directly or indirectly affect PAs.

Resources and biophysical processes exist over a range of different scales and vary in their grain (or frequency) and their extent (or duration) in space and in time. The scale of socioeconomic processes depends heavily on the scale of economic and political organization and the level of international interest in a particular PA (Fig. 3). It ranges from individuals to networks of organizations and includes the effective scales of social institutions (rules, laws, policies, and norms) that govern the extent of resource-related rights and management responsibilities (Cumming et al. 2006). For example, in creating an urban PA, a country's constitution may provide for national-level tenure rights that must then be applied within the local context of municipal policies and bylaws. Scale-dependent system components and interactions may influence PAs in different ways depending on how their relative magnitude and frequency change across different scales. It is often unclear where resilience, or a lack of resilience, resides, both within and between scales. The interactions between different spatial and temporal scales of both pattern and process, and their potential effects on resilience, are recurring themes in the ecological literature (e.g., Peterson et al. 1998, Cumming et al. 2006).

Dealing with the many scale dependencies of PAs is conceptually challenging. However, as Cash et al. (2006) point out, ignorance of cross-scale interactions tends to reveal itself in a wide range of management problems. Therefore, a useful starting point is to be explicit about the spatial and temporal elements of the problem and their key scales (Fig. 4). PAs in contemporary conservation efforts are developed as networks (Vimal et al. 2012). They are planned and increasingly managed as part of local, regional, and international conservation systems. For example, in the French national park and biosphere reserve design approach, new PAs are designed as a set of zones that range from strictly protected areas (the core area of a national park or nature reserve) to integrated zones in surrounding areas where integrated management of natural resources is implemented with local stakeholders and landowners (Batisse 1997, Mathevet et al. 2010).

Social-ecological interactions occur most intensively within and between entities that operate at similar scales (Allen and Starr 1982, Levin 1992, 1999; Fig. 2). For example, in South Africa, provincial administrations, such as Cape Nature or Ezemvelo-KZN Parks, manage provincial parks, while national parks are regulated nationally by South Africa National (SAN) Parks. At the same time, actors and processes at scales and levels above and below the focal scale influence pattern-process interactions via flows between nested elements. Matter includes the exchange of physical materials across scales and levels, such as water, carbon, and nitrogen. Organisms, including people, as well as mobile animals and plant propagules, link scales and levels via their movements (e.g., labor, migration, and transhumance). Information flows include the exchange of ideas, perceptions, and skills across scales. These local-to-global flows and the ways in which they are mediated and managed can play an important role in the function and performance of the PA (Mathevet et al. 2010, Thompson et al. 2011) and may consolidate ecological and social interdependence in biodiversity policy that goes beyond park boundaries, such as the health of the tourism sector in and around PAs (Hall 2010, Biggs 2011). Rules link institutions and regulations across scales, for example with global treaties affecting regulations within PAs. In addition, flows of information, perceptions, and money across scales are central to the functioning of the nature-based tourism sector in many of the world's PAs (e.g., Biggs 2011).

The presence of different interlinked subsystems across different scales (Fig. 4) suggests the presence of multiple action arenas where decisions related to PAs are made and a strong need to somehow align multiple subsystems to coordinate responses to common threats (e.g., climate change or an escalation of poaching activity). This observation aligns neatly with Holling's ideas about panarchies (Holling and Gunderson 2002), which suggest that some degree of synchrony in system cycles is a necessary precondition for effective interventions (Westley et al. 2002).

The adoption of a multi-scale, social-ecological perspective on the resilience of PAs (Figs. 2–4) provides a useful way of organizing and thinking through their long-term sustainability. Over the last decade, conservation organizations have increasingly recognized that the protection of ecosystems requires that key ecosystem functions and processes be maintained at multiple scales (Poiani et al. 2000). Several of the world's largest conservation nongovernmental organizations (NGOs) have developed stratified, ecoregional-based plans and approaches to formally structure the process of developing and maintaining PA networks (e.g., The Nature Conservancy 2003, Loucks et al. 2004). Poiani et al. (2000), for instance, developed a hierarchical classification for habitats (ranging from small patches through the matrix to entire regions) and associated species (ranging from small patch species through to regional and long-distance migratory species; Fig. 4) as part of The Nature Conservancy's Conservation by Design initiative.

We propose that a similar leap forward must be taken by recognizing that multi-scale socioeconomic (and further, social-ecological) functional landscapes exist and that they are integral to understanding and managing PAs for long-term sustainability. For example, the Man and the Biosphere Program (MAB; UNESCO) integrates social and ecological goals and aims to ensure the sustainable use of natural resources, while also emphasizing the interdependencies of cultural and natural landscapes (Batisse 1971, 1997, IUCN 1979, German MAB National Committee 2005). Such areas are structured and organized at a range of social and ecological scales, depending on the particular set of negotiated goals and objectives. The new concept of ecological solidarity, a core feature of the 2006 law reforming national park policy in France, similarly stresses the need to reconnect people to their PAs. Ecological solidarity is both social and ecological; it is based on social recognition of the spatial interdependence among natural organisms, including people, and their physical environment. This sets the scene for a vision of nature conservation and management of PAs. Ecological solidarity offers a pragmatic compromise between ecocentric and anthropocentric ethics. It suggests that biodiversity conservation at different spatial and temporal scales needs to be collectively explored by local communities and stakeholders to give social meaning to the establishment of PAs, to the expansion of ecological networks, and to the integrated management of cultural landscapes (Mathevet 2012).

As an example, conservation of a local-scale species, such as an endemic butterfly, typically requires fewer resources and a much finer scale of management than that which is required to conserve species that use their landscape at a regional scale (e.g., migratory songbirds). In the same way, meeting local stakeholder needs and demands within and around a PA requires different and much finer-scale action than governmental resource policies, the international tourist market, or the international trade in animal products. These ideas can be summarized by uniting the ecological approach of Poiani et al. (2000) with a socioeconomic perspective (Fig. 5).

Fig. 5 provides a way of conceptualizing and comparing the different scales and levels at which social and ecological systems are organized. It does not, however, provide a dynamic temporal perspective for understanding interactions between scales. One of the key components of incorporating scale and scaling in a framework for the analysis of PA resilience is that of understanding feedbacks, both within and between scales. Formally, a cross-scale feedback occurs if A influences B and B influences A, and A and B are system elements (whether human or not, but excluding interactions) that exist at different scales. For instance, global demand drives the prices of many commodities, but production is often limited to a smaller subset of locations. If local conditions in the production location influence global prices, a local-to-global interaction occurs. If global prices also influence local actions, a cross-scale feedback occurs. Such feedbacks may be extremely difficult to manage given the inherent complexity of social-ecological systems (Berkes et al. 2006). For example, the Asian demand for rhinoceros horn is driven by cultural beliefs. Coupled with limits on local production (i.e., a small number of slowly reproducing rhinos), it has created spiraling commodity price increases and a massive conservation problem for African PAs (Biggs et al. 2013). Our future ability to manage individual resources, or PAs as a whole, will depend on our ability to devise a system that can detect potentially harmful feedbacks and respond to them in a timely manner (Hughes et al. 2005, Biggs et al. 2013).

The different social-ecological system elements that determine the resilience of an individual PA may be connected in different ways and to varying degrees of strength (Figs. 2–4). One of the challenges in analyzing PA resilience is to determine which influences are the strongest within the system and which are sufficiently weak that they can safely be ignored or disregarded during analysis (keeping in mind that sometimes, weak influences and dormant social networks can be important in times of crisis). Closed feedback loops (A influences B influences C influences A) are also of particular importance because they can produce surprising dynamics, such as dampening or exacerbation of local variability. In practice, these feedbacks (and especially those that reinforce one another) are critical

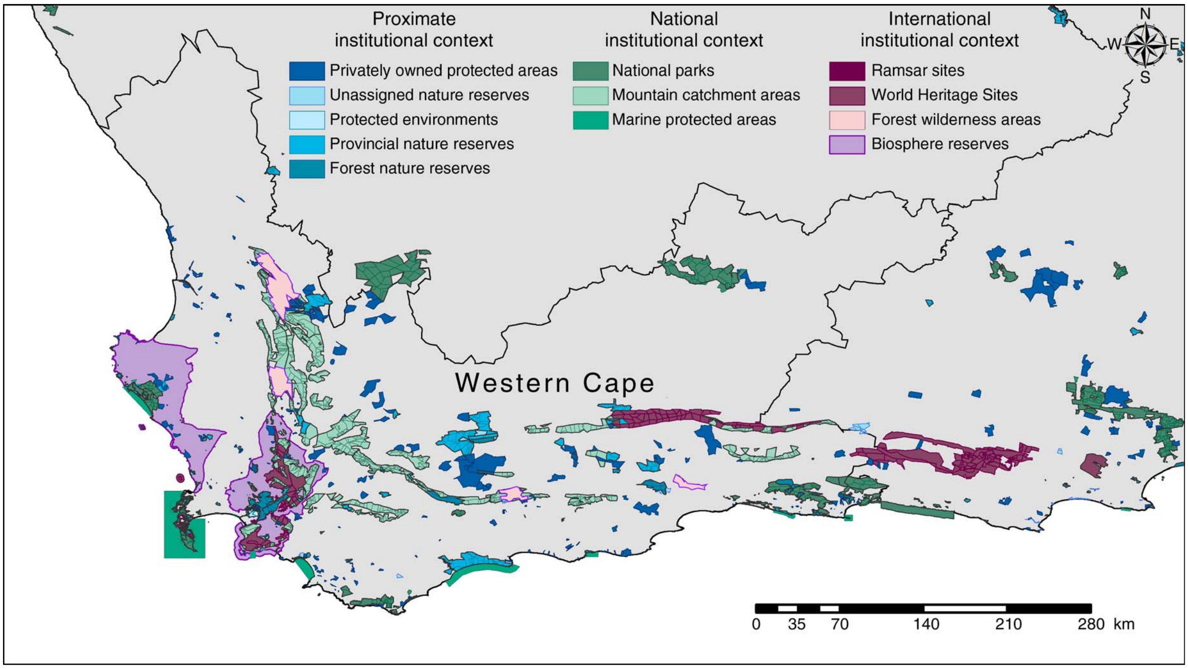

FIG. 3. Protected areas in the Western Cape, South Africa, showing the proximate, national, and international institutional context of each different area in geographic space. These different institutional levels interact with ecological and social processes at different geographic scales.

for system performance and must be considered in the design of environmental policies as they are directly responsible for the stability of a social-ecological system in a given state. Conversely, if system change is desired, they must, in some direct or indirect manner (e.g., through modifying other inter-linkages which feed into it but can be influenced), be overcome. For example, in *Understanding the resilience of protected areas, Case*

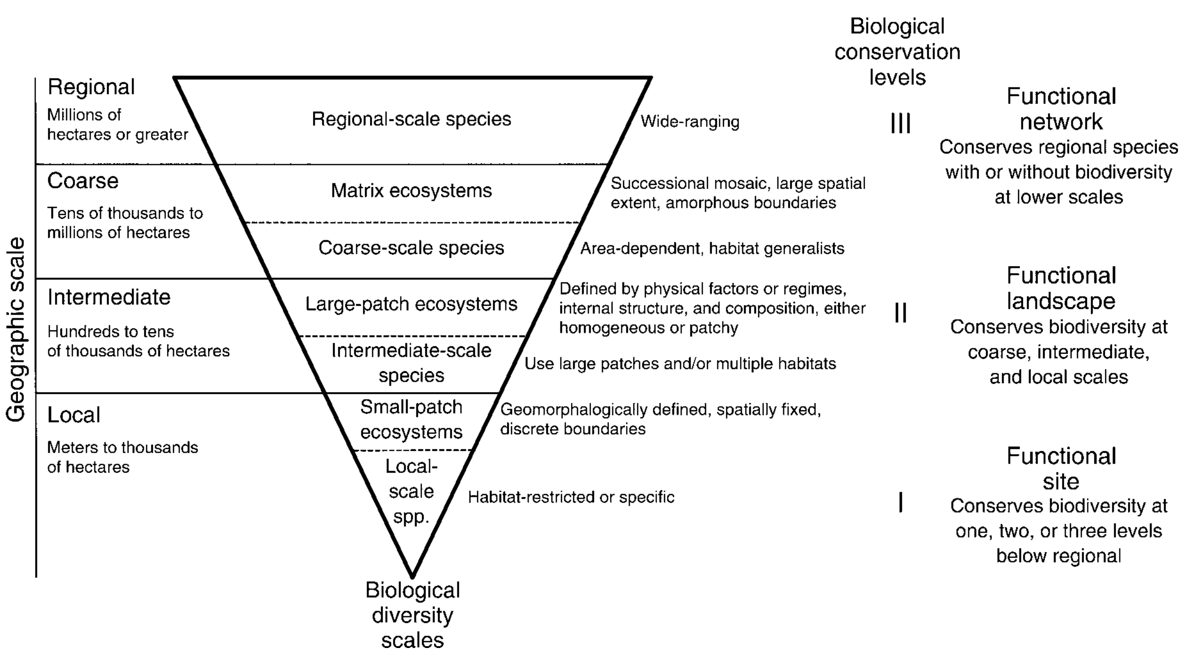

FIG. 4. The depiction by Poiani et al. (2000) of the components of an ecologically functional landscape. Different species have different habitat requirements and if a full range of ecological function is to be retained, habitat conservation must be undertaken in a nested manner, with wide-ranging, regional species having access to high quality patches at local scales. Note that, despite its emphasis on functional landscapes, this figure does not directly include people and the scales at which they modify landscapes.

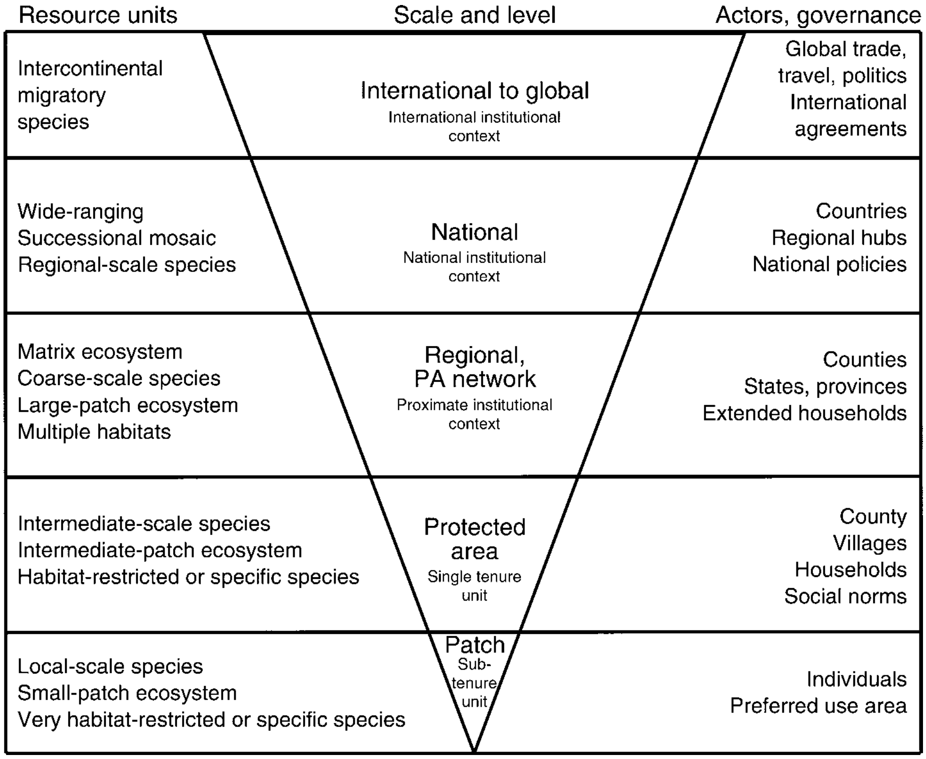

FIG. 5. Summary of social-ecological patterns and processes at different scales. Pattern–process interactions across and between these different scales must be reconciled if effective, sustainable conservation is to occur. In addition, different actors and processes operating at the same scale may interact in important ways. This figure extends the depiction of Poiani et al. (2000) of the ecological components of a functional landscape.

study 1, about the Eastern Cape, and in Maciejewski and Kerley (2014), managers' perceptions of what tourists want to see provide a powerful driver for the ecological management of private PAs (PPAs). This influence is cross-scale in the sense that tourists come from a far wider extent than the PA. By their actions, managers, in turn, influence the likelihood that tourists will visit the PA, setting up a cross-scale feedback that can result in harmful ecological effects (e.g., habitat alteration by excessive numbers of elephants, and resulting species loss) within PA boundaries. Breaking this feedback requires that managers be willing to accept data indicating that tourist numbers would be unaffected by lower stocking rates, and willing to take the risk of reducing population levels of charismatic megafauna, such as elephants.

While many studies have implied or discussed the importance of scaling principles and cross-scale dynamics for PAs, few have explicitly analyzed them. Some exceptions include Jones et al. (2013) and Mills et al. (2010; both on MPAs) and Guerrero et al. (2013). Guerrero et al. (2013) identified eight ways in which scale mismatches between actors and resources involved in the spatial planning process manifest themselves. These include ecosystem or ecological processes that extend beyond governance boundaries; the absence of resolution-appropriate data for decision making; a lack of implementation capacity; threats to ecological diversity that operate at diverse spatial and temporal scales; mismatches between funding and the long-term nature of ecological processes; rates of implementation that do not reflect the rate of change of the ecological system; lack of appropriate indicators for monitoring activities; and the occurrence of ecological change at scales smaller or larger than the scale of implementation of management actions or monitoring.

Among the most important questions in this context are whether, and how, PAs may contribute to desirable regional resilience (e.g., Plumptre et al. 2007, Slotow and Hunter 2009, Cantú-Salazar and Gaston 2010, Laurance 2013, Sjöstedt 2013); and conversely, how regional resilience may influence the resilience of individual PAs (González et al. 2008, Jones et al. 2013).

UNDERSTANDING THE RESILIENCE OF PROTECTED AREAS

We have argued that PAs are multi-scale and multi-level social-ecological systems and that an explicit recognition of scale and cross-scale interactions must be incorporated in analyses of PA resilience if we are to advance our understanding of their dynamics, manage them better, and, ultimately, foster their resilience. The third logical step in this line of argument is to consider empirical evidence that indicates whether, and how, cross-scale feedbacks may, in practice, influence the resilience of specific PAs, and how PAs may, in turn, influence regional resilience. The starting point is to define different scales and levels; this is followed by a more detailed consideration of system dynamics. We illustrate these steps below for three real-world examples, noting that space constraints and the goals of this article do not permit the next step, which would be a full resilience analysis of each case. As the subsequent discussion shows, the nature of the interaction between regional and local resilience may be quite strongly dependent on context-specific factors.

Case study 1: social-ecological dynamics of private protected areas in the Eastern Cape

Private Protected Areas (PPAs) constitute a high proportion of conservation land in South Africa. Exact figures are hard to obtain, but according to the PAs Act 57 of 2003, approximately 7% of the country's land is in statutory national parks and 17% in some form of private conservation area (Cousins et al. 2008). In southern Africa, ecotourism generates roughly the same revenue as farming, forestry, and fisheries combined (Scholes and Biggs 2004). Growth in the ecotourism industry has had substantial impacts in the Eastern Cape, where large areas of marginal pastoral lands have given way to PPAs. Private PAs may fall within any of the IUCN categories. Some believe they are better represented under categories IV–VI, although many private PAs fit the management objectives of categories I–III (Dudley 2008; Table 1).

At the sub-tenure level and patch extent, within PAs, former agricultural fields with interspersed natural areas have been converted into more economically viable game farms. This involves restoring the vegetation and reintroducing wildlife into the area. At the PA level, system dynamics and related ecological management decisions are heavily driven by economic processes. Private PAs aim to build populations of charismatic species at stocking levels that ensure tourist satisfaction. It has been estimated that during the establishment of PPAs, the introduction of species to the Eastern Cape cost between \$97 500 and \$1.8 million (Sims-Castley et al. 2005). Stocked animals are often extralimital species, such as giraffe, which did not historically occur in the Eastern Cape. These nonindigenous introductions have several negative effects including hybridization, degradation of habitat, and low survival rates and competitive exclusion of indigenous species (Chapin et al. 2000, Castley et al. 2001). Stocking charismatic species, such as the African elephant (*Loxodonta africana*), above ecological carrying capacity to meet social demands and ensure tourist satisfaction may also have negative ecological impacts. Numerous studies have documented significant impacts of elephants on biodiversity (e.g., Cumming et al. 1997, Blignaut et al. 2008, Kerley et al. 2008).

At regional, national, and international levels and extents, the main driving forces are social-ecological processes, represented by two conflicting trends. On one hand, the land-conversion trend increases ecotourism in the Eastern Cape, potentially leading to an increase in income and job opportunities, and resulting in social uplift and poverty alleviation in the rural communities surrounding the PPAs. On the other hand, the ecological carrying capacity of the PPAs places a threshold on the types and numbers of species that can be introduced. The habitat fragmentation and land degradation that can result from overstocking large herbivores may reduce the number of national and international tourists visiting the area. In addition, as a consequence of South Africa's history, many areas of the Eastern Cape are contested (Cundill et al. 2005); reserve creation may engender social resentment and create political opposition to conservation, particularly if it entails the loss of jobs formerly provided by agriculture (Brooks et al. 2011).

Case study 2: man and the biosphere (MAB) case, regime shifts on the Causse Méjan

The Causse Méjan is a limestone plateau (1000 m average altitude) in the Cévennes Mountains of France. It is home to the largest steppe-like grassland in France (Fonderflick et al. 2013) and is part of the core area of the Cévennes National Park (372 000 ha) and the Cévennes Biosphere Reserve. Both PAs were created to maintain a rural way of life (including sheep and cattle farming and cheese production) as well as to support the conservation of indigenous grassland and several endangered species (e.g., vultures, Przewalski's horse). The Causse Méjan is an IUCN category VI PA (Table 1). Farmers are the managers of open meadows and steppes, which cover 37% of the core area; the rest is forest (O'Rourke 1999, Etienne and Le Page 2002). The plateau is ecologically vulnerable to bush encroachment and invasion by pine, boxwood, and juniper trees (Etienne 2001).

At the patch scale, the main ecological driving force is the pine seed rain intensity. There is a threshold of grazing pressure above which pine encroachment is impossible. Below this threshold, pine tree regeneration can be controlled by mechanical or manual removal of pine seedlings. The transformation of grassland to woodland represents a local ecological regime shift, but may not be a regime shift at the extent of an individual farm, because the main driving forces at the sub-tenure level are economic. Here, social-ecological regime shifts are provoked by changes in the percentage of a farm covered by pine forest, but the threshold will differ according to the area of grassland per stock required by the farming system (Kinzig et al. 2006). The farmer will select which farming system to practice for cultural and economic reasons that are largely derived from higher levels, such as national prices for livestock (Etienne and Le Page 2002). Both vegetation patches and farms occur within the broader extent of the biosphere reserve.

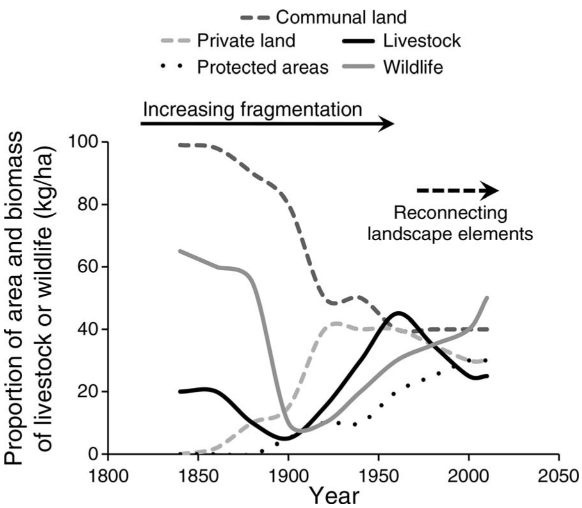

FIG. 6. Timeline showing changes in tenure or land use and wildlife and livestock populations in the Great Limpopo Transfrontier Conservation Area (GLTFCA) between approximately 1830 and 2010. The 1890 decline in wildlife and livestock was due to the rinderpest pandemic. The early period was characterized by increasing ecological and social fragmentation, followed by GLTFCA formation and moves to reconnect landscape elements for conservation.

At the biosphere reserve (PA and PA-network levels) and the regional extent, the main driving forces are both social and ecological, potentially producing two conflicting kinds of system change. On one hand, a regime shift may occur between cheese and timber production, depending on the unstable interactions between Roquefort cheese, Fedou cheese (a local cheese that, like Roquefort, is produced from sheep's milk), and lamb meat producers and timber producers (O'Rourke 1999, Kinzig et al. 2006). On the other hand, the pine–grassland dynamic may result in ecological regime shifts and the loss of open grassland biodiversity (Kinzig et al. 2006). Finally, national level institutions, policies, and international commodity demands will influence economic tradeoffs in this system.

Interestingly, two recent changes have provoked a new regime shift and management paradigm. First, in June 2011, the Causse Méjan and some neighboring sites of the Cévennes, were declared as world cultural heritage sites by UNESCO for their agropastoral Mediterranean landscape. Second, in the summer of 2012, and for the first time in the 21st Century, wolf attacks were registered ($n = 36$ attacks) and 22 ewes killed. The Causse Méjan social-ecological system is now at a threshold. Will it switch to a bushy and abandoned farmland landscape, supporting the establishment of a permanent wolf pack, or will it remain an agropastoral landscape, giving priority to sustainable sheep grazing practices and the conservation of open grassland? This dilemma questions the goals and practices of the national park, especially in its core area, as well as the adaptive capacity of farmers to integrate predators into their grazing system.

Case study 3: the Great Limpopo Transfrontier Conservation Area

The Great Limpopo Transfrontier Conservation Area (GLTFCA; ~90 000 km^2) includes adjacent parts of Mozambique, South Africa, and Zimbabwe. The core PA comprises three national parks (IUCN category II; Table 1), Limpopo in Mozambique, Kruger in South Africa, and Gonarezhou in Zimbabwe. Other PAs, mostly IUCN category VI, are included in each country, as are areas of communal and private land. State PAs cover 53% and communal lands 34% of the area, respectively (Cumming et al. 2013). The core GLTFCA, created by treaty between the three countries, is embedded within a provisional transfrontier conservation area that may serve as a buffer that increases the resilience of the GLTFCA. Within South Africa, the Kruger to Canyons Biosphere initiative (Coetzee et al. 2012) is extending the area under protection (IUCN category VI; Table 1).

Historically, Khoisan people occupied the area for millennia before Bantu agropastoralists arrived some 2000 years ago. Livestock appeared in areas adjacent to and within the GLTFCA between 600 and 1200 AD and various species of antelope, hippo, and elephant were hunted, and ivory was traded at the coast (Plug 2000). The period 1200–1800 AD was characterized by shifting tribal control of the region and Nguni invasions.

The entry of smallpox and measles into the region in the 1830s and the rinderpest pandemic in 1895 took their toll on both humans and ungulates respectively. The major transitions and drivers and associated social-ecological changes in the GLTFCA landscape are summarized in Fig. 6. At the patch scale and subtenure unit level, within the GLTFCA, changes have occurred in ecological habitat connectivity, disturbance regimes, water availability, and herbivore species composition and abundance as well as in the settlement patterns of people and their farming practices. At the protected-area scale, numerous changes have occurred in boundaries and associated tenure rights (see detailed explanations in Cumming et al. [2007], and Andersson and Cumming [2013]). The key feature of the changes that have occurred since 1830 is that they have largely been driven by political dictates at international and national levels. Initial change was driven by European colonization of the three countries, and then by national policies of racial segregation, resulting in the development of dual agricultural systems in South Africa and Zimbabwe. This resulted, on the one hand, in the development of large commercial farms on privately owned land, and, on the other, in increased densities of traditional small scale agropastoral farms in communal lands. Superimposed on this matrix were the formation of state PAs and the resulting displacement of people.

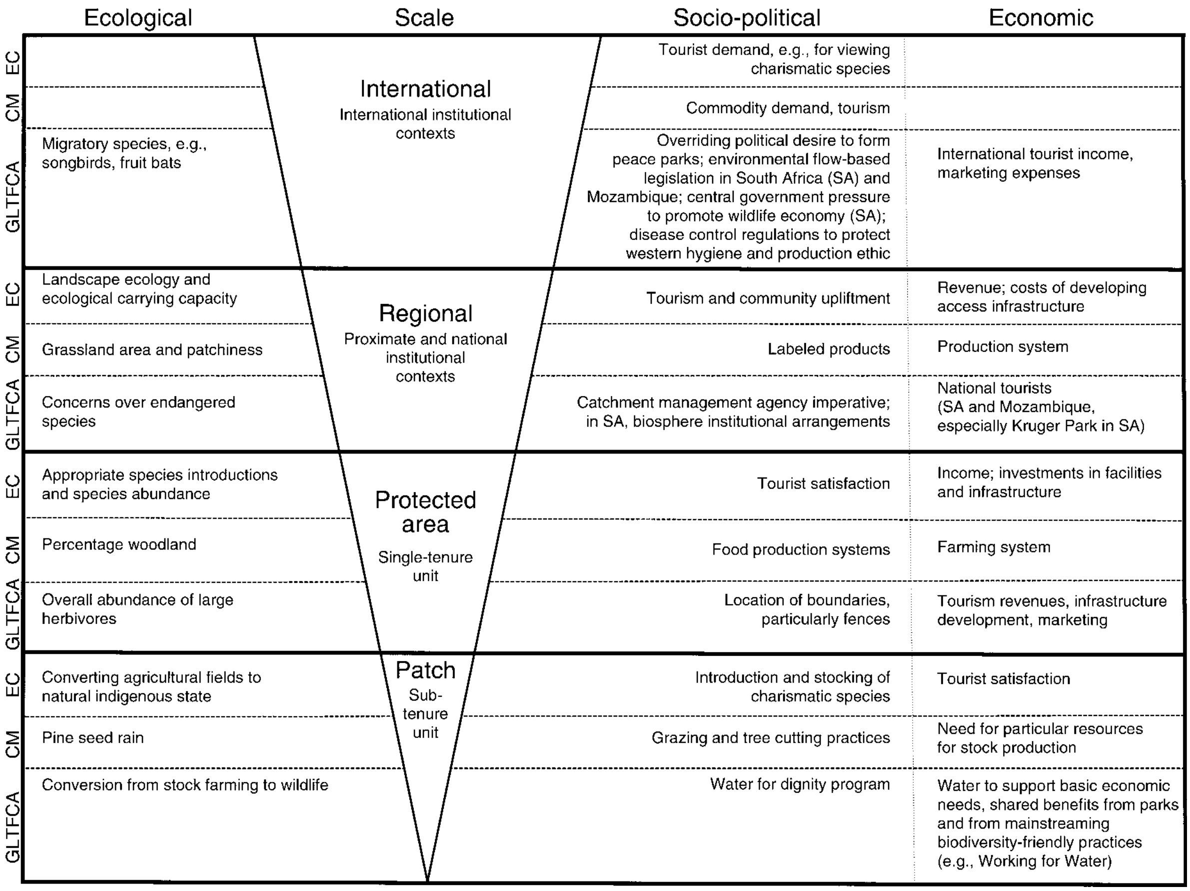

FIG. 7. Overview showing examples of issues identified as particularly important in each of the three case studies at different spatial scales in ecological, sociopolitical, and economic categories, respectively. The case studies are indicated on the left of the diagram (EC, Eastern Cape; CM, Causse Méjan; GLTFCA, Great Limpopo Transfrontier Conservation Area). Note that this list is not intended to be exhaustive, and many of the issues that are indicated for individual case studies are also relevant to other case studies in the same compartment. For example, tourism and community upliftment are important in all three areas.

The continuing top-down influences of international and national policies and legislation on resource management in the GLTFCA continue, with significant impacts on the management of animal diseases (e.g., foot and mouth disease) and the conservation and management of three species of charismatic megaherbivores (elephant and black and white rhinoceros; Biggs et al. 2013).

Key elements within case studies

Despite the different locations and scales of each of the three case studies, they share considerable commonality in their key drivers (Fig. 7).

Interestingly, our case studies suggest that ecological processes are often most directly relevant to PAs at intermediate to finer scales. In the Eastern Cape case study, carrying capacity and habitat fragmentation both occur at the patch and PA scales. Similarly, pine seed rain intensity, grazing pressure, bush encroachment, grassland to woodland transformation, predator–prey dynamics, and species home-ranges are finer-scale elements in the Causse Méjan. In the GLTFCA, ecological habitat connectivity, disturbance regimes, and herbivore species composition and abundance are also patch- and protected-area scale processes and patterns.

At broader scales, the dominant processes that shape and alter PAs are primarily sociopolitical and economic. In our case studies, the top-down drivers were elements such as tourism demands (Eastern Cape case study), international policies and commodity demands (Causse Méjan), and colonization and international and national policy changes (GLTFCA).

Sociopolitical and economic processes may, of course, impact ecosystems via impacts on the abiotic environment, as in the case of anthropogenic climate change, which is driven by human socioeconomic demands for such things as energy, transport, and manufactured goods. The main exception to this general pattern arises when migratory species are particularly important elements of a PA; this is not the case in any of our examples, but it is not uncommon. We could also

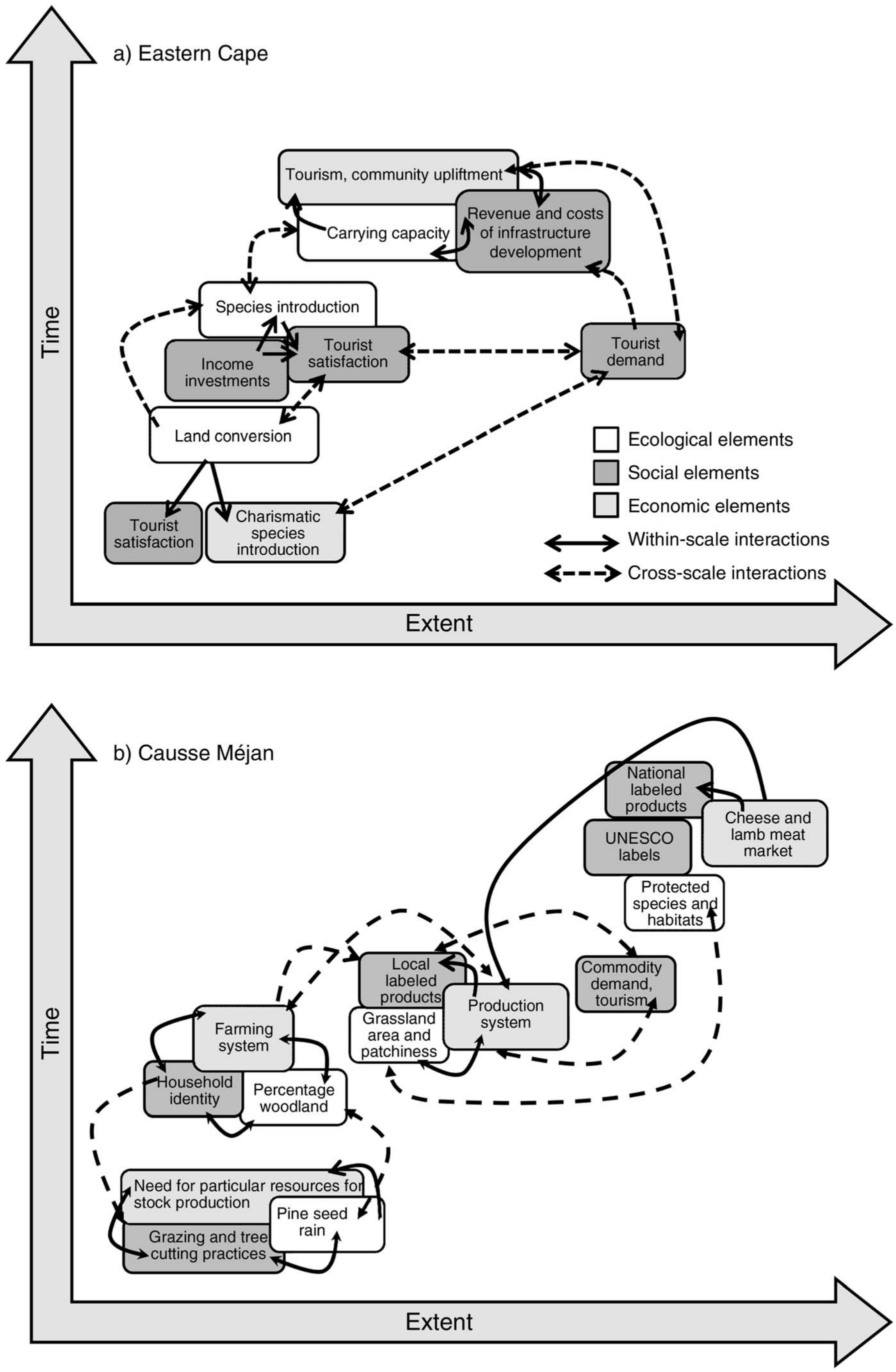

FIG. 8. Diagrams presenting a dynamic perspective for each case study system, (a) Eastern Cape; (b) Causse Méjan; (c) Great Limpopo Transfrontier Conservation Area. As indicated in the legend, the different colors for each box represent different kinds of system elements (social, economic, and ecological) and arrows indicate interactions and feedbacks within and between scales. These elements are plotted on the notional spatial (on the x-axis) and temporal (on the y-axis) scales at which they exist. The lengths of the boxes are not drawn to scale.

envisage that regional ecological influences become relatively more important for smaller PAs that are more dependent on colonization from nearby natural areas that are not necessarily within the boundaries of the PA (Bengtsson et al. 2003).

Dynamic interactions within case studies

If we consider a more dynamic representation of cross-scale interactions, the different variables summarized in Fig. 7 interact to drive change in PAs. In Fig. 8,

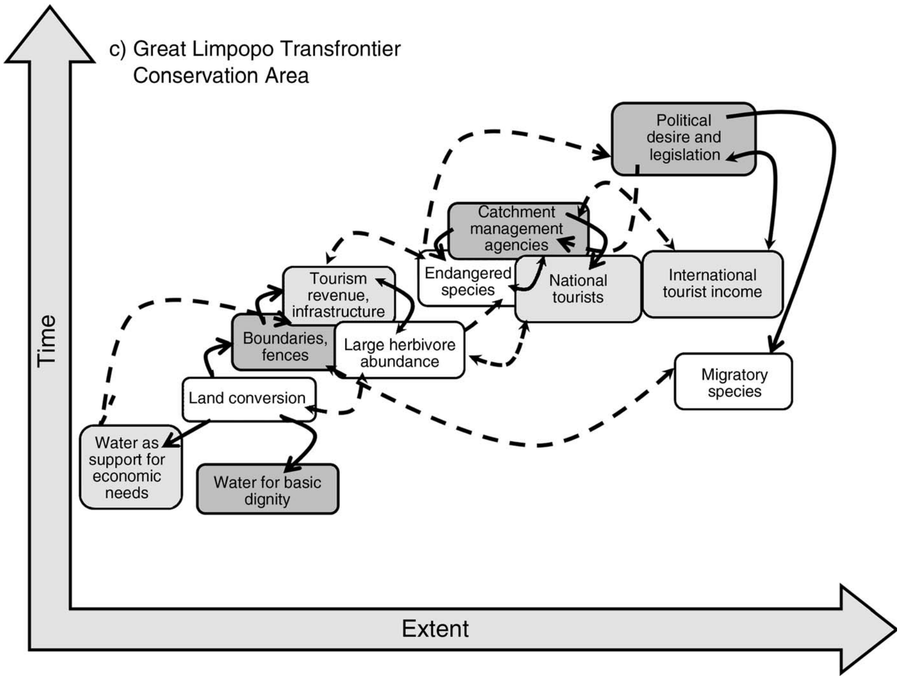

FIG. 8. Continued

we graph the spatial scale of our case-study variables against a notional speed at which these processes typically operate.

As these graphical depictions show, temporal scales do not arrange as readily along a hierarchy as spatial scales, creating opportunities for spatial–temporal scale mismatches (Cumming et al. 2006).

Since system changes are usually driven by feedbacks, particularly cross-scale feedbacks (Walker et al. 2006), it follows that slower feedbacks and feedbacks from slower processes will take longer to drive change than feedbacks from faster processes. Our examples show that top-down, broadscale processes like tourism demand can change over short time periods, while processes like habitat fragmentation manifest at a smaller spatial scale, but can take much longer to manifest and drive change. If, as our PA examples show, ecological processes such as succession and trophic cascades generally occur at smaller, slower scales (i.e., more gradually and at smaller extents, noting that biophysical perturbations are not ecological processes) and socioeconomic drivers occur at broader, faster ones, an emerging hypothesis is that, because of differential selection, PA social-ecological systems gradually become better adapted to cope with changes that result from sociopolitical drivers than with feedbacks from ecological processes. As a result of inertia and cross-scale gradients, top-down sociopolitical processes may drive the system to develop along a trajectory that renders it less resilient to large shocks that may eventually manifest from cross-scale ecological feedbacks. For example, timber demand during and after the second world war led to forest fire management policies in the United States that were designed to save timber; resulting management approaches eventually led to the hugely destructive 1988 fire in Yellowstone National Park.

Case study insights

Figs. 7 and 8 provide strong support for two general points that we have emphasized throughout the paper. First, PAs function as social-ecological systems, and, hence, understanding their social and economic components is as fundamental as understanding their ecology, if we are to analyze and manage their resilience. Second, cross-scale processes are highly relevant to the resilience of PAs and should be considered as integral to any analysis, rather than treated as subordinate to analyses of system dynamics at a single scale.

In addition to current cross-scale influences, the history and current objectives of each case-study PA play an important role in their current resilience. In the Causse Méjan, with its long history of human use and livelihood support, the PA is politically uncontested and is seen as a way of maintaining its unique regional identity. In southern Africa, with its colonial history, PAs are sometimes seen as a form of neocolonial land grab. This is particularly true in South Africa, where the memory of apartheid is still recent. About 40% of national and provincial PAs in the Eastern Cape are under some form of land claim from historically dispossessed local communities, and the political acceptability of PPAs is unclear. The potential for land redistribution from conservation to agriculture, whether legally or through illegal occupation (as has occurred in Zimbabwe), therefore, represents a very real possibility. PAs in South Africa must maintain their sociopolitical resilience by remaining accessible and continuing to cater to and support all strata of society, even if this reduces their overall potential economic viability. Similarly, although the GLTFCA was created after the end of apartheid, Kruger Park has a contested history, and the greater PA was also created in a relatively top-down manner by intergovernmental agreements. Its continued viability as a conservation area, thus, depends heavily on maintaining its political acceptability.

It is obvious that PAs and their effectiveness in conserving biodiversity will be influenced by regional changes, particularly in relation to politics, governance, and conflict. Uncertainty over land tenure can definitively undermine conservation efforts. For example, ongoing conflict in the Democratic Republic of the Congo, and the displacement of local communities from their land, is endangering key populations of chimpanzees and gorillas; and poor governance and land appropriations in Zimbabwe have undoubtedly contributed to declines in rhinoceros populations in Zimbabwean PAs. One of the starkest conservation challenges in regions with poor governance remains that of working out how to protect PAs against the winds of political change.

Our case studies also suggest that PAs contribute to regional social-ecological dynamics and, hence, to regional social-ecological resilience. For example, in the Eastern Cape, if PAs maintain patches of indigenous vegetation that would otherwise be converted to agriculture, they may be able to cumulatively reduce local fragmentation and maintain a range of ecosystem services and natural processes (as has been shown in similar systems, e.g., seed dispersal by cavity-nesting birds that depend on dead wood in old, large trees; Joseph et al. 2011) that contribute positively to human well-being (Cumming and Spiesman 2006). Similarly, in the Causse Méjan, the PA contributes to building and maintaining a regional identity that includes an awareness of the reliance of the community on ecosystems.

Discussion

We have argued that, if we are to understand and enhance the long-term resilience of PAs, we must adopt an inter- or trans-disciplinary perspective that incorporates (at a minimum) elements of ecology and social science. Similarly, our analysis shows that questions of scale and recognition of cross-scale influences are of fundamental importance for PAs. Our case studies illustrate the interlinked nature of PAs as social-ecological systems. Intriguingly, it is particularly at broader scales that social, political, and economic considerations become paramount. While this may be due in part to ways of thinking or management practices that are still rooted in the internationally validated and powerful wilderness discourse, it also reflects the broad-scale nature of socioeconomic processes and ongoing globalization.

Our case-study analysis does not explicitly consider an additional element of scale-related problems and multi-scale interactions, that of emergent higher-level system properties arising from the interactions of elements at a single scale. Many PAs belong to socioeconomic networks. These may be formal, as in the case of national and provincial parks, which are generally the responsibility of a governmental management agency; or informal, through exchanges of information and resources (e.g., Goss and Cumming 2013). PAs are also members of an ecological network that facilitates the propagation and movements of animals and plants. Membership in a network may increase the resilience of an individual PA (e.g., by providing additional options for problem solving) or decrease it, if it acts to serve the interests of local, regional, and global elites (e.g., if membership in a network demands the imposition of locally inappropriate management practices). Clearly, network membership and its relevance for PA resilience will change with scale and should, thus, form part of any scaling analysis of PA resilience.

Although they remain propositions rather than established generalities, our cross-scale extension of Ostrom's SES framework suggests some general theoretical principles for the resilience of PAs. These propositions can serve as the basis for more specific hypotheses that future studies about social-ecological resilience of PAs can test. First, there is a relationship between the scales and levels at which different system elements exist and the frequency and/or magnitude of their interactions. This is a general principle that is derived from hierarchy theory and has been further reinforced by ecological research (Allen and Starr 1982, Levin 1992, 2005). Fine-scale processes may be irrelevant for understanding system dynamics at larger scales of analysis, or, conversely, may occur at speeds such that larger-scale dynamics are largely irrelevant for their outcomes. For example, the movements of individual atoms are inconsequential to understanding an animal's movement path; and, continental drift has had a profound influence on global species composition, but is largely irrelevant for understanding PAs at the time scales that are of interest to managers. It may also be easier to generalize about larger-scale pattern–process dynamics because a considerable amount of fine-scale variation is averaged out at broader scales (Levin 1992). Social-ecological feedbacks should therefore be most pronounced when they occur between a given functional scale of the ecosystem and the most closely aligned socioeconomic scale, and/or the scales immediately above or below the focal scale (see Fig. 4). For analyses of PA resilience, this means that recognizing and making explicit the ways in which system scales and levels align and interact with one another should clarify the most important perturbations against which resilience and adaptive capacity must be built, and help in making decisions about management tradeoffs. For example, in the GLTFCA, threats to the area's protected status from higher-level political processes may suggest enhancing social acceptability and community engagement through providing greater access to parts of the PA or the resources that it contains (e.g., permitting mopane worm harvesting; Makhado et al. 2009, Gondo et al. 2010), whereas, threats from pathogens introduced by or transmitted to livestock in neighboring areas may require greater segregation and reduced access (Rodwell et al. 2001, Caron et al. 2003).

Second, the kinds of interactions and feedback loops in which PAs participate may have differing consequences for system resilience, particularly in relation to the spatial and temporal scales of different actors and interactions. Although interactions between closely aligned ecological scales and socioeconomic levels (e.g., the extent of grassland that is necessary for game viewing, the scale at which the manager can implement controlled burns, and the monthly gate revenue of the PA) may dominate the usual dynamics of the PA, very broadscale or very slow variables, acting either directly or indirectly, can have important implications for overall system resilience, regime shifts, and management (Carpenter and Gunderson 2001, Lundy and Montgomery 2010). For example, a gradual trend towards regional deforestation may affect rainfall and temperature patterns within a PA, potentially leading to irreversible changes in vegetation composition and long-term impacts on ecosystem service provision to surrounding human communities. A closely related phenomenon is that of the shifting baseline, where change that is slow by human standards may mean that degraded ecosystem states (e.g., reduced size of fishes in marine PAs or lower levels of forage in a rangeland) become regarded as normal. Slow variables in particular can lead to surprises and push PAs into traps (i.e., states in which feedbacks maintain an undesirable system state, such as a low-diversity thicket in a savanna system) that can result in a loss of resilience and eventual collapse (Carpenter and Turner 2000).

Third, we would expect to find decay in the strengths of drivers (and related feedback effects) with both distance and time. For example, the numbers of tourists visiting a PA decline with increasing distance from airports and major cities (A. De Vos et al., *unpublished manuscript*). Remote PAs, thus, experience lower human impacts and are managed differently from those that are more accessible. Similarly, while path dependencies may be important in understanding the current locations of PAs, their influence also diminishes with time. For example, many southern African PAs were originally set aside for hunting (rather than exploited for farming) because of the presence of sleeping sickness, malaria, and tick-borne diseases. Tsetse flies have been eradicated in some areas and their distributions, and those of malaria vectors and ticks, are likely to change further as the global climate is altered by people (Rogers and Randolph 1993, 2000, Cumming and Van Vuuren 2006), making all three kinds of disease increasingly less relevant to the location of PAs. For PA resilience, the principle of time- and distance-based declines in driver and feedback strengths suggests that PA resilience will correlate with both ecological and socioeconomic connectivity, but in different ways for different drivers, depending on whether resilience is enhanced or reduced by the distance effect. Remoteness may result in fewer visitors and lower economic resilience, for example, but may also reduce the potential impacts of such factors as poaching, pesticide use on neighboring farmland, and water extraction outside the PA.

Fourth, the resilience of a complex system should correlate to its size; larger and older PAs, and those established in areas that involve more people, should be more resilient (although not inevitably so). Note that we use older here to refer to PAs that have had natural habitat cover for a longer period of time, and in contrast to areas that are reclaimed or restored from farmland or other land uses; some newly proclaimed PAs may have old ecosystems and young social systems. Larger, older PAs will be more resilient to natural perturbations, such as fires or pest outbreaks, by virtue of their naturally heterogeneous habitats and high species diversity; are more likely to contain effectively self-regulating food webs that include such elements as top predators and mega-herbivores; are more likely to include natural resources that society depends on or values highly, such as catchment areas, mountain peaks, or iconic waterfalls; will tend to have a greater diversity of stakeholders (since stakeholders are often accumulated over time) and a stronger public interest and participation in management (being better known and more likely to contain highly charismatic species), making it less likely that a PA is rezoned or de-gazetted; may have a history that invests them with greater cultural meaning (e.g., more people remember childhood holidays there, and it may have achieved iconic status, like Yellowstone National Park or Kruger National Park); will have larger sunk costs, in the form of infrastructure and investment in the park; are more likely to contain multiple IUCN categories, thereby achieving multiple goals that different stakeholders might have; and are less likely to experience the level of social change that is needed to transform their management or for them to be deproclaimed. It is possible, of course, that revolt processes occur that lead to change in larger PAs, and/or that their size makes them a more obvious target for land redistribution initiatives, but, on average, we would expect them to be more resilient.

Fifth, given the many different ways in which power relations work in different societies, the relative importance of top-down and bottom-up influences is likely to be asymmetrical and dependent on the context in which the PA exists. As we have shown in the three case studies, understanding context-dependent factors is essential to the proper functioning of a PA. Therefore, there are no governance panaceas for building PA resilience that can be applied with equal success to all situations (Ostrom and Cox 2010). For example, in a nation with a weak government, it may be very difficult to buffer PAs from higher-level influences (e.g., development pressures, resource acquisition by the rich and powerful, or regional conflicts) or to implement policies and laws at scales relevant for effective PA management. Normative issues, value systems, and attitudes will influence PA resilience. Incorporating stakeholders in building local resilience, even where regional resilience is low, should be a major focus of conservation efforts. Current thinking suggests that the growing role of NGOs, international agencies, scientific groups, and private operators should be explored in the context of the development of polycentric governance of PAs where community-based management, integrated and conservation development projects, and adaptive co-management approaches are promoted and implemented. It is not clear yet, however, whether such consensus-based approaches will be sufficient to maintain PAs in the face of demographic and globalization processes.

Our framework and proposed principles have implications for PA management and planning, although the uptake and application of some of these insights might be challenging. Our case studies show that PA managers and planners cannot afford to ignore either ecological or social dynamics, or (more importantly) their interactions at scales and levels below and above that of the PA. Analyses of the key drivers of change will assist with identifying the relevant scales of processes that are likely to influence PA management and planning. Such analyses must be undertaken with a clear idea of the PA's social-ecological role, goals, and objectives. When new PAs are planned, emphasis on larger, multi-objective, and multi-IUCN category PAs may lead to improved long-term viability of the area. Cross-scale institutional linkages have the potential to serve as a link between top-down and bottom-up influences. However, while incorporating these elements into management and planning would be desirable, national and international legal and political systems may not readily allow for adaptively managing PAs as interacting cross-scale SESs (Garmestani and Allen in press). Similarly, institutional and cultural constraints may further exacerbate the challenges of changing embedded management approaches. In particular, many PAs have a top-down, command-and-control history and approach to management (e.g., Andersson and Cumming 2013, Goss and Cumming 2013). Challenging these legal, political, institutional, and cultural constraints is paramount for making PAs more resilient into the future.

We have argued throughout this paper that understanding PAs as social-ecological systems is integral to developing the approaches, and the science, that will be required to maintain PAs as functional and effective conservation tools into the next century. While awareness of the multi-faceted nature of PAs has been gradually building in conservation biology for many years, our understanding of their dynamics is still weak in some areas, particularly in relation to quantifying and managing the ability of PAs to withstand shocks arising from socioeconomic and governance-related variance at higher and lower scales. Concepts from social-ecological systems research that explicitly address cross-scale feedback loops and resilience appear to offer a range of useful conclusions in this context, and we look forward to further growth in this important area of research.

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