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Protected areas as social-ecological systems: perspectives from resilience and social-ecological systems theory

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Protected areas as social-ecological systems: perspectives from resilience and social-ecological systems theory

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Abstract. Conservation biology and applied ecology increasingly recognize that natural resource management is both an outcome and a driver of social, economic, and ecological dynamics. Protected areas offer a fundamental approach to conserving ecosystems, but they are also social-ecological systems whose ecological management and sustainability are heavily influenced by people. This editorial, and the papers in the invited feature that it introduces, discuss three emerging themes in social-ecological systems approaches to understanding protected areas: (1) the resilience and sustainability of protected areas, including analyses of their internal dynamics, their effectiveness, and the resilience of the landscapes within which they occur; (2) the relevance of spatial context and scale for protected areas, including such factors as geographic connectivity, context, exchanges between protected areas and their surrounding landscapes, and scale dependency in the provision of ecosystem services; and (3) efforts to reframe what protected areas are and how they both define and are defined by the relationships of people and nature. These emerging themes have the potential to transform management and policy approaches for protected areas and have important implications for conservation, in both theory and practice.

Key words: complexity; connectivity; conservation; institution; management; national park; natural resources; policy; protected areas as socioecological systems; scale; sustainability.

Introduction

The last 50 years have seen fundamental shifts in applied ecology and conservation. Their scope has broadened from a focus on single populations of species, together with the preservation of "pristine" locations, to the recognition that conservation problems encompass a wide variety of disciplines, systems, and solutions, with ecosystems and social systems being inextricably connected (Allen et al. 2011). Many ecologists now embrace a complex systems perspective on social-ecological systems, including thresholds, feedbacks, and emergent properties such as resilience (Folke et al. 2004). In conservation biology, objectives of maintaining biodiversity, ecosystem structure, and ecological processes in the face of anthropogenic change remain; but the scope of conservation has changed profoundly, and its nexus with human-centered disciplines, such as psychology, politics, sociology, and economics, has become an exciting and fast-moving frontier (Groom et al. 2006).

Protected area management is often viewed as a primarily ecological problem, in which managers are "outside" the system and protected areas must be preserved in a historically defined "wild" state. This perspective ignores the relevance of location, context, and connectivity, both ecological and socioeconomic; and particularly, that managers and policy makers, as well as people who work in and visit protected areas, live in a social context that creates demands and expectations about ecosystem management. Although ecosystem management focuses on biodiversity, management institutions, their agendas and goals, such as setting target population sizes of animals, fire policies, access rights, or control of invasive species, are social constructs that are created and debated in political arenas (Macneil 2013, Bell and Morrison 2015, Cinner and McClanahan 2015). Failure to recognize the plurality (social, ecological, and economic) of protected areas has in the past created many conservation problems.

Biodiversity conservation seeks to understand the interactions of people and nature and manage those interactions, or create the appropriate enabling conditions for them to occur, to achieve acceptable ethical,

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equitable, and political solutions for diverse stakeholders (Groom et al. 2006). Conservation solutions often seem to be so heavily tailored to a local context that they are unique, but there is a growing sense within the conservation community that many lessons learned in one context have elements that can be translated to others. The translation of knowledge between conservation situations (i.e., understanding different problems and solutions from the perspective of a general theory, rather than as idiosyncratic individual case studies) requires general conceptual structures (hypotheses, theories, and frameworks [Cumming et al. 2015]). These can identify shared elements of seemingly disparate problems, support predictions, and guide decision-making in data-poor situations. Without general frameworks and theories, every conservation and management dilemma is conducted in isolation, and learning is limited.

One of the most potentially useful emerging frameworks for conservation biology is that of social-ecological systems (SESs; also termed coupled systems, or coupled human-natural systems [Berkes et al. 2003]). People depend on ecosystems in a wide variety of ways. This dependency often requires modifying or managing ecosystems to enhance the delivery of ecological goods and services, particularly given human population expansion and increasing demand for ecosystem-derived products. Four common general elements of human interventions are simplification, reduction in natural variability, fragmentation and loss of contagious processes, and the introduction of hard boundaries (Turner et al. 2001). For example, in the context of protected areas, people may reduce habitat diversity, harvest animals or plants, alter disturbance regimes, strive to keep natural populations within pre-defined limits, or construct fences that limit movement and population expansion. These changes have consequences for system function, stability, and resilience.

As ecosystems respond to intervention and use by people, they often do unexpected things; for example, pest outbreaks and unusually large fires occur, forests are lost, or shallow lakes become dominated by toxic algae. Often the system is large, the disturbance infrequent, and the responses complex; and many changes are triggered by events in societies and economies outside the local ecosystem, as discussed by Cumming et al. (2015) in this feature. Thus, the outcomes of management interventions can be highly uncertain. Action is often necessary even when there is high uncertainty surrounding the system's response (Williams 2011), and unexpected outcomes may trigger crises and/or create new demands and expectations in the human socioeconomic system. Modification of ecosystems by people can thus initiate a series of feedback loops that begin with purposeful management or other interventions and cycle through the ecosystem and the socioeconomic system back to management (Fig. 1). Just as two pendulums connected by a spring will behave differently from two unconnected pendulums, SES dynamics are both qualitatively and quantitatively different from those of either social systems or ecosystems alone.

Social-ecological feedbacks and interactions vary with scale, as does the provision of ecosystem goods and services to and from SESs (Birgé et al. 2016). As scale (time and space) broadens, ecosystem controllability decreases; but the suite of ecosystem services available for management increases, creating a tension whereby increasing scale reduces the potential for management but increases the need for it.

The establishment of protected areas remains one of the most fundamental tools available to conservation, and it is important that protected areas are developed in a way that is ecologically, economically, and politically sustainable (Cumming 2017). Social-ecological systems perspectives offer a balanced and nuanced approach to protected area management, as well as a holistic framework for comparing and contrasting conservation successes and failures. Three particularly interesting and useful themes within social-ecological systems approaches to understanding protected areas emerge from the papers in this invited feature. They include (1) increasing attention to the resilience and sustainability of protected areas and the landscapes in which they occur; (2) increasing consideration of the relevance of spatial context and scale for protected areas and the ecosystems services they provide; and (3) efforts to reframe what protected areas are and how they both define and are defined by the relationships of people and nature. These themes, which we discuss in more detail below, connect the papers in this invited feature.

Resilience and Sustainability of Protected Areas

Many social-ecological analyses focus on questions of system stability and dynamics, particularly in relation to resilience, vulnerability, risk, and adaptation. These concepts are integral to the new paradigm in applied ecology and conservation biology, because viewing a protected area (and its surrounding landscapes and communities) as a social-ecological system is a valuable conceptual step toward conservation-relevant interdisciplinary or transdisciplinary analysis. Systems analyses begin with problem identification and clarification: defining what the system is, what the key elements of interest and relevance are, and how a particular problem arises (Walker et al. 2002). Systems definitions are often dominated by concerns about inter-relationships, particularly those that might cause feedbacks between cause and effect, and persistent feedbacks that are critical to maintaining system structure. They attempt to understand and capture the relevant complexity of the problem.

Rather than thinking of conservation as an effort to either prolong the life of a dying patient or optimize particular variables (whether number of species, returns on conservation dollars, or the design of protected areas), SES perspectives recognize the inevitability of change and also, in many cases, the need for it. This de-emphasizes

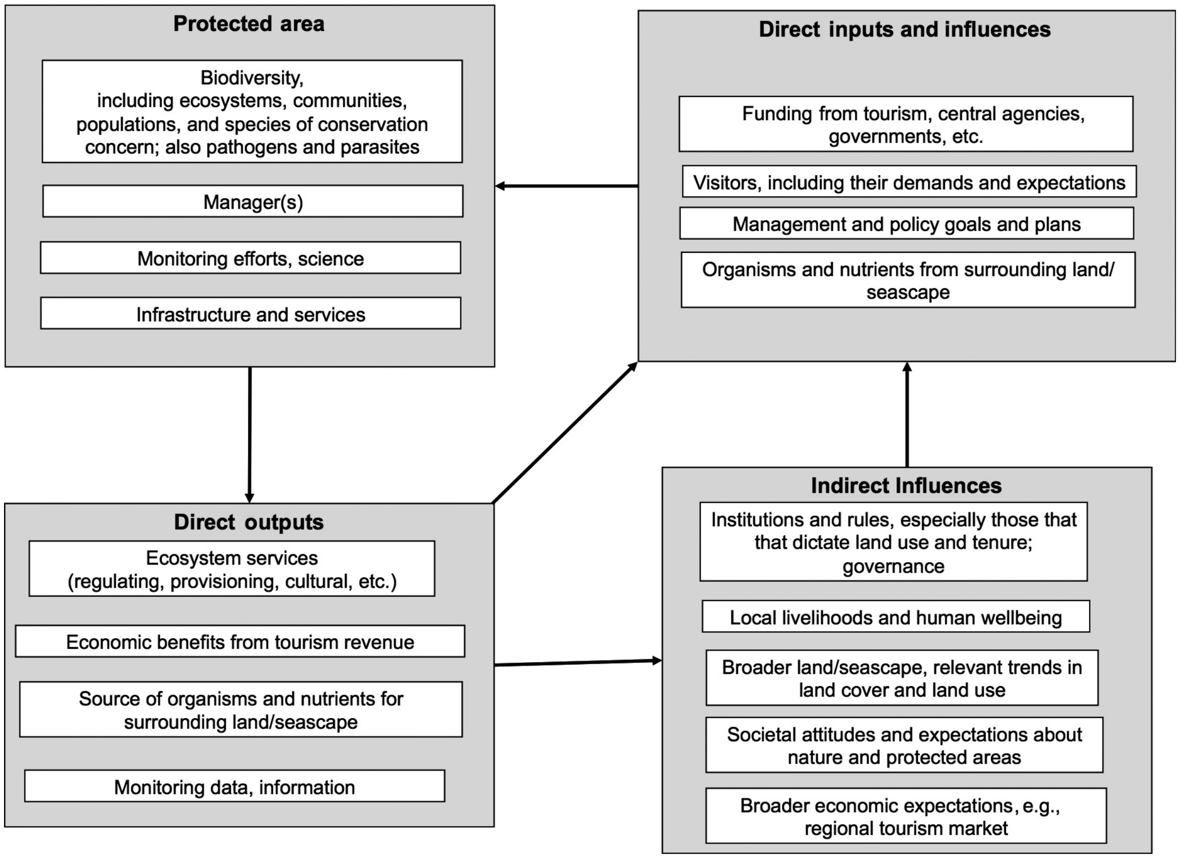

Fig. 1. A systems perspective on social-ecological feedbacks in protected area management. In addition to interactions and feedbacks that occur within protected areas, their direct outputs have add-on effects that subsequently influence both their internal dynamics and their future outputs.

the identity of individual species in favor of functions and services. The goals of conservation are thus to create enabling and facilitating conditions for species persistence and evolutionary processes, to ensure that system elements that are critical for coping with perturbations are retained (even if this makes the system less efficient), and to steer systems away from potentially catastrophic regime shifts (e.g., from woodland to desert, as in the Sahel) with consequences for ecosystems and people (Folke et al. 2005). Conversely, in some situations protected areas have deteriorated and managers may need to transform or restore the system, which means creating a different system; heavily invaded protected areas are examples (Chaffin and Gunderson 2016). The shift in thinking entailed by SES approaches is to move away from efforts to optimize production, and toward less “efficient” but ultimately more resilient and more sustainable ways of achieving conservation and socioeconomic goals.

Resilience has been proposed as an organizing framework for social-ecological analysis but critiqued as difficult to define, operationalize, or measure (Quinlan et al. 2015, Angeler and Allen 2016). A standard three-part definition of resilience in social-ecological systems research includes (1) the ability of a system to absorb disturbance while remaining within the same domain of attraction (i.e., retaining the same controls on structure and function) without changing state; (2) the degree to which the system is capable of self-organization; and (3) the degree to which the system can adapt (Carpenter et al. 2001). Resilience can also be described as the ability of a system to maintain its identity (Cumming and Collier 2005). A focus on identity and identity-related thresholds (i.e., points beyond which the identity of the system is lost) can be used to link tangible management goals, empirical data, and resilience theory (Cumming et al. 2005). Resilience is an important component of sustainability, which can be viewed as the likelihood that a system retains its identity indefinitely.

Resilience and sustainability are emergent properties of complex systems. In SESs, they imply a predictably steady, though variable, delivery of ecosystem services and/or disservices to people. The regime shifts that occur when the resilience of a system has been exceeded have consequences for the various forms of capital (natural, social, economic) in a system and may be difficult to reverse due to hysteresis. However, periods of rapid transformation can also offer windows of opportunity for the introduction of new system elements and dynamics and the loss of dysfunctional or problematic elements and interactions (Holling 2001, Westley et al. 2002).

Protected area managers face several major challenges in learning to manage protected areas sustainably and for greater resilience (Allen et al. 2011). Among others, they include (1) describing and analyzing the key elements and dynamics of the social-ecological system, particularly where monitoring data are lacking or inadequate, and understanding where their areas are vulnerable and where resilience resides; (2) determining the relevant scales present in a system (Angeler et al. 2015), and the trade-offs in shifting management focus across scales (Birgé et al. 2016); (3) managing perturbations to remain within expected levels, while avoiding problematic feedbacks to the social and political components of protected areas and their surroundings; (4) learning how to work with, and balance, effective biodiversity conservation against the political and socioeconomic elements of protected areas (such as managing human–wildlife conflict, tourist demand for greater access to wilderness areas, poaching, and budgetary restrictions); and (5) managing and coping with spatial elements of resilience, such as habitat connectivity and exchanges with the surrounding landscape.

Several articles in this invited feature touch directly on the themes of resilience and sustainability. Cumming et al. (2015) offer an expanded framework for thinking about social-ecological problems and scale dependencies; Maciejewski and Kerley (2014) provide evidence that overstocking of elephant, which is unsustainable in the long term, does not necessarily result in greater tourist revenue; and Maciejewski et al. (2015) consider the relationship between resilience and the scales of different pattern–process interactions in the context of nature-based tourism.

Relevance of Space and Scale

Evidence of an important role for spatial elements of protected area dynamics, and resilience, is rapidly accumulating. Protected areas are inherently spatial entities; they have been designated on maps for particular reasons, with clearly identified boundaries and (usually) a clearly articulated justification for their inclusion of particular ecological and cultural assets, such as endangered species, unique natural features such as waterfalls or mountains, or sites of archaeological importance. However, most protected areas are multi-functional. In addition to their core role in conserving biodiversity, they may provide important ecosystem services (and disservices) to surrounding non-protected areas and adjacent communities (DeFries et al. 2010, Palomo et al. 2013). Protected areas may, for example, provide clean water to cities, non-timber forest products, grazing and thatch grass, and the maintenance of breeding grounds or source populations of ecologically and economically important species such as pollinators, spiders, harvested wild species such as reef-breeding fish, and migratory species (Cumming 2017). In addition, protected areas may enhance the quality of life of people living outside protected areas through the provision of cultural services to visitors (Ament et al. 2016).

Conservation biologists have long been interested in the relevance of ecological habitat connectivity for biodiversity conservation. Connectivity between protected areas is critical for the persistence of biotic elements, but can be equally important for socioeconomic processes that relate directly to protected area management and sustainability. Social and economic exchanges may, for example, include invasive species control, sharing of equipment or trained personnel for fire (Twidwell et al. 2013) or pathogen management, translocations or restocking of wildlife species, and information about incipient problems or management innovations (Maciejewski and Cumming 2015). The connections between protected areas and adjacent non-protected areas can also be important for ecological and social-ecological dynamics (De Vos et al. 2016). Those connections also vary with scale, and over time, thus emphasizing the critical need to identify scales and scaling relationships within protected areas.

Protected areas can be viewed as both ecological and economic networks (Uden et al. 2014, Maciejewski and Cumming 2015, 2016). They also affect and are affected by structures and processes at hierarchical levels above and below themselves (Perz and Almeyda 2010, Allen and Giampietro 2014). Given the spatially explicit nature of protected areas, such interactions are often defined by spatial scale, and there is a need for alignment between spatial and temporal scales and the institutional levels at which protected areas are governed (Cumming et al. 2015).

Focusing on spatial scale, a complex system such as an ecosystem can be decomposed into structural and process elements that can be defined over a fixed range of spatial and temporal scales. A terrestrial ecosystem dominated by needle-leafed evergreens, for example, has discrete structures and processes at a number of scales (Ludwig et al. 1978, Crawford and Jennings 1989). It can be described at a leaf or needle scale (centimeters to meters in space and months to years in time); a tree scale (multiple meters and decades); or a forest scale (kilometers and centuries). At each scale, there is a characteristic pattern in structure, with different processes (e.g., lightning strikes, spruce budworm herbivory, long-term climate cycles) driving different patterns at different scales, and feedbacks occurring between pattern and process both within and between scales.

Ecosystems and social systems are characterized by bottom-up and top-down controls and thresholds, multiple scales and nonlinear dynamics. Processes are generally scale specific, and a limited number of processes operating at distinct scales are responsible for the characteristic structures in time and space that define specific systems (Holling 2001). This is important for humanity, and management, because self-organization (reinforcement between process and structure) in complex systems such as ecosystems can mean that they resist movement away from a particular state or domain of attraction. In shallow lakes, for example, the presence of macrophytes and zooplankton helps to buffer the effects of phosphorus addition and keep the lake in a clear water state that is good for fishing, swimming, and drinking (Scheffer and Jeppesen 2007). Thus, where ecological processes reinforce and buffer each other, we can expect reasonably predictable dynamics and the relatively constant provision of ecosystem goods and services.

Conservativeness and self-organization in ecosystems are due in part to the positive interactions among biotic and abiotic elements. For example, animals exploit necessary resources, such as food and breeding sites, in space and time. In doing so they may change ecological structures in ways that favor their own needs. Large herbivores, for example, can alter the dynamics of succession (and competition among grasses, bushes, and trees) to improve their own habitat (Jones et al. 1994). Self-organization often involves other biotic system elements as well. For example, many grasses are pyrophilic and, therefore, highly flammable (Brooks et al. 2004). In the absence of fire, succession would often eliminate grasses. However, the presence of pyrophilic grasses encourages fire, which subsequently favors grasses and excludes competitors (Peterson 2002).

Protected areas may contribute to broader-scale spatial resilience in the areas in which they are located. Ideas about spatial resilience originally focused on the importance of ecological legacies (i.e., elements such as species or habitat characteristics that persist after disturbance) and connectivity among neighboring systems for withstanding disturbance and avoiding regime changes at broader spatial extents than individual focal systems (Nystrom and Folke 2001). Ecological memory is expected to increase with landscape extent and to some degree with landscape heterogeneity and diversity, suggesting that fostering or actively conserving particular places as protected areas may provide a means to enhance the ability of SESs to absorb landscape disturbances (Bengtsson et al. 2003). In this context, spatial resilience was simply defined as ecological resilience at broader spatial scales (i.e., beyond local habitats; Obura 2005), or more accurately, the ways in which broader-scale (regional) resilience affects local (protected area) resilience and vice-versa.

The emphasis on resilience at spatial scales greater than the focal system has dominated subsequent spatial resilience references. Spatial resilience can also be more explicitly considered as the relevance of spatial system properties (e.g., heterogeneity, connectivity, context, location, and network membership), both internal and external, for resilience (Cumming 2011*a*, *b*). Since interaction strengths often decay with distance, rather than being all or nothing, analyses of protected area resilience may have to select a distance or time period over which to define the boundaries of the study system. Thus, "internal" may be defined in social, economic, or ecological terms by a geographic boundary (e.g., a watershed or a provincial boundary), by participation in a spatially segregated supply chain (e.g., timber is harvested in one location, cut in another, sold in another, and bought in yet another), or by shared elements, such as the movements of individuals between habitat patches within a single metapopulation at time scales relevant to a single generation. Spatial resilience can be more explicitly considered as an emergent property of the spatial arrangement, differences, and interactions among internal elements of resilience (i.e., those within the focal protected area), external elements of resilience (i.e., those outside the protected area), and other spatially relevant aspects of resilience (e.g., adaptations to environmental change; Cumming 2011*a*, *b*, Allen et al. 2016). Internal and external components interact to affect the spatial feedbacks that either maintain a level of local stability within a landscape or push it into a different state. Spatial resilience offers a way of connecting typical "landscape ecology" variables, such as heterogeneity in land use and land cover distributions, woodland cover, and the spatial configuration of surrounding green spaces, with socioeconomic networks, trade, and feedbacks between social and ecological elements of the system at several different scales (Cumming et al. 2017). Analysis of space and scale in complex adaptive systems in turn provides an entry point for the development of new theory and analytical tools (e.g., Sundstrom et al. 2017).

For protected area management, consideration of space and scale and their relationships to resilience raise many additional challenges to those listed earlier. Some of these that seem to us to be of highest priority include (1) developing and working with spatial data sets, such as atlases and remote sensing data, to better understand spatial dynamics and the role of heterogeneity within protected areas; (2) developing a better general framework to facilitate or direct the interactions of protected areas with their surrounding landscapes, including both ecological and socioeconomic spillover effects; (3) learning to align ecological, social, and economic processes and their interactions, particularly where spatial, temporal, or functional mismatches between scales (and resulting problems; Cumming et al. 2006, Mills et al. 2010, Guerrero et al. 2013) are possible; and (4) developing a better understanding of when feedbacks between social and ecological system elements are important and when they can largely be disregarded(Cumming et al. 2005).

Space and scale are central themes in this invited feature. Uden et al. (2014) present a case study that focuses on ecological connectivity across a lake network and demonstrate the strong influence of scale on the function of ecological networks. Cumming et al. (2015) offer a new framework for thinking about scale in the context of social-ecological systems analysis, extending Ostrom's (2009) sustainability framework and connecting social-ecological approaches to the concepts of functional ecosystems and multi-scale management objectives. This approach is taken further by Maciejewski et al. (2015) in considering the problem of identifying and resolving scale mismatches, which can create management problems when the scales of socioeconomic and ecological processes are misaligned.

Reframing Protected Areas

As humanity's impact on the Earth increases, natural areas are increasingly coming under threat from human activities (Craigie et al. 2010). Declines in the extent of many natural habitats, and increasing extinction rates, are accompanied by increasing recognition of the need for extensive, well-connected networks of protected areas that can ensure the persistence of representative examples of ecological communities into the future (Hannah et al. 2007). Given the apparently inadequate global coverage of formal protected areas of stronger IUCN category status, there have been numerous calls for the development of non-stationary approaches to protection that facilitate the co-existence of people and nature in ways that would allow expansion of the conservation estate without the loss of either core natural areas or human livelihoods.

Unesco's "Man and the Biosphere Programme" , for example, seeks "the rational and sustainable use and conservation of the resources of the biosphere... for the improvement of the overall relationship between people and their environment" (see document *online*).[5] Biosphere reserves include three interrelated zones that fulfill three complementary and mutually reinforcing functions: core area(s) that comprise a strictly protected ecosystem "for biodiversity"; buffer zones that surround or adjoin the core area and are used for "activities compatible with sound ecological practices that can reinforce scientific research, monitoring, training and education"; and transition areas, where the greatest economic activity is allowed, that foster economic and human development that is socio-culturally and ecologically sustainable.

Protected areas have traditionally been created and maintained by national and provincial governments and agencies, with some additional contributions from NGOs. Recent decades have seen a significant increase in the amount of conservation land that it is held under private or community ownership. In South Africa, for example, the area of land in private nature reserves (both individually and community owned) is estimated at nearly twice that of public nature reserves (Cousins et al. 2008). The rise of private protected areas, and their overall contributions to the national biodiversity estate, are, however, largely undocumented and poorly understood (Clements et al. 2016). A variety of important questions about private conservation efforts remain unanswered. For instance, can we rely on private nature reserves to support biodiversity conservation over time frames of 50–100 years? How do they contribute to both social and ecological elements of conservation goals and strategies? And how resilient will private conservation be, in an uncertain future, to social, economic, and ecological change?

A variety of other approaches attempt to foster conditions in which ecosystems can persist in the face of human activity outside formally protected areas. These are evident in such areas as legislation that protects endangered species; urban greening and peri-urban landscape planning for biodiversity; agro-ecosystem policy and design; the formation of community-based conservation programs, such as CAMPFIRE (Communal Areas Management Programme For Indigenous REsources; Bond 2001), that seek to achieve sustainable multi-species systems; and incentive schemes that promote better management of soil, water, forests, and other natural resources.

Despite the many initiatives that exist to support and nurture ecosystems, global extinction rates are still high and increasing. A fundamental shift in attitudes, both within broader society and within conservation organizations, may be necessary if we are to reduce the current extinction rate of species and maintain the ecosystem structures and functions that humanity depends upon. During such a social transition, protected areas have a potentially important role to play in both the ecological realm (as source habitats for species, reservoirs for relict populations, and locations for ecological research) and as social-ecological entities that can contribute to framing political debates, educating the public, and helping rural communities to retain culturally important values and livelihoods in the face of rampant development and urbanization.

These problems are discussed in detail by Mathevet et al. (2016), the concluding article of the invited feature. Mathevet et al. (2016) lay out a vision for "ecological solidarity," which takes into account how human interactions with the environment embody cultural, social and economic values. Ecological solidarity accepts the legitimacy of different types of knowledge about social-ecological processes and recognizes the diversity of values as a practical foundation for action. It promotes a process of learning to live resiliently, using science and social learning as tools to foster adaptive management and governance of biodiversity areas. Ecological solidarity has the potential to provide a framework for the integrated management of cultural landscapes, emphasizing the need for collective exploration by local communities and stakeholders to achieve its effective integration into land planning and conservation management strategies.

Discussion

The articles in this invited feature highlight emerging directions for research on protected areas as social-ecological systems. They include an improved understanding of the resilience and sustainability of protected areas; the closely related concern of understanding the relevance of spatial and temporal context and scale for

[5] http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/ [accessed 10-7-17]

protected areas; and the need to reframe and expand our toolbox for using protected areas to achieve biodiversity conservation, both by direct conservation measures and through the less direct influence that protected areas can have on human attitudes and relationships to nature. The papers in the feature suggest that management can be informed and potentially improved by explicitly considering social, ecological, and economic aspects of protected areas, in a synthetic SES framework such as is offered by the sustainability framework (Ostrom 2009, Ostrom and Cox 2010); and for protected areas specifically, by the concept of ecological solidarity (Mathevet et al. 2016). Such frameworks must also explicitly consider hierarchical dynamics and scale, and incorporate spatial analyses that consider not only what happens within the protected area but also its surroundings and its membership in different networks, both ecological and socioeconomic (Cumming et al. 2015, Maciejewski and Cumming 2015, 2016).

In practical terms, an integrated social-ecological perspective has much to offer protected area managers, policy makers, and satellite communities. Recognizing, describing, and quantifying the many benefits that protected areas provide (Cumming 2017), and seeking win-win solutions that foster both biodiversity conservation and human livelihoods, will be essential if protected areas are to justify their continued existence. Finding appropriate management solutions to ensure protected area persistence will mean applying many of the principles that are already well documented in the SES literature: stakeholder engagement, transparency around decision-making, paying attention to mutual learning processes, and building trust and strong social networks that can be used to solve problems.

The SES perspective also highlights a likely future need for monitoring and modelling both ecological and socioeconomic processes (Reyers et al. 2013). If socioeconomic feedbacks are critical for protected area persistence, and particularly if potential collapses of protected areas are more driven by socioeconomic than by ecological pressures (Cumming et al. 2015), managing protected areas proactively for long-term persistence requires that managers consider potential socioeconomic threats well in advance of the point at which they materialize. For example, recognition of the likelihood that anthropogenic climate change will alter habitat suitability and cause species range shifts is already influencing plans for expansion and further development of protected area networks in some locations (Loarie et al. 2009); and other analyses have identified concerns around provision of ecosystem services (such as water) to human communities (Schröter et al. 2005).

If protected areas are expected to provide ecosystem services in addition to achieving their fundamental goal of biodiversity conservation, measures of conservation success will require not only ecological but also social and economic data that show whether service production is meeting goals and whether or not ecosystem production of potential services is being used (i.e., whether potential services are actually benefitting the communities that they are supposedly provided for). Protected area managers can expect to need a wider and much more interdisciplinary range of data in the future (Reyers et al. 2013).

As discussed above and in Maciejewski et al. (2015), scale mismatches arise when the scales and levels of social, economic, and ecological processes are not suitably aligned. They can have strongly negative consequences for protected area management, and recognizing and resolving scale mismatches may have profound consequences for efforts to ensure protected area persistence.

Law can be another significant hindrance to the development of new approaches for managing protected areas, and one that may offer considerable opportunities for change to foster resilience of protected areas in desirable states, or to erode resilience of those in undesirable states (Garmestani and Allen 2014, Green et al. 2014). Creating adaptive legal frameworks may make a difference here, as well as legal statutes that explicitly incorporate double loop learning such that the laws are revisited and assessed regularly.

Although the SES literature offers a wide range of resources to help managers and conservation biologists, SES research is a dynamic and fast-moving field. The articles in this invited feature point the way toward a number of future research directions that we regard as priorities more generally for future research on social-ecological systems. In particular, protected areas can offer replicates of SESs that have similar goals and objectives, with protected area research contributing via comparative analyses to increased understanding of feedbacks across networks; the importance of connectivity as a function of scale; thresholds and tipping points in SES dynamics; relationships between SESs and ecosystem services; and adaptive management.

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