Ecosystem Services, Ecosystem Resilience, and Resilience of Ecosystem Management Policy

J.B. Ruhl
Vanderbilt University Law School

F. Stuart Chapin III
University of Alaska Fairbanks


This paper can be downloaded without charge from the Social Science Research Network Electronic Paper Collection:

http://ssrn.com/abstract=2514427

SEVEN

Ecosystem Services, Ecosystem Resilience, and Resilience of Ecosystem Management Policy

J. B. RUHL AND F. STUART CHAPIN III

Two emerging theoretical models have captivated ecological science and policy over the past decade. One is the concept of ecosystem services, which focuses on the benefits that people derive from ecosystems, including the flows of economically valuable services to human populations (Costanza et al. 1997; Daily 1997; Ruhl et al. 2007; Ruhl and Salzman 2007). The other is resilience theory, which explores how natural and social systems withstand disturbances over time (Gunderson and Holling 2002; Gunderson et al. 2010). In this chapter, we examine the connections between the two.

Ecosystem services theory and resilience theory have both gained tremendous stock in ecosystem management policy over the past decade (Ruhl and Salzman 2007; Benson and Garmestani 2011). The reason is simple—each resonates firmly in the modern conception of ecosystems as complex adaptive systems (Levin 1999). Ecosystem services theory merges the disciplines of ecology, geography, and economics to gain a better understanding of how complex ecological landscapes produce a natural economy that sustains human and social capital (Ruhl et al. 2007). Resilience theory studies the social-ecological interface to gain a better understanding of how dynamic forces in nature affect social systems, and vice versa (Benson and Garmestani 2011). Standing alone, each of these theoretical models has established substantial independent credibility throughout academic, government, and private research bodies. Less attention has been paid, however, to the relationship between ecosystem services theory and resilience theory. Are the two mutually antagonistic or will one support application of the other? How will knowing about one model influence how the other is developed and used? Given how important ecosystem services theory and resilience theory have become to environmental policy, it is fitting to devote attention to these questions.

We approach the topic from two perspectives. The first is to ask whether using the concept of ecosystem services in policy can support the resilience of ecological systems. Is there anything to be gained in sustainable ecosystem management by applying ecosystem services theory, and are there any risks from doing so? The second perspective is to ask whether using the concept of ecosystem services in ecosystem management policy can support the resilience of policy itself. Will using ecosystem services concepts help ecosystem management policy deliver on its goals over sustained time frames in the face of massive perturbations, such as global climate and economic changes?

The reason for dividing the analysis into these two perspectives is that promoting resilience of ecosystems, if that is our policy goal, does not necessarily demand that we achieve resilience in ecosystem management policy, and likewise, achieving resilience in ecosystem management policy does not necessarily confer ecosystem resilience. The two, quite simply, are not the same or even necessarily compatible, and this is often overlooked in resilience theory literature. It may be desirable to support resilience in both ecosystems and ecosystem management policy, but there may be complex trade-offs between the two that make mutual optimization unattainable. How and where we apply ecosystem services theory, therefore, may depend on our overall objectives for how and where we desire resilience in nature and in policy.

Our discussion opens with a background on the features of ecosystem services theory relevant to the resilience context. The two perspectives on how applying ecosystem services in policy could support or undermine resilience are then explored, resilience of ecosystems first, followed by resilience in ecosystem management policy. Given what is learned through those two interrogations, the chapter concludes with some thoughts about how and where ecosystem services theory can
most usefully be employed to support the policy goals of resilience of ecosystems and resilience in ecosystem management policy.

Major Themes and Implications of Ecosystem Services Theory

The concept of ecosystem services is a classic old/new idea. Plato expounded on the values humans derived from healthy ecosystems, as did the influential geographer George Perkins Marsh centuries later (Mooney and Ehrlich 1997). It is obvious that healthy, sustainable ecosystems are good not just for bugs and bunnies, but for humans as well, so what is new and important about making that observation for purposes of environmental policy in the twenty-first century?

The answer can be traced to several trends that have unfolded since the dawn of the modern era of American environmental law and policy in the early 1970s. Before 1970, environmental law consisted primarily of the common law of nuisance and smatterings of ad hoc state and federal legislative measures having to do mostly with public lands and natural resource extraction (Lazarus 2004). There was no broad, coherent environmental policy at national or state levels. With public attention focused on environmental disasters such as Love Canal, however, beginning in 1970 Congress and President Nixon in short order hammered out a series of landmark environmental protection statutes covering, among other things, water pollution, air pollution, coastal zone management, environmental impact assessment, federal public land management, and endangered species protection (Lazarus 2004). This new statutory regime set in motion several related policy debates that did not crescendo until the mid-1990s and which bore directly on the emergence of ecosystem services theory.

The first policy debate concerned the balance between what is often described (usually derisively) as command-and-control regulation of land use and pollution behavior versus market-based instruments, such as pollution trading and wetlands banking (Freeman and Kolstad 2007). Fueled by the apparent success of the sulfur-dioxide emissions trading program designed to control acid rain, which was the result of 1990 amendments to the Clean Air Act, sentiment in favor of relying more on the market-based approaches to achieve environmental policy goals had grown strong by the mid-1990s. Much of this debate centered on the nation’s primary ecological regulation statute, the Endangered Species Act of 1973, which was under intense fire in Congress during the early 1990s (Ruhl 1998).

Another policy tension building during this period was between the rise of economic cost–benefit analysis as a method of developing and assessing policy choices and the growing discontent with its incomplete (some would say cavalier) treatment of environmental values (Ackerman and Heinerzling 2004). The premise of cost–benefit analysis as practiced at the time was that overall efficiency should be an important driver in how policy decisions are made and implemented and that careful comparison of the costs and benefits of alternative policy choices could usefully inform how best to achieve the efficiency goal. The problem was that the science of cost–benefit analysis was not very advanced when it came to describing the benefits of maintaining ecological integrity. The result was that many cost–benefit analyses simply described benefits such as flood protection and groundwater recharge from forests and other ecosystem resources as “unquantified benefits” that had little influence in the analysis, given the hard numbers that could be assigned to costs such as lost jobs and other economic impacts (Ackerman and Heinerzling 2004).

The third policy debate centered around the theories of ecosystem management and adaptive management, which were gaining force in the early 1990s, particularly as they were proposed for application to federal public lands (Grumbine 1994). There was growing concern that the “multiple-use” mandate of public land units such as national forests and grazing lands had been implemented by the land management agencies with too strong a bias toward resource use and extraction at the expense of sustainable ecological integrity. By the mid-1990s, this increasingly vocal movement for a “nature first” ecosystem-scale approach to public land management had grown in strength (Christensen et al. 1996; Brooks et al. 2002).

Perhaps one reason the concept of ecosystem services captured attention during this time frame was its ability to inform and possibly help resolve each of these policy tensions. Unlike the musings of Plato and Marsh, modern ecosystem services theory is a rigorous scientific discipline merging ecology, economics, and geography to go beyond
simply observing the importance to humans of healthy ecosystems, to actually describing what those values are, their ecological sources, and their human beneficiaries. By focusing on the economic value supplied to human populations from intact, healthy, sustainable ecological resources, ecosystem services theory matched up well with the trend toward market-based thinking in environmental policy. Also, by driving research toward improving the capacity to describe those economic values, ecosystem services theory could provide a much stronger voice for ecological values in cost–benefit analysis. And the idea that intact ecosystems provide economic values to potentially distant populations across many scales reframes the debate over multiple use of public lands by clarifying a broader set of trade-offs between resource depletion and resource protection.

The stage was therefore well set for ecosystem services concepts to hit the scene with a splash in 1997, first in an article in *Nature* (Costanza et al. 1997) and later that same year in a more comprehensive book titled *Nature's Services* (Daily 1997). In the *Nature* article, lead author Robert Costanza and his research team estimated the global economic value of ecosystem services at over US $30 trillion annually, and *Nature's Services*, edited by Gretchen Daily, surveyed an array of ecological systems such as wetlands and forests as sources of numerous ecosystem services streams. These groundbreaking works were instrumental in placing the concept of ecosystem services firmly on the map several years later when the United Nations Millennium Ecosystem Assessment (MEA) organized its reports around the theme (MEA 2003). The volume of literature developing and applying the theory of ecosystem services has exploded since then (Ruhl et al. 2007; Gomez-Baggethun et al. 2010).

The MEA reports were influential in developing the now widely accepted typology of ecosystem services, under which benefits flow to human populations in four streams: (1) *provisioning services* are commodities, such as food, wood, fiber, and water; (2) *regulating services* moderate or control environmental conditions, such as flood control by wetlands, water purification by aquifers, and carbon sequestration by forests; (3) *cultural services* include recreation, education, and aesthetics; and (4) *supporting services*, such as nutrient cycling, soil formation, and primary production, make the previous three service streams possible (MEA 2003). To put these in a concrete context, think of the public lands management debate mentioned above, in which advocates of ecosystem management theory accused the traditional agency management regimes of overly favoring resource use and extraction. Translated into the ecosystem services lexicon, that debate focuses on the balance between provisioning services (e.g., timber harvests and water diversions) and readily monetized cultural services (e.g., hunting and off-road vehicles) on the one side, and regulating services (e.g., carbon sequestration and groundwater recharge), supporting services (e.g., nutrient cycling and soil formation), and those cultural services not readily monetized (e.g., sense of place, aesthetic value) on the other. What this framework adds to that debate is the clear sense that public lands not only provide value through on-site use and extraction, but also supply value to potentially large and distant human populations through off-site flows of regulating and supporting services (Ruhl 2010b). (For the sake of simplicity, reference to cultural services in the remainder of this chapter applies to those that are readily monetized rather than the full suite of cultural services.)

The capacity of ecosystem services theory to reframe such debates is a potentially powerful force in environmental policy, but it is for that very reason that the theory has attracted critics as well as advocates. Advocates of using ecosystem services concepts in environmental decisions make the case that to the extent money talks, as it increasingly has through the trends toward market-based approaches, cost–benefit analysis, and multiple-use land management, failing to frame environmental protection in economic terms is folly—the environment will not get a seat at the table. But critics argue that a larger seat may come at too great a cost. One objection is that going down the ecosystem services road will serve only to commodify nature and crowd out other bases for resource protection, such as intrinsic values, ethical concerns, and social equity (McCauley 2006; Kosoy and Corbera 2010). Another is that managing resources to produce ecosystem services may lead to optimization strategies favoring particular services that have a high current value, such as carbon sequestration, and thereby possibly diminish other services, such as groundwater recharge (Dasgupta 2001; Bennett et al. 2009).

There is something of merit behind both views. Ecosystem services theory truly can make a difference in how resource allocation decisions
are viewed and made. Unlike provisioning and cultural services, the market value of which is embedded in commodity prices and entry fees and thus easily measured and monitored, regulating and supporting services tend to behave more like nonmarket public goods (Lant et al. 2008). It is difficult for the owner of honeybee habitat to charge for pollination services enjoyed on distant farms or for the farmers to charge for groundwater recharge enjoyed by the honeybee habitat owner. Likewise, landowners and urban dwellers enjoying services flowing from other parcels see them as “free” and thus have little incentive to invest in the resources providing them.

Landowners thus have incentives to optimize provisioning and cultural services available to them, but little incentive to provide regulating and supporting services that benefit people in other places. In this respect, for example, a farm is like any other ecological unit—changes in one ecosystem usually affect other ecosystems, however we draw the boundaries. But as highly managed ecological units, farms significantly tilt the production frontier for ecosystem services toward provisioning and cultural services and away from regulating and supporting services (Ryszkowski 1995; Bjorklund et al. 1999). Ecological practices at a cornfield are designed to produce corn efficiently within the relevant regulatory and economic environment. Putting aside the question of whether regulation of farms has established appropriate environmental performance baselines, unless farmers are paid to provide off-site regulating and supporting services such as carbon sequestration and groundwater recharge, one would not expect to find significant flows of off-site regulating and supporting services from farms, except as they might be incidental to optimizing the on-site provisioning and cultural services upon which the farmer makes a living. Seen from this perspective, ecosystem services theory focuses environmental policy on salient questions (such as how to shift the farm services production frontier to a more multifunctional mix) and toward effective approaches (probably by using incentives and other payment mechanisms) (Ruhl 2008; Yang et al. 2010). Careful analyses of the identity and location of beneficiaries and providers of different types of ecosystem services thus set the stage for considering a range of policies and payment schemes to address different types of trade-offs among ecosystem services (Bennett et al. 2009; Kinzig et al. 2011; Seppelt et al. 2011).

But there may be danger in overplaying the ecosystem services card. There is an old adage in resource management that “if you manage for ducks, you get ducks,” and the same could be the result of making ecosystem services production the driving goal of policy decisions. For example, managing for particular ecosystem services outputs might or might not produce the biodiversity characteristics we wish to maintain for other purposes (Duarte 2000; Balvanera et al. 2001; Bhaskar and Adams 2009). Similarly, the drive to commodify services, such as through the practice of allowing landowners to sell “credits” for a broad array of “stacked” services generated through resource conservation, has become the subject of intense controversy over whether it truly will lead to sound ecosystem management decisions (Kosoy and Corbera 2010; Kinzig et al. 2011). The fear is that landowners will chase dollars, which may lead to more conservation, but will it be the desired conservation?

Another critique of ecosystem services theory is that despite garnering much attention among academics and policy makers, it has yet to gain much traction in hard law (Salzman 1998; Fischman 2001; Ruhl and Gregg 2001; Ruhl et al. 2007). Even when ecosystem services have been recognized in statutes, agency regulations, or judicial opinions as legally relevant, very little detail has been offered regarding how to implement the concept through legal rules and standards. As an example, although the U.S. Army Corps of Engineers and Environmental Protection Agency recently promulgated regulations requiring that provision of ecosystem services be maintained or replaced at wetland impact sites, the regulations contain absolutely no details on which services matter; how, where, and when they must be measured; or how the agencies will ensure that land developers meet the requirement (Ruhl et al. 2009). Although the lack of progress on integrating ecosystem services concepts into environmental law can be attributed at least in part to the need for more focused, policy-relevant research, the enthusiasm that greeted the emergence of ecosystem services theory in the 1990s has dampened as it becomes increasingly clear that the knowledge base is still limited and translating the theory into enforceable law may be more difficult than thought.

We do not, however, intend to resolve the debate over ecosystem services theory or propose specific legal text. Rather, the focus here is to ask how using ecosystem services concepts to shape environmental
decisions could promote or undermine resilience in the environment and in environmental policy. For that purpose, the foregoing discussion illuminates five key features of ecosystem services theory warranting particular emphasis.

First, ecosystem services theory is fundamentally anthropocentric in focus—it is about how ecological systems deliver economic value to humans. Two ecologically indistinguishable wetlands, for example, may deliver vastly different ecosystem services profiles based on proximity to human populations. While this does not necessarily mean one wetland is “better” than the other, it does mean they are different at least in their proximity to people, and this difference may influence ecosystem management policy.

Second, notwithstanding this anthropocentric focus, ecosystem services theory is not intended to displace other reasons for managing and protecting ecological integrity, such as the intrinsic value of species or ethical beliefs about human responsibilities toward nature. Knowing the ecosystem services profile of a wetland parcel adds to the information available for making ecosystem management decisions without detracting from any other scientific, economic, or moral basis for decision making (Costanza et al. 1989).

Third, where ecosystem services theory pushes hardest on conventional economic thinking about the environment is with respect to regulating and supporting services. Indeed, it is unlikely that ecosystem services theory offers much besides semantics when it comes to managing provisioning and cultural services already deeply embedded in economic markets and resource management policy. Calling corn a "provisioning service" or hunting a "cultural service" hardly changes the policy dialogue. Regulating and supporting services, by contrast, have been largely ignored as explicit benefits in markets and in policy, and thus present the greatest opportunity for scientific and policy advancement through attention to their service values (Lant et al. 2008).

Fourth, just as ecosystem services theory does not displace other bases for environmental protection decisions, neither does it displace other bases for economic development decisions. Even if all regulating and supporting ecosystem services values were somehow integrated into market prices, the fact that maintaining ecological integrity of a wetland parcel provides economic value to some humans does not mean the owner will favor that use over, say, a housing subdivision. In the absence of policies imposing regulatory constraints on land use decisions, therefore, ecosystem services will have to compete in the market along with alternative uses of land and resources.

Fifth, ecosystem services theory exposes and recognizes inherent trade-offs. It exposes trade-offs environmental policy has been making without the benefit of complete information about consequences, such as through the cost–benefit analysis practice of dumping ecosystem services into the “unquantified benefits” category. But it also recognizes trade-offs between ecosystem services, such as the tension between provisioning/cultural services and regulating/supporting services, as well as between beneficiary populations, such as the trade-off that could occur between favoring the global benefit of carbon sequestration at the expense of the local benefit of groundwater recharge (Jackson et al. 2005; Kinzig et al. 2011).

The overarching principle to draw from these features is that ecosystem services theory is not a panacea. It does not offer a complete theory of ecological or economic decision making, or even one with clear and unequivocal outcomes. Rather, ecosystem services theory expands the analytical devices available for decision making, which in some contexts may clarify decisions and in other contexts may cloud them with yet more uncertainty and controversy. This chapter isolates just one of the many parameters over which these effects could play out—resilience as a policy goal for the environment and for environmental policy.

Ecosystem Services and Ecological Resilience

Ecosystem services theory has only recently been put into practice and is not yet a dominant force in the hard law of environmental decision making. Asking what ecosystem services theory offers the policy goal of resilience thus remains itself largely a theoretical question, particularly given that the exact dimensions and properties of resilience are themselves not very far developed beyond theory. We can adopt the conventional general definition of resilience as the flexibility of an ecological or social-ecological system to adjust to unforeseen shocks and stresses and to sustain its fundamental structure, function, and identity (Holling
of watersheds within larger watersheds, through which drought might devastate some smaller watersheds while only moderately impairing the larger watershed system as a whole. Forests also can respond to stress with modularity resilience by transitioning components on micro-levels, as may happen when a wetland area transforms to upland in sustained drought, while not losing overall forest system integrity at larger scales. Finally, forests evolve as even natural disturbances and long-term changes in exogenous conditions such as climate introduce new species, change watercourses, and alter temperature regimes.

The overall resilience of an ecosystem to stress and perturbation at different spatial and temporal scales is a function of how these five resilience qualities are packaged over any given space and time span. Although it would be ideal to maximize all five properties of resilience in a natural or social system, it is far more likely that trade-offs will limit that possibility, forcing difficult decisions about system design. For example, reliability and efficiency appear most in keeping with the concept of engineering resilience, whereas scalability, modularity, and evolvability match up with ecological resilience (Holling and Gunderson [2002, 28] describe engineering resilience as focusing on “maintaining efficiency of function,” whereas ecological resilience “focuses on maintaining existence of function”). A system that is highly efficient in using scarce resources might as a consequence have less modularity due to lack of redundancy in important system functions. A recurrent system design question, therefore, is which of these resilience properties to favor.

That is, of course, an ever-present and complex policy decision in environmental management. Simply put, what kind of an ecosystem are we trying to attain and maintain through our management strategies? The answer, naturally, will differ based on circumstances and often will be highly contested for a given ecological unit. This chapter, therefore, assumes no fixed set of principles or goals. Rather, our objective is to ask a focused question: Assuming that achieving and maintaining a prescribed quality of ecological resilience is one of the policy goals of a particular environmental management program, how might using the theory and practice of ecosystem services contribute to or detract from attaining that goal? The following discussion examines that question through the model of the five resilience properties.
Reliability

Over the past few decades, ecologists have increasingly moved toward the model of ecosystems as complex adaptive systems in which disturbance regimes play a pivotal role in sustaining system dynamics (Levin 1999). Flood, fire, drought, and storm shake up ecosystems by introducing diversity, putting pressure on weak links, and triggering feedback processes. The capacity to "bounce back" from such disturbances is the hallmark of resilience in a complex system, and that is no less the case for ecosystems. Far from existing in fragile states of perfect equilibrium, as anyone who has witnessed the carpet of green emerging only weeks after a forest fire will attest, ecosystems exhibit tremendous capacity to rebuild after even severe disturbances. This capacity is tied in part to the diversity and redundancy of ecosystem components and processes, which are in turn promoted (and tested) by disturbance regimes.

Disturbance is thus, ironically, a source of sustainability for ecosystems by maintaining a diversity of ecosystem components from which ecosystems can rebuild. Of course, as the geologic record all too clearly reveals, ecosystems are not impervious to disturbance; nonlinear tipping points may be encountered, such as after periods of protracted drought or cold, that overwhelm redundancies and feedback processes critical to system reliability and "flip" an ecosystem into an entirely new and starkly different set of system dynamics.

A central question around which much of environmental policy revolves is how humans contribute to maintaining or degrading ecosystem reliability from small to global scales. How will a land development project interfere with wetland processes and make it less likely the larger wetland system will withstand the next severe drought? How can conservation measures be taken to restore reliability to a degraded wetland system? What are the consequences to reliability mechanisms in marine and other ecosystems of continued rise in anthropogenic releases of carbon dioxide into the atmosphere? Humans can hardly escape the reality that we are a disturbance regime unlike any other for ecosystems (Vitousek et al. 1997), but unlike fire and flood, we can ask what kind of disturbance regime we want to be—the kind that contributes to ecosystem dynamics or the kind that pushes ecosystems to the next nonlinear tipping point.

So how can ecosystem services theory help answer that question? As a starting point, it seems reasonable to assume that the more people know about the economic values they derive from ecosystem services, the more they will take them into account in decision making. The market and policy demand curves for ecological conditions that provide preferred ecosystem services values thus are likely to shift to the right—that is, to increase in demand—as more and more people seek continued supply of the previously poorly understood benefits. No doubt, for example, owners of coastal properties along the Gulf of Mexico have in recent years increased their appreciation of the value of coastal wetland and dune systems. As noted above, moreover, the greatest potential for increased information about ecosystem services, and thus the greatest engine of increased demand, is through research illuminating the sources and beneficiaries of regulating and supporting services.

It is not entirely clear, however, how increased demand for ecosystem services will influence ecosystem reliability. Indeed, it could lead to decisions that intervene drastically in ecosystem processes. For example, public demand for provisioning and cultural ecosystem services on public lands led for decades to policies such as fire suppression and flood control that are now discredited as having degraded ecosystem reliability properties. Whereas under natural conditions a forest fire might have been contained to a limited area and low intensity, thus allowing the forest to repair the affected components, in some forest types the excess underbrush built up under fire suppression policies led to high-intensity fires that overwhelmed reliability capacity (Schoennagel et al. 2004). Similar missteps could follow from policies designed to meet increasing demand for regulating and supporting services. Intense management for carbon sequestration benefits, for example, could interfere not only with other services but also with ecosystem processes critical to sustained reliability (e.g., as a result of favoring species with high sequestration capacity). In other words, simply saying "we are managing to promote ecosystem services" does not necessarily advance the reliability of ecological components—it will depend on which services and how we manage for them.

On balance, however, a general shift in demand favoring regulating and supporting ecosystem services is likely to lead to decisions promoting ecological reliability, because improved information about the range
of services provided by ecosystems will lead to more informed decisions about the trade-offs inevitably associated with resource management decisions. Provisioning services (corn, timber, minerals) and cultural services (rafting, hiking, visitation) focus management on narrow commodities and activities as the primary output of highly managed ecosystems, whereas regulating services (water purification, flood control) and supporting services (nutrient cycling, decomposition) depend more on the work of an intact, dynamic background of ecosystem processes and structure. An ecosystem services framework also raises awareness of need for restoration to provide a greater spectrum of services from degraded ecosystems that are characterized by high-reliability resilience.

Ecosystem services policy could therefore be shaped to promote demand for regulating and supporting services as a way of enhancing ecosystem reliability. Consider, for example, that farm policy increasingly has focused on how to shift working agricultural lands toward a multifunctional profile in which the payoff to farmers for increased land conservation practices is compensation for the enhanced flow of regulating and supporting services to surrounding lands (Ruhl 2008). The intended result of such policies is to create more complex and varied agricultural landscapes with greater integration of areas functioning closer to natural ecological conditions. With careful attention to potential downsides, therefore, ecosystem services policies can be used to promote land use practices that boost ecosystem reliability at landscape scales.

**Efficiency**

Increased knowledge about ecosystem services benefits inevitably will lead to more economically efficient decisions about use of land and resources. If a municipal water system demands increased water supply and local farmers can increase groundwater recharge through altered land use practices, it may pay for both to sit at the bargaining table (Ruhl 2008). The question, however, is whether the potential ecosystem services theory offers to achieve economic efficiency translates into a capacity to also achieve ecological efficiency (Muradian et al. 2010; Pascual et al. 2010).

Ecological efficiency can be thought of as the capacity to maintain functions critical to sustained ecological integrity, even when essential resources such as water and nutrients become scarce. Two wetlands could be compared based on, say, biomass production and nutrient conversion during periods of drought as a way of comparing their respective efficiency attributes. The conclusion that one is more "efficient" than the other may be largely an anthropocentric perspective, but nevertheless, measuring and comparing ecological efficiency contributes to our knowledge about how ecosystems function and also how they respond to stress-inducing disturbance, including anthropogenic disturbance, that can push an ecosystem to its efficiency limits.

As with the reliability property, ecosystem services policy could affect ecological efficiency for better or worse depending on the choices made regarding which services to promote and how. Policies designed to enhance flows of provisioning and cultural services seem more likely to lead to interventions in ecosystem processes that could degrade efficiency, whereas policies designed to keep the suite of regulating and supporting services intact are more likely to keep ecological processes closer to their natural efficiency conditions. Efficiency thus is yet another potential trade-off factor that must be integrated into ecosystem services policy choices.

But ecosystem services may prove useful in this respect, not only as a policy driver but as a policy metric (Ruhl 2010a). Changes in the flow of ecosystem services from a particular landscape tell us something about conditions in the ecosystem. A sharp drop in a particular service, such as pollination, may indicate that scarcity of resources has tapped an ecosystem's efficiency capacity. Indeed, building ecosystem services measurements into policy as an ecological efficiency metric could serve to link economic and ecological efficiency in ways that will attune economic decisions to ecological conditions. If a voluntary or regulatory market exists for an economically valuable ecosystem service, a drop in the flow of the service is likely to get the attention of the sellers and the buyers, driving them to investigate the cause and invest in remedies. Even in the absence of a market, real-time information about the flow of service levels to human populations is likely to reinforce connections the public makes between their economic conditions and the ecological conditions making them possible. Where sustained economic efficiency
depends on secure ecological efficiency, those interested in maintaining
the former are all the more likely to be interested in maintaining the
latter. Building ecosystem services metrics into policy through regula-
tory markets, performance standards, and other instruments can help
reinforce that relationship.

**Scalability**

Time and size matter in ecosystem dynamics, and thus temporal and
spatial scales are a central focus of ecological research, particularly with
the rise of the complex adaptive systems model of ecosystems (Peter-
son et al. 1998). Complex relationships between “small/fast” and “large/
slow” ecological processes across landscapes produce feedback loops
and emergent behaviors that make the study of scale properties vitally
important to a more complete understanding of ecological conditions
(Carpenter and Turner 2000). The scalability property of resilience cap-
tures the importance of these complex cross-scale relationships and
the ability of a system to respond to disturbance or change at one scale
through responses at other scales (Rodriguez et al. 2006).

Increased attention to ecosystem services flows is likely to place
emphasis on scale properties in ecosystems supplying valuable ser-
vice and perhaps even make scale a contentious issue in policy
decisions. Consider again, for example, potential trade-offs between
carbon sequestration and groundwater recharge in forest ecosystems.
The service values of carbon sequestration promoted at a forest parcel
are enjoyed globally, but with a long lag time and highly dispersed per
capita benefits. Groundwater recharge, by contrast, is enjoyed at a far
more local level with immediate and measurable payoff for local water
users. Policy decisions favoring one service versus the other thus could
pit one scale of human beneficiaries against another as well (Ruhl
2010b). As knowledge about such scale trade-offs increases through
research, ecosystem services policy could become contentious, even
if it shifts focus from provisioning/cultural services to regulating/sup-
porting services.

Moreover, if market and regulatory policies drive private and pub-
lic land managers toward services with particularized scale properties,
management decisions may work toward “locking in” the ecological condi-
tions that best optimize service flow at the scale desired by empow-
ered users, which could undermine overall scalability of the ecosystem.
If the money is in carbon, for example, land managers will drive decision
making to favor carbon sequestration. It is not at all clear, however, what
managing to sustain a high sequestration vegetative regime means at
other ecosystem scales and for overall ecosystem scalability. Increased
carbon sequestration, for example, may reduce landscape heterogene-
ity and complexity in the short term but increase fuel loads, leading
to wildfires that increase landscape heterogeneity and scalability in the
long term (Turner 2010). It will be imperative, therefore, for ecosystem
services research to focus on improving knowledge about cross-scale
relationships and trade-offs and for policy to be attentive to how choices
among service flow alternatives affect ecosystem-scale properties and
scalability capacities.

Here again there is reason to believe at a general level that a shift
in demand from provisioning/cultural services to regulating/support-
ing services is likely on balance to enhance ecological scalability. Provi-
sioning and cultural services are most easily visualized, managed, and
delivered at the scale of a particular management unit (e.g., forest stand,
watershed, estuary). By contrast, regulating and supporting services link
ecosystems in one place with those in another (e.g., forest with distant
stream; coastal wetland with protected inland area; carbon sequestra-
tion in one stand with the atmosphere experienced by people globally).,
Therefore, managing to enhance regulating and supporting services
necessarily requires greater consideration and maintenance of the scal-
able properties of linked ecosystems.

**Modularity**

Although disturbance regimes promote ecological resilience by intro-
ducing periodic restructuring of ecosystem components, human inter-
vention in ecosystem dynamics has frequently overwhelmed resilience
by undermining modularity properties. The introduction of nonnative
species, for example, has often led to ecological restructuring that rad-
cally shifts an ecosystem into a new regime. On a much larger scale,
climate change will lead to species migrations and altered hydrological conditions of magnitudes that surely will test ecological modularity across the landscape (Fox 2007; Williams et al. 2007). Some ecosystems will "absorb" the structural changes and others will not.

Ironically, ecosystem services policy could lead to decisions that reduce ecosystem modularity, or at least de-emphasize it as a desired resilience property. This is not because ecosystem services policy is likely to be a source of ecological restructuring, but rather because it could lead resource managers to resist restructuring forces. A farm, for example, can be thought of as a highly structured and maintained ecosystem-services production unit—it's just that it is producing provisioning/cultural services rather than regulating/supporting services—and farmers quite rationally resist forces that threaten to restructure components of the production unit. One concern, therefore, is that even with a shift in policy emphasis toward greater production of regulating and supporting services, land managers will continue to behave as farmers do—they will resist any restructuring of the production unit. The ecological implications of intervening in disturbance regimes, even when the reason for doing so is to enhance or maintain supplies of regulating and supporting services, must be studied and taken into account in ecosystem services policy.

Evolvability

A resilient ecosystem is not necessarily an unchanging ecosystem. The evolvability resilience property captures the idea that an ecosystem is a dynamic system that adapts to its exogenous context over time (Levin 1999). Even with no help from humans, species migrate, climates change, and volcanoes erupt. A resilient ecosystem uses reliability, efficiency, scalability, and modularity to respond to these outside forces, and depending on the mix and success of the blend of these properties, some ecosystems will remain relatively static (high-reliability resilience), some will evolve over the course of time, and some will "flip" into vastly different dynamic states (low-reliability resilience). With countless human interventions, of course, the evolvability property of ecosystems has been tested time and again at unnatural frequencies and extremes, with anthropogenic climate change posing the most global and intense of such tests ever.

How ecosystem services concepts interact with the evolvability property is a complex question rife with potential policy controversy. The theme that has built in the foregoing sections is that ecosystem services policy, at least in some applications, could develop into something that might be described as an advanced version of farm policy. That is, just as farmers have traditionally managed agricultural lands to optimize provisioning and cultural ecosystem services, so too might land managers of the future respond to ecosystem services market and regulatory policy by managing lands to optimize regulating and supporting services. The question is whether those land managers will treat their resources as "farms" for ecosystem services. Will they, in other words, manage for resilience of the engineering type by focusing on enhancing reliability and efficiency of the service production unit to keep it "intact," as in unchanged over time, while placing less or no emphasis on the ecological resilience properties of scalability, modularity, and most holistically, evolvability?

Particularly with climate change impacts looming, ecosystem services policy could take one of two overarching directions in this regard. One would be to manage ecosystems for familiar policy goals, such as biodiversity, recreation, wilderness, or water quality, and let ecosystem services profiles of the managed areas follow from there. Another would be to manage ecosystems for the most economically valuable sets of ecosystem services, particularly regulating and supporting services, treating other policy goals as incidental benefits. The more policy favors the latter approach, the more likely it is that the "farm" model will creep into ecosystem services decision making. Of course, this may be a profoundly positive development in terms of the economic value derived from ecosystems, and it may very well lead to greater conservation of lands and resources, but it may also lead to management decisions focused on "protecting" ecosystem services production units from disturbance regimes and evolving conditions. Just as a row crop farm trades off evolvability for efficiency, will a pollination "farm" or a carbon sequestration "farm" do the same, and if so, is that the kind of conservation policy that achieves our desired quality and quantity of resilience in ecosystems?
The more likely scenario is that neither of these extremes will predominate and ecosystem services concepts will be integrated into policy decisions in varying ways and intensities across the spectrum of environmental management programs. Maintaining some areas as wilderness or habitat for an endangered species are narrow but time-tested policy goals unlikely to be supplanted by ecosystem services concepts, yet land managers pursuing those goals can make note of their incidental ecosystem services benefits. Maintaining other areas as ecosystem services “farms,” such as high-yield carbon sequestration forest projects, may become a practical necessity that policy makers cannot avoid despite the trade-offs. For the many public and private land management contexts between those extremes, ecosystem services concepts can help inform and facilitate decisions about how to balance the five resilience properties depending on the broad set of goals established for a particular resource area. Because we cannot know the future value of different balances of ecosystem services, a portfolio approach that manages different portions of the landscape for different balances of ecosystem services maximizes evolvability resilience (Bormann and Kiester 2004). Most profoundly, greater awareness of the value of regulating and supporting services is likely on balance to lead to greater appreciation of the scalability, modularity, and evolvability resilience properties in ecological systems.

In sum, one thing can be concluded with confidence about the ecosystem services concept and resilience of ecosystems: ecosystem services theory expands our understanding and articulation of what an ecosystem is useful for, even in the absence of precise monetization of service values, and this new knowledge base undoubtedly will be relevant and useful for making decisions about the design and implementation of ecosystem management goals. How we use that new knowledge will make all the difference in how ecosystem services concepts contribute to ecological resilience. This observation thus leads directly to the other side of the coin—how can ecosystem services concepts contribute to the resilience of ecosystem management policy?

Ecosystem Services and Ecosystem Management Policy Resilience

Law and policy is a complex social system that, one would reasonably hope, productively incorporates resilience properties such as reliability, efficiency, scalability, modularity, and evolvability (Ruhl 2011). The previous section pointed directly at ecosystem management policy as the gatekeeper for how ecosystem services concepts will influence ecosystem resilience. This assumes, of course, that ecosystem management policy will embrace ecosystem services concepts and use them in decision making. But that leads to the questions this section takes on—how will using ecosystem services concepts in ecosystem management policy influence the resilience of ecosystem management policy, and what kind of policy resilience are we seeking? Just as with resilience of ecosystems, for example, environmental policy resilience is not always desirable. Environmental policies that are locked in place (high-reliability resilience) by special interests to support extractive use of ecosystems often degrade regulating and supporting services and undermine overall ecosystem resilience (Troester 2003; Beier et al. 2009). Rather than work through the five resilience properties to address those questions, but nevertheless taking them into account, this section assembles our holistic conclusions about how ecosystem services concepts could enhance or impede ecosystem management policy resilience.

Factors Enhancing Policy Resilience

Let us start by assuming a world in which all the information desired about ecosystem services in any setting and scale is inexpensively and readily at our fingertips. How might this ideal state of information access make ecosystem management more resilient? Several key effects rise prominently to mind.

First, knowledge about ecosystem services is likely to make clearer and more direct the connections people have with ecosystems and with one another. For many people, policies designed to protect habitat for an endangered fly would be a hard sell, but if those policies are also framed as protecting the ecosystem services humans receive from the conserved habitat, they are more likely to receive public support. Similarly, if two landowners in an agricultural district learn that one’s property supplies groundwater recharge services to the area and the other’s property supplies pollination services, they are more likely to take an interest in each other’s land management practices. An ecosystem management policy that is...
policy that builds on and reinforces these connections strengthens its legitimacy among regulated and other affected entities.

Second, knowledge about ecosystem services can improve the capacity of decision methods such as cost–benefit analysis and environmental impact assessment to conduct fully informed analyses of policy options and their trade-offs. If ecosystem management decisions are to be based on cost–benefit analysis, then better information about costs and benefits should lead to better decisions. Likewise, if environmental impact assessments are to inform action agencies and the public about the effects of different agency alternatives, profiles of how each alternative alters ecosystem services flows should improve the alternatives comparison analysis. Indeed even raw political discourse over ecosystem management policies can make use of improved information about the consequences of different political positions and interest group demands.

Knowledge about ecosystem services can also enhance the information available to voluntary and regulatory markets and other market-based instruments. Compensatory wetland mitigation, for example, is supposed to compensate for resource losses suffered at development impact sites, but such compensation is incomplete without accounting for ecosystem services losses (Ruhl et al. 2009). By requiring compensation for those losses, regulatory wetland mitigation markets will more accurately value ecosystem services and integrate them into the participants’ decisions. Similarly, payment programs, such as farm conservation subsidies, can use ecosystem services concepts to more efficiently allocate subsidy payments to areas where agricultural conservation has economic as well as ecological value (Yang et al. 2010). And regulators need not always be involved, as knowledge about ecosystem services has begun to open up pure voluntary market transactions, such as payment for enhanced groundwater recharge (Ruhl 2008).

Finally, knowledge about ecosystem services can serve to build important metrics for ecosystem management policy. For example, measuring ecosystem services outputs from particular resource units could serve as a performance metric for public land management, water quality protection, and other environmental regulation programs (Ruhl 2010a). Indeed, because ecosystem services practice ultimately works toward the universally fungible metric of market values, it can serve as a metric for cross-program comparisons.

These and similar effects of integrating ecosystem services concepts into ecosystem management policy are likely to enhance the resilience of management decision processes. The reliability of and confidence in regulatory decisions will be improved by tapping into this previously undeveloped (or ignored) knowledge base. Market outcomes will produce greater efficiency as more complete information about resource values is made available. Policy itself can become more evolvable as research on ecosystem services improves the breadth and depth of detail about ecosystem services over time. In short, given the importance that people and policy makers place on knowing the economic impacts of their decisions, it is reasonable to expect that integrating ecosystem services concepts into ecosystem management decision making will contribute to decisions that enjoy greater precision and legitimacy and from which resilience is likely to be enhanced. Now, however, we must return to the real world, where all the information desired about ecosystem services in any setting and scale is not inexpensively and readily at our fingertips.

**Factors Impeding Policy Resilience**

For any of the resilience-enhancing effects discussed above to take hold, knowledge about ecosystem services must be robust. But as the discussion of ecosystem services theory opening this chapter explained, the very nature of ecosystem services is that they are highly varied across time and space. This is true both ecologically and economically. Thus, a wetland parcel in Florida and one in Maine may both meet the general criteria for what makes a wetland, but they may be ecologically quite different. And even two ecologically indistinguishable wetland parcels in the same area could present vastly different economic profiles. Several studies have shown, for example, that wetlands credited for mitigation of losses at urban development impact sites often are located in areas with sparse human population densities, meaning they necessarily do not deliver the same levels of ecosystem services as did the destroyed wetlands (Ruhl and Salzman 2006). Moreover, even two wetland parcels that are ecologically and economically similar could be providing their respective service values (e.g., groundwater recharge) at different times.
(i.e., depending on when it rains). The upshot is that knowledge about ecosystem services is profoundly place and time specific, and this quality could substantially restrain policy resilience in several ways.

First, the idea that decision makers will have robust ecosystem services information at their fingertips for any context seems unrealistic, if not fantasy. We simply cannot afford it, and even if the financial support were deep, the scientific capacity to produce highly textured data about ecosystem services is not nearly developed, at least not now or anytime soon. This means that decision making using ecosystem services will have to employ shortcuts and generalizations, such as proxies and partial measurements. For example, based on representative samples and studies, an agency might adopt a set formula for service valuation, such as one acre of wetland type X located within 5 miles of population density Y has a value of $Z. To the extent such techniques rely on coarser and more general inputs, their reliability, and thus their resilience-enhancing effects, necessarily diminish. At some point, such proxies and other shortcuts, practically necessary as they may be, are so poor in quality that decisions using them suffer from the familiar garbage-in–garbage-out effect. To be sure, environmental policy is rife with dilemmas of this sort—what to measure, how much to measure, how to pay for it—the point here being that ecosystem services practice will be no exception.

The second drag effect using ecosystem services concepts could pose for policy resilience has to do with the dark side of how people behave when they have more knowledge. Knowing more about how one is connected to ecosystems may have the resilience-enhancing effect posited above, but it also may lead to greater conflict and competition between people. Carbon sequestration serves again as an example: If new knowledge about ecosystem services trade-offs shows that forest sequestration capacity comes at the expense of some groundwater recharge capacity, will local and national interests conflict over where to locate sequestration projects? Similarly, as new knowledge about the off-site benefits of public lands becomes available, will yet more interest groups enter the fray of contested public land management decisions? Surely ecosystem management policy is no stranger to conflict and competition between people over resource allocation decisions, and new information can also lead to new alliances of cooperation and coordination, but knowledge about ecosystem services will inevitably be a two-way street in terms of resolving and fueling controversy.

None of this is meant to suggest that using ecosystem services concepts in ecosystem management decision making is any more problematic than using any other form of information about the environment. But ecosystem services literature tends to paint a very rosy picture, whereas the hard reality is that the policy world can be a rough and tumble place even for what in many respects is a positive take on ecosystems and their value to humans. It is quite possible, in other words, that some interests and institutions will use knowledge about ecosystem services in ways that gum up the policy works, so to speak, and thereby impede ecosystem management policy resilience. That effect may be outweighed by the resilience-enhancing effects outlined above, but whether it will or not remains to be seen.

Conclusion

Will using ecosystem services concepts enhance ecological resilience, ecosystem management policy resilience, or both? It all depends. That is not a particularly satisfying answer, but the theme built through this chapter is that much will depend on how robust knowledge about ecosystem services becomes and, perhaps most important, how decision makers use that knowledge. There is nothing inherent about ecosystem services theory and practice that will lead inexorably to resilience-enhancing outcomes for ecosystems or for policy. Rather, several overarching effects will drive the direction in which ecosystem services concepts move ecological and policy resilience.

First, ecosystem services theory adds a new dimension to ecosystem management decision making, principally with respect to regulating and supporting services, that expands the economic understanding of ecosystems. This broadened economic conception of ecosystems is likely to also expand the range of ecological management criteria decision makers take into account. For example, whereas a forest land manager might previously have focused predominantly on timber value and thus also on resilience of the ecosystem processes supporting timber, now other service values might become important to the management goals, which
in turn may make resilience of other ecosystem processes important. As the resilience of more ecosystem processes becomes more important, overall ecological resilience is likely on balance to be enhanced.

On the other hand, the flip side is the scenario in which new knowledge about ecosystem services drives a land manager to focus even more on one particular service—i.e., the one that laid the golden egg. Even if this service is a regulating or supporting service, such as carbon sequestration or groundwater recharge, the focus on one service is likely to drive management decisions toward enhancing the resilience of ecosystem processes supporting that service, possibly to the detriment of other processes. Overall ecosystem resilience could suffer.

Ecosystem management goals for different ecosystems are likely to run the gamut from promoting broad ecosystem services profiles to single services, with everything in between. In all such contexts the quality of the management decision will depend on the quality of the information available about the service or services being managed. Poor quality information will make poor decisions more probable. High quality information, if even attainable, will be costly. Regardless of the information quality, moreover, any form of new information will open up new fronts for interest group conflict and competition (as well as cooperation and coordination). Policy resilience will be tested in some contexts and supported in others.

From this mixed bag of possibilities comes one conclusion that is clear and definitive: ecosystem services theory and resilience theory will inevitably meet through ecosystem management decision making. Ecosystem management is the birthplace of both theories and the testing ground for their practice and implementation. How each performs when they intersect is the question that motivated this chapter, and its answer is just now beginning to materialize in the field.

References


---

Climate change, when combined with more conventional stress from human exploitation, calls into question the capacity of both existing ecological communities and resource management institutions to experience disturbances while substantially retaining their same functions and identities (Zellmer and Gunderson 2009; Ruhl 2011). In other words, the physical and biological effects of climate change raise fundamental challenges to the resilience of natural ecosystems (Gunderson and Holling 2002). Perhaps more importantly, the projected scope of ecological shifts from global climate change—and uncertainty about such changes—significantly stresses the capacity of legal institutions to manage ecosystem change (Camacho 2009). Existing governmental institutions lack the adaptive capacity to manage such substantial changes to ecological and legal systems. In particular, regulators and managers lack information about ecological effects and alternative management strategies for managing the effects of climate change (Karkkainen 2008; Camacho 2009), as well as the institutional infrastructure for obtaining such information (Peters 2008).

A number of recent initiatives have been proposed to address the effects of climate change on ecological systems. However, these nascent programs do not fully meet the needs for developing adaptive capacity. A federal, publicly accessible, and system-wide portal and clearinghouse