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Research, part of a Special Feature on Law and Social-Ecological Resilience

A Framework for Resilience-based Governance of Social-Ecological Systems

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ABSTRACT. Panarchy provides a heuristic to characterize the cross-scale dynamics of social-ecological systems and a framework for how governance institutions should behave to be compatible with the ecosystems they manage. Managing for resilience will likely require reform of law to account for the dynamics of social-ecological systems and achieve a substantive mandate that accommodates the need for adaptation. In this paper, we suggest expansive legal reform by identifying the principles of reflexive law as a possible mechanism for achieving a shift to resilience-based governance and leveraging cross-scale dynamics to provide resilience-based responses to increasingly challenging environmental conditions.

Key Words: *adaptive governance; adaptive management; environmental governance; intermediaries; panarchy; reflexive law; resilience; resilience-based governance*

INTRODUCTION

The Millennium Ecosystem Assessment (MA 2005) confirms that over the past 50 years humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history. The MA further acknowledges that, although these changes to ecosystems have contributed to substantial net gains in human well-being and economic development, they have come with growing costs associated with the degradation of many ecosystem services and increased risks of nonlinear changes. Like many experts in the field, the MA authors emphasize the need for more flexible, iterative, and adaptive approaches to governance to achieve Millennium Development Goals. Although these approaches are increasingly called for within the academic literature and even within natural resource management agencies (e.g., Williams et al. 2009), many systems of governance still lack the necessary flexibility to accommodate dynamic systems (Liu et al. 2007, Ostrom 2009). In the U.S., ecosystem management has had limited success because of entrained institutional hierarchies, as well as the lack of favorable legislation (Gelcich et al. 2010). This legal and institutional rigidity can limit the experimentation necessary for environmental governance in light of our current understanding of the dynamics of ecological and social systems (Garmestani et al. 2009*a*). This point is critical because some scholars contend that environmental governance can only succeed if rules, e.g., laws, evolve with the system of interest (Dietz et al. 2003). The primary problems with our current framework for environmental law are that it does not often account for scale and tends to lock-in "fixes" because of the need for certainty in the legal process (Karkkainen 2006). This is particularly evident in the United States, where a complex suite of regulatory frameworks often constrains the management flexibility necessary to engage in adaptive management (Craig 2010). Thus, managing for resilience will likely require reform of law to account for the dynamics of social-ecological systems (Cosens 2010, Benson and Garmestani 2011*a*).

Taking these points to heart, we concur with Flournoy and Driesen (2010:XX) that "we cannot reliably protect a natural resource legacy without a strong and enforceable substantive mandate." The question becomes how to achieve a substantive mandate in a manner that accommodates the need for adaptation, as well as enforceability at a broad scale that fosters rather than diminishes creativity at smaller scales. Elsewhere, we have suggested minor reforms (see Garmestani et al. 2009*a*, Benson and Garmestani 2011*a*, 2011*b*) to the law to manage for resilience. In this paper, we suggest more expansive legal reform by identifying the principles of reflexive law as a possible mechanism for achieving a shift to resilience-based governance and leveraging cross-scale dynamics to provide resilience-based responses to increasingly challenging environmental conditions. We first present the critical features to our resilience-based governance framework by summarizing resilience and panarchy, adaptive management and adaptive governance, and reflexive law. We discuss the critical features of resilience-based governance, and we treat the reflexive mechanisms that could allow governance to better mimic social-ecological systems. We then illustrate this integration of resilience science, i.e., panarchy, adaptive management, and adaptive governance, with reflexive law via an example application to a social-ecological system, i.e., Florida Bay, USA, followed by a summary of recommendations for resilience-based governance.

RESILIENCE AND PANARCHY

Resilience is the capacity of a complex system to remain within a regime in the face of external perturbations and/or internal change (Holling 1973). When a complex system is forced beyond the boundaries of a regime, i.e., a regime shift, the new regime is typically characterized by a new set of structures

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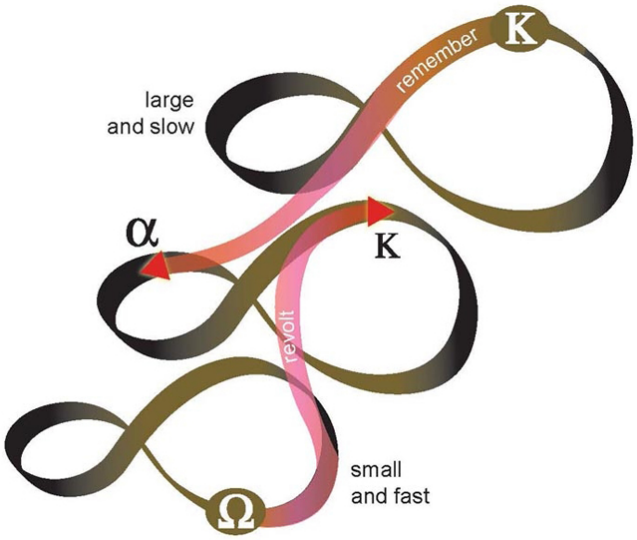
and processes. An adaptive cycle describes the processes of development and decay in a system, and captures the dynamic character of structures and processes in complex systems (Gunderson and Holling 2002). A panarchy is a nested set of adaptive cycles (Fig. 1; Gunderson and Holling 2002). Panarchy differs from hierarchy in that conditions can arise that trigger "bottom-up," i.e., cross-scale cascading, change in the system (Garmestani et al. 2009*b*). Because of this subtle, but critical difference, the panarchy model does a better job of capturing the dynamics of complex systems, e.g., "surprise." Further, levels in a panarchy are not static states, but rather adaptive cycles that are interconnected to other adaptive cycles in the panarchy. Each cycle operates over a discrete range of scale in both time and space and is connected to adjacent levels (adaptive cycles). Adaptive cycles do not exist in isolation. Because adaptive cycles operate over specific ranges of scale, a system's resilience is dependent upon the interactions between structure and dynamics at multiple scales (Gunderson and Holling 2002). Panarchy was developed to specifically address issues of scale, as well as cross-scale dynamics (Groffman et al. 2006).

Fig. 1. A classic representation of a panarchy: a nested set of adaptive cycles. Adapted from Gunderson and Holling (2002).



In ecosystems, different processes and structures dominate at different spatial and temporal scales. Small and fast processes and structures dominate at small scales, whereas large and slow processes and structures dominate at larger scales (Allen et al. 2011*a*). These processes and structures are separated by discontinuities that are thresholds between adaptive cycles in a panarchy. A threshold is the point at which a system has lost enough resilience, where change occurs in the processes and structures of the system, and results in the system reorganizing into a new regime characterized by a different set of processes and structures (Groffman et al. 2006). Understanding thresholds is essential to managing for resilience, and requires an immense amount of information and focus on novel ways in which to characterize thresholds, and therefore, regime shifts. Thresholds are upper and lower level indicators, and can be defined as management goals that represent the current understanding of the conditions of a system (Smith et al. 2009). When a threshold is reached or is predicted to be reached, management actions can be applied, and thresholds can be recalibrated in an adaptive manner if new information suggests the threshold is incorrect (Smith et al. 2009). Thresholds should be treated as hypotheses to be put at risk with monitoring data and represent the multidimensional regime in which variation is acceptable for system resilience (Smith et al. 2009). When working to establish thresholds for specific "slow variables," thresholds should be categorized, i.e., known, strongly suspected, and if possible, to establish the degree of confidence in the threshold estimates (Walker et al. 2009). The identification or "setting" of thresholds is very difficult, and fraught with uncertainty, but is an essential component in resilience science (Walker et al. 2009). Thus, thresholds should be set that can shift with improved information because ignoring this critical aspect to managing for resilience almost guarantees failure in environmental governance (Susskind et al. 2012).

ADAPTIVE MANAGEMENT AND ADAPTIVE GOVERNANCE

Both adaptive management and adaptive governance are vehicles for putting resilience theory into practice. Adaptive management is an environmental management strategy that attempts to reduce the inherent uncertainty in ecosystems (Green and Garmestani 2012). Adaptive management operates in an iterative manner, rather than providing discrete conclusions based on science, acknowledging that our understanding of natural systems is constantly evolving (Benson 2010*a*). A central tenant of adaptive management is that "management involves a continual learning process that cannot conveniently be separated into functions like 'research' and ongoing 'regulatory activities,' and probably never converges to a state of blissful equilibrium involving full knowledge and optimum productivity" (Walters 1986:8-9, Walters and Holling 1990). Adaptive management often takes place within more conventional governance frameworks. For example, the U.S. Department of Interior has embraced an adaptive management approach to many of its ongoing activities (Williams et al. 2009). Organizational conditions have an impact on outcomes from an adaptive management paradigm. In an assessment of the Northwest Forest Plan, a large-scale environmental management project that included adaptive management, Bormann et al. (2007) concluded that adaptive management can be effective if: (1) collaboration

exists between scientists and managers; and (2) adaptive management is formalized as core agency business. Doremus (2001) contends that it may be possible to combine finality and flexibility via incremental decisions that can be revisited after monitoring for a period of time appropriate to the environmental resource of interest. In essence, the legal framework would need to be reformed to accommodate dynamic processes. Adaptive management is unlikely to be effective without legal reform, and without adaptive management, environmental governance is unlikely to succeed (see Ruhl 2005). For example, if the National Environmental Policy Act (NEPA) were to be reconfigured to integrate adaptive management and account for resilience, several specific reforms are necessary (see Benson and Garmestani 2011*b*). This model shifts NEPA's process from a linear model to an iterative process better suited to dynamic systems. Similarly, it moves the theoretical advancements of panarchy and resilience into practical consideration by natural resource managers.

Adaptive governance is a form of governance that is dependent upon adaptive management and incorporates formal institutions, informal groups/networks, and individuals at multiple scales for purposes of collaborative environmental management (Folke et al. 2005). Cosens (2010) notes the broadened understanding of adaptive governance to include not only formal legal frameworks and institutions but also collaboration and cooperation across different levels of government, as well as nongovernmental and individual action (see also Huitema et al. 2009). There has recently been amplified interest in developing environmental management approaches that are based upon the scale of interest and collaboration, e.g., adaptive governance (Karkkainen 2006). Within this context, governance includes the organizations and actors that implement the laws, regulations, and programs for environmental management in formal and informal ways (Hennessey 1994, Hughes et al. 2005). Adaptive governance requires the capacity to learn to manage for resilience, and thus any institutional arrangement that does not have this capacity is not appropriate for managing social-ecological systems (Hennessey 1994). Bridging organizations, enabling legislation, and government policies can also contribute to the success of an adaptive governance framework; governance creates a vision and management actualizes the vision (Folke et al. 2005). Social networks also have the capacity to allow for development of new ideas, to facilitate communication between entities, and to create the flexibility necessary for the interplay of the fluid (ecological systems) and the rigid (organizations) for successful environmental management (Folke et al. 2005). Leadership has been well established as a critical factor in facilitating good environmental management (Folke et al. 2005, Steelman and Tucker 2005). Leaders develop and facilitate a vision for environmental management, incorporating local knowledge and information from social networks (Folke et al. 2005). Because a degree of uncertainty is inherent in social-ecological systems, the generation of adaptive capacity in management entities is a necessary "insurance policy" for sustainability (Gunderson 1999). Adaptive capacity in social-ecological systems is characterized by open and frequent lines of communication, collaboration, and action between both formal and informal institutions at multiple scales.

Another key component of adaptive governance is polycentric systems (Folke et al. 2005). Polycentric systems are complex adaptive systems without a central authority controlling the processes and structures of the systems (Andersson and Ostrom 2008). Polycentric systems are characterized by multiple governance units at multiple scales, with each unit having some capacity to govern at its scale (Ostrom 2010). Local knowledge of ecological and social conditions is often a critical aspect to managing for resilience, and polycentric systems are designed to allow for this knowledge to shape governance (Janssen et al. 2007, Ostrom 2010). Polycentric systems are better adapted to social-ecological dynamics because these coupled systems of governance and management effectively link scales via diverse information flow capabilities (Beier et al. 2009, Ostrom 2010). The dynamics of social-ecological systems make it necessary to create or nurture governance systems that utilize a suite of policy instruments (Andersson and Ostrom 2008). Fostering good environmental governance is context-specific, and although generalized guidance that accounts for scale may be useful, a "blueprint formula" for environmental governance is a recipe for disaster (Andersson and Ostrom 2008).

REFLEXIVE LAW

Resilience science, i.e., panarchy, adaptive management, and adaptive governance, can be integrated into environmental governance with concepts from reflexive law. Reflexive law is an area of law developed in Europe that appears to have some promising aspects for purposes of environmental governance in the U.S. (Teubner 1983). Reflexive law emerged as an alternative legal framework for regulation between government-imposed regulatory requirements and neoliberal movements toward privatization (Calliess 2001). The concept of reflexive law arises from both systems and critical theories, more specifically the systems theory of Niklas Luhmann and discourse theory of Jürgen Habermas (Calliess 2001, Scheuerman 2001). It addresses the nature in which substantive law imposes specific societal values and substantive social aims through enforceable frameworks (Capps and Olsen 2002). As a result, "the legal system becomes insensitive to the normative autonomy of other subsystems" (Capps and Olsen 2002:551). By contrast, reflexive law "shifts theoretical focus from the level of norms to the level of communication" (Calliess 2001).

Reflexive law, in the classic sense, does not regulate the outcome of social processes but rather installs, corrects, and redefines democratic self-regulatory mechanisms (Teubner

1983). The goal of reflexive law is to produce a better fit between institutional and social structures via facilitation, as opposed to comprehensive regulation (Teubner 1983). In an applied context, Nolon (2009:8) suggests that reflexive law might serve as a means by which a legal system "imposes procedural, rather than substantive requirements that are designed to trigger reflexive responses among those implicated in the problem that the proscribed features are designed to solve." Essentially, reflexive law seeks to determine the organizational and procedural aspects of regulated action (Fiorino 1999). Thus, instead of detailed rules for a specific environmental issue, e.g., air quality or energy conservation, reflexive environmental law provides a procedural process with room for innovation (Orts 1995). Some reflexive law proponents argue that traditional law must transition in response to the stratification of society into different forms of organization that require a legal framework that matches such organization (Teubner 1983). For example, reflexive law identifies the structures that allow regulation to deal with environmental problems (Teubner 1983). Another aspect of reflexive law that is appealing for managing for resilience is its recognition of the importance of learning for the legal process (Teubner 1983). Reflexive law is also concerned with process, which is an aspect of the theory that works well with managing for resilience, if the process is scale-dependent and iterative, i.e., "back-ended".

Although this aspect of reflexive environmental law is appealing for scale-dependent management, for it to be legally sound, there would need to be a modification because the "slow variables", and therefore the threshold for a particular environmental issue would need to be established (see Walker et al. 2009). Thus, the process has freedom for innovation, so long as there are trigger points for management actions, i.e., thresholds. Government would set the standards or goals for a particular action, but work with regulated entities to achieve the outcome, which may change in response to new information regarding the system (Fiorino 1999, Allen et al. 2011*b*).

There are other reforms that would improve the aspects of reflexive law that are useful for managing for resilience. Dorf (2003) has advocated for a version of reflexive law that incorporates top-down, as well as bottom-up aspects of data collection and integration into the management paradigm. Dorf's adaptation of reflexive law, which he discusses within the context of sexual privacy, is an appealing add-on to classic regulatory law, i.e., command and control. In particular, the top-down and bottom-up flow of data and therefore information between scales would likely do a better job of mimicking social-ecological dynamics. This variation of reflexive law has potential for environmental management because thresholds can be set, but the path to get there is left to development at relevant scales. Further, the iterative nature of this version of reflexive law would likely make it more palpable to modify thresholds in light of emerging information on the dynamics of social-ecological systems. Dorf (2003) characterizes this version of reflexive law as "rolling regulation," which appears to be a useful mechanism by which the legal and regulatory system could better mimic the ecological systems they are tasked with managing. Thus, it may be possible to integrate reflexive elements into decision making frameworks within agencies to foster creativity and communication between refined scales, e.g., those taking resilience-based actions on the ground, and higher (broader) scales of authority.

RECOMMENDATIONS FOR RESILIENCE-BASED GOVERNANCE

Environmental management is more likely to succeed when governance is tuned to the social-ecological systems it manages (van Bueren and ten Heuvelhof 2005). It is unlikely that a new institutional arrangement will replace the current natural resource management organizational hierarchy in the United States in the near future. Organizational change is very expensive, and negative feedbacks operate to maintain the status quo for a variety of reasons, e.g., sunk costs, interaction patterns, interdependencies (van Bueren and ten Heuvelhof 2005). For this reason, reform of governance mechanisms is likely to proceed in an incremental fashion (van Bueren and ten Heuvelhof 2005). Most natural resource management organizational hierarchies are currently built around assumptions of stability in ecological systems, which can be managed for "sustained-yield" (Craig 2010). Although this approach has worked to some extent, a more rapidly changing environment warrants a reformed organizational arrangement to better mimic and respond to ecosystem dynamics. To shift to resilience-based governance, we should integrate resilience science, i.e., panarchy, adaptive management, and adaptive governance, with reflexive law and we offer suggestions for manifesting this transition.

Complex, cross-scale problems demand that information and innovations be shared across scales for good environmental management (Moore and Westley 2011). Organizational structures and requirements could be reworked to more creatively delegate management responsibilities between large and smaller scales utilizing reflexive mechanisms. To some extent, this occurs already because delegation is a familiar concept within many environmental legal frameworks. Many requirements under the Clean Air Act, for example, combine national standards with state implementation. That said, the current level of flexibility is limited. In most cases, federal law largely proscribes how state implementation will take place, rather than allowing states to create their own processes and procedures. In addition, these approaches are still tied to traditional scales of governance, which ignores the capacity for new scales of governance to emerge. There are several mechanisms for accelerating the process of organizational modification. First, organizational learning can

be facilitated by communication and information flow between levels in organizations operating at different scales. To improve environmental governance, federal and state level natural resource organizations can improve their capacity to rapidly receive, digest, and act upon communication and information from smaller scales (Westley 1995). An innovation that emerges at a small-scale can sometimes "scale-up" if adequate networks exist at the scale of the innovation, as well as higher scales, with cross-scale linkages (Moore and Westley 2011). It is likely that there are certain network structures that are essential to initiate and support innovation across scales, and have the capacity to address complex problems (Moore and Westley 2011).

Natural resource management agencies often do not adapt their management schemes in response to new information about the system of interest because they lack the programmatic infrastructure for learning (Camacho 2009). The explicit requirement of organizational learning is rarely incorporated into natural resources management. Intermediaries, e.g., networks, can provide the capacity to link organizations at multiple scales, which in turn creates the capacity for cross-scale organizational learning via information exchange, communication, and deliberation (Reed et al. 2010). Gunderson et al. (2006) contend that learning can be facilitated via networks, but these networks need venues for dialogue and debate. Universities, for example, can act as venues for this critical role for networks (Camacho 2011). For networks to enhance resilience they must be: (1) open in their connections beyond the scale of interest; and (2) have flexibility within the context of the existing institutional and organizational hierarchy (Gunderson et al. 2006).

Enhancements in information sharing can be utilized because communication and learning are essential elements in managing for resilience (Gunderson et al. 2006, Longstaff and Yang 2008). In a study of adaptive comanagement of natural resources in South Africa, Cundill and Fabricius (2010) also found that creating the conditions for self-organization, i.e., cross-scale linkages, in addition to funding for long-term social learning and information flow, is critical for manifesting sound environmental management. Communication between experts and decision makers must be active, iterative, and inclusive for effective system management (Cash et al. 2003). Cash et al. (2003) found that if communication was infrequent or occurred only at the inception of a project, the effectiveness of the project declined. Camacho (2009) advocates for a framework that promotes interagency information sharing and a recommendation that Congress require agencies to monitor and adapt their policies in response to changing conditions. Information sharing could be further facilitated by the formation of a publicly accessible information clearinghouse (Camacho 2009). Camacho (2009) also asserts that Congress should require agencies to implement adaptive governance that would: (1) require and provide funding for monitoring; and (2) require the creation, monitoring, and adjustment of adaptive management plans and overall agency programs. Clearly, promoting communication between actors in a social-ecological system is a critical element for resilience-based governance (Cash et al. 2003).

Second, adaptive capacity can be fostered via more specific and sustained cultivation of intermediaries, which can be creative so long as communication and information flow occur. Organizations moving forward will require both the ability to take advantage of formal rules at a broad scale, while also fostering the creativity and innovation that occurs at smaller scales. The problems associated with scale are not endemic to formal organizational hierarchies; rather, the problem of how to link discrete scales is known to be an issue in collaborative ventures as well (Prager 2010). As has been documented by several researchers, to manifest sound environmental management, an intermediary, e.g., bridging organization, is critical to facilitate communication between levels in a hierarchy (Olsson et al. 2006, Prager 2010). Cash and Moser (2000) have proposed a set of guidelines for environmental governance in this regard: (1) utilize boundary organizations; (2) account for scale by allocating resources, and engaging technical expertise and decision making authority that best matches the scale of the system; and (3) utilize adaptive management. Cash and Moser (2000) contend that boundary organizations operate as "information brokerages" and communicators of research needs for a system of interest.

The federalist literature researches how government actions at one scale influence the actions of government at other scales (Cash and Moser 2000). However, delegating management responsibilities from large to smaller scales is most effective when implemented by enabling policies developed at the large scale, e.g., federal level, but supplemented by intermediaries (Cash and Moser 2000, Garmestani et al. 2009*a*). Bridging organizations and networks are advocated as the method to improve environmental management, yet there is no mandate for their formation. Intermediaries are simply expected to emerge via the self-organization of the institutional milieu. Research has been conducted upon informal mechanisms, for example, bridging organizations, informal networks, and shadow networks, but relatively little research has addressed the formal mechanisms, i.e., legal mechanisms, to manifest the inclusion of informal mechanisms into environmental governance. Policy makers should explore how to foster intermediaries because allowing for communication is essential to managing for resilience (Prager 2010). Scientific information must inform policy and management at multiple scales, but there is often a disconnect between science and management, so intermediaries, e.g., bridging organizations, must bridge the disconnect, i.e., threshold, between scales in an organizational hierarchy (Tribbia and Moser 2008, Garmestani et al. 2009*a*). The bridging function served by

intermediaries has the capacity to create improved policy options because of the tightening of the feedback between science and managers in an iterative manner.

Third, it may be necessary to rethink interactions between formal rules or informal arrangements for ecosystem management. In a study of a marine reserve network in the Gulf of California, Mexico, Cudney-Bueno and Basurto (2009) analyzed commons problems and found that there are no clear answers; rather, the resolution of commons problems was often scale-dependent. They found that rules created and enforced at a local scale resulted in a rapid increase in resource abundance. However, as information "scaled up" from the local scale to a regional scale, outsiders moved in and began poaching, resulting in a dramatic negative effect on the fishery and compliance with the locally created rules (Cudney-Bueno and Basurto 2009). Cudney-Bueno and Basurto (2009) demonstrate that cooperative management of common pool resources can emerge quickly at a local scale, but without cross-scale linkages to formal rules and governance at regional and national scales, a locally managed resource can quickly fall prey to outsiders, e.g., poachers, to the locally-derived governance arrangements. Thus, cooperation and social capital are simply not enough when creating a natural resource management scheme (Cudney-Bueno and Basurto 2009).

In the U.S., regional networks offer promise in this regard. One example is the U.S. Fire Learning Network (FLN), a collaboration between federal natural resource agencies and The Nature Conservancy formed in 2002. Butler and Goldstein (2010) contend FLN is an example of a network that has overcome what they refer to as "rigidity traps," which in this case involved the role of fire suppression in forest management, when scientific evidence indicated that restoration of fire regimes was a more sound long-term policy choice. FLN has allowed for more effective communication and information exchange, which in turn has created opportunities for innovation in fire management. Encouraging collaboration between NGOs and government has the capacity to improve environmental management (Imperial 1999). Further, the work done at FLN has resulted in the scaling up of policy innovations at the regional network scale to affect federal fire and land management policy, but importantly, change has been incremental at this stage in the process (Butler and Goldstein 2010). Regional climate initiatives also provide relevant examples in this regard (see Benson 2010*b*).

EXAMPLE: FLORIDA BAY

The governance of Florida Bay offers an illustration of the above recommendations. The Florida Bay is a 2200 km² estuary at the southern end of the State of Florida (Gunderson and Holling 2002). A regime shift occurred in the Florida Bay in the early 1990s in which the system shifted from an oligotrophic state to a turbid state dominated by phytoplankton blooms (Groffman et al. 2006). This shift resulted in changes in processes such as water clarity, primary production, nutrient cycling, and food webs (Groffman et al. 2006). The regime shift was likely driven by a combination of human and natural factors, including increased nutrients from septic systems, drought, water diversion, and removal of grazers (Groffman et al. 2006). A further complicating factor is that driver variables in the system operate at different scales, with some variables that responded to perturbation quickly, e.g., water clarity, and some that responded slowly, e.g., salinity. The critical aspect is that research is ongoing, and geared toward establishing quantitative thresholds for factors driven by human activity (Groffman et al. 2006).

We can characterize the Florida Bay regime shift based on the scale of the process and impact of interest. Once we have the ecosystem scales established, we can use the panarchy model to delineate the scale at which the associated management entities operate. Panarchy allows us to reconceptualize social-ecological systems in a manner that has the capacity to better match governance to the environment. Matching governance and ecosystems is a persistent problem (Folke et al. 2007, Olsson et al. 2007) that requires aspects of adaptive management, adaptive governance, and reflexive mechanisms, e.g., monitoring and iteration of policy. For example, characterizing the responsibilities of management agencies, that is, local, state, regional, national, and international, for the Florida Bay at a variety of scales provides us with a better understanding of the "fit" between governance and the environment. The scale-dependent features of the panarchy model are very useful in this respect. This characterization of a social-ecological system can help identify areas where there is a poor fit between management and ecosystems, and this is very useful because the characterization of appropriate scale in the Florida Bay example is fraught with problems. For instance, can Florida Bay be seen as distinct from the Everglades, the Gulf of Mexico, the Atlantic Ocean, Florida, the southeastern U.S., the U.S., or even the planet? This quandary highlights the critical importance of cultivating cross-scale linkages to manifest sound environmental governance. Having said all that, we have to be able to partition systems into scales in some manner, or our attempts to deal with these environmental issues are likely to fail. Thus, in this example, the first step in characterizing management of the Florida Bay is to delineate the management levels and social-ecological scales that affect the system. The Bay itself is the smallest scale in this example, the Everglades is the next scale up, followed by Florida, and the United States. We recognize that we are excluding the Gulf of Mexico, the Atlantic Ocean, and the planet from this panarchy, but at this stage, we are trying to provide a representative example of the problem of scale for environmental governance (Fig. 2). The Bay is governed by multiple federal, e.g., NPS; state, e.g., Florida Fish and Wildlife Conservation Commission; and local agencies, e.g., county and municipal natural resource entities;

Table 1. Summary of elements necessary for the integration of resilience science, i.e., panarchy, adaptive management and adaptive governance, and reflexive law as applied to the Florida Bay example.

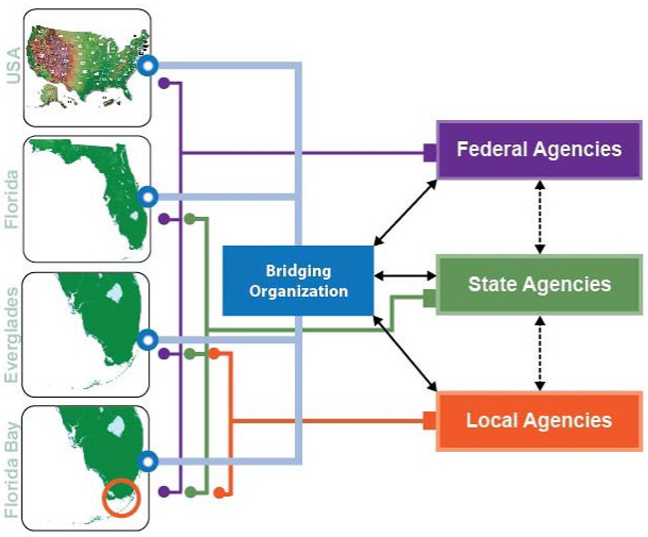
• Delineate scale: Managing for resilience entails characterizing ecological and governance scales, e.g., Florida Bay, State of Florida. Panarchy (Gunderson and Holling 2002) is a powerful tool for characterizing linked social-ecological systems.
• Identify critical slow variables: Because we have yet to develop the capacity to measure system resilience (but see Allen et al. 2005), "surrogates" should be developed when conducting resilience science (Carpenter et al. 2005). Resilience surrogates are based upon stakeholder assessments, models, historical profiling, and case studies (Carpenter et al. 2005).
• Identify scale-dependent ecological thresholds: Researchers should use models and scenario analysis to reveal processes that act to stabilize or destabilize a system, which could lead to identification of resilience surrogates (Carpenter et al. 2005). Examples of resilience surrogates include distance of a system variable from a system threshold; the rate at which a system variable is moving toward or away from a threshold; and external perturbations, e.g., shocks, controls, that could change the rate of change of a system variable (Bennett et al. 2005).
• Link those ecological thresholds to legal thresholds: The panarchy framework, when coupled with scenario analysis, nonlinear modeling, and leading indicators (Scheffer et al. 2012), should use a detailed analysis of a specific ecosystem to apply theory to real-world situations (Groffman et al. 2006). Intermediaries and local knowledge should also be tapped. This should allow governance to reflexively recalibrate the linked thresholds in an iterative manner based upon new information.

NGOs, e.g., Everglades Foundation; and universities, e.g., University of Florida. The Everglades is governed by multiple federal, e.g., NPS; state, e.g., Florida Fish and Wildlife Conservation Commission; and local agencies, e.g., county and municipal natural resource entities; NGOs, e.g., Everglades Foundation; and universities, e.g., University of Florida. The State of Florida is governed by multiple federal, e.g., NPS; state, e.g., Florida Fish and Wildlife Conservation Commission; and local agencies, e.g., county and municipal natural resource entities. The United States is governed by multiple federal agencies, e.g., NPS.

We can clearly see in Figure 2 that environmental governance of the Florida Bay will require cross- and within-scale information flow and communication. Leaders and networks focused upon the Florida Bay can serve to generate active communication between experts and decision makers. Further, this organizational learning can be fostered by intermediaries, and in the Florida Bay this role could be filled by a university, e.g., University of Florida, or perhaps an NGO, e.g., Everglades Foundation. This recommendation dovetails nicely because the adaptive capacity of the Florida Bay can be enhanced by the active cultivation of intermediaries. Whether the cultivation of intermediaries should be best left to informal or formal arrangements is a judgment call, and should be left to the stakeholders in the Florida Bay, at this stage.

The Florida Bay example provides generalized guidance for manifesting the transition toward resilience-based governance in social-ecological systems (Table 1). Sound environmental governance appears to depend upon creating the conditions that allow for synergism between the hierarchy of organizations and institutions, rather than creating a broad, top-down arrangement that has the capacity to stymie creativity and innovation.

Fig. 2. Environmental governance of the Florida Bay: the combination of panarchy, adaptive management and adaptive governance, and reflexive law. In this panarchy, the United States is at the top scale, Florida the next scale, followed by the Everglades, and then Florida Bay at the smallest ecological scale. Federal, state, and local management agencies are linked to their scales of governance, and an intermediary, e.g., bridging organization, is offered as the vehicle to fill gaps in "scale-matching," and to facilitate communication and information flow. Map of USA (www.usgs.gov/state); Map of Florida (www.florida-map.org/topo-map.htm).



CONCLUSION

Often management organizations are not matched with the scales they manage; in short, accounting for scale is critical for sound environmental management (Karkkainen 2006, Garmestani et al. 2009*a*). Thus, our current understanding of social-ecological systems indicates that we will need to incorporate a degree of flexibility into the future design of environmental policy (Fiorino 1999). Existing regulatory law is typically characterized by regulation via command and control (Scheuerman 2001). Karkkainen (2006) contends that law can be flexible with respect to standards for environmental management that reflect the dynamics of ecological systems, but will require reform at the organizational and legal level. Craig and Ruhl (2010:1) have argued that governance of coastal ecosystems should shift to place-based, i.e., scale-specific, adaptive management regimes that utilize a suite of "innovative and flexible regulatory instruments." This position is very similar to one taken by Garmestani et al. (2009*a*), which advocated for panarchy couched within the context of adaptive governance as a policy option for "sound" environmental management, utilizing a suite of policy instruments that are tailored for the appropriate scale to be managed.

Reflexive law establishes procedural and organizational norms, but does not establish specific "outcomes" as the end result of the process (Sheuerman 2001). To manage for resilience, scale-specific "slow variables" will need to be identified, taking into account cross-scale dynamics, and the process by which government and regulated entities arrive at prescribed outcomes should be open to novel solutions. Federal agencies thus will have an oversight role that is necessary to insure that outcomes are met, but not dictate the process by which said outcomes are realized. Reflexive law allows for iterative processes in the law and policy process. In particular, learning occurs over time, and some laws will need to be revamped or done away with, whereas more complex problems may require superseding legislation (Orts 2011). Orts (2011) contends that a bottom-up legal process has the capacity to be better than comprehensive approaches, in that the environmental problem, e.g., climate change, can be divided into different categories. Then, policy makers can determine which regulatory and/or market strategies are most appropriate and at which scales (Orts 2011).

We proceeded along this line of inquiry under the assumption that sound environmental governance is not possible in the U. S. without formal, and therefore enforceable rules governing information flow and communication between natural resource organizations at multiple scales. Although we advocate for allowing flexibility, e.g., local governance, in scale-dependent management options, the cross-scale nature of the dynamics of linked social-ecological systems makes it necessary for a federal government agency to ultimately be responsible for and have final decision making authority (Gaines 2003). Resilience-based governance will require organizational learning, cross-scale linkages, and adaptive capacity to govern in a more flexible, iterative, and adaptive manner. We suggest a framework of resilience-based governance of social-ecological systems, which focuses upon the integration of resilience science, i.e., panarchy, adaptive management, and adaptive governance, with reflexive law.

Responses to this article can be read online at:
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