Scenario Studies as a Synthetic and Integrative Research Activity for Long-Term Ecological Research

JONATHAN R. THOMPSON, ARNIM WIEK, FREDERICK J. SWANSON, STEPHEN R. CARPENTER, NANCY FRESCO, TERESA HOLLINGSWORTH, THOMAS A. SPIES, AND DAVID R. FOSTER

Scenario studies have emerged as a powerful approach for synthesizing diverse forms of research and for articulating and evaluating alternative socioecological futures. Unlike predictive modeling, scenarios do not attempt to forecast the precise or probable state of any variable at a given point in the future. Instead, comparisons among a set of contrasting scenarios are used to understand the systemic relationships and dynamics of complex socioecological systems and to define a range of possibilities and uncertainties in quantitative and qualitative terms. We describe five examples of scenario studies affiliated with the US Long Term Ecological Research (LTER) Network and evaluate them in terms of their ability to advance the LTER Network's capacity for conducting science, promoting social and ecological science synthesis, and increasing the saliency of research through sustained outreach activities. We conclude with an argument that scenario studies should be advanced programmatically within large socioecological research programs to encourage prescient thinking in an era of unprecedented global change.

Keywords: socioecological systems, science synthesis, participatory engagement, futures

Public investment in science increasingly comes with the expectation that research will address the complex challenges that society faces and will contribute to strategies that sustain the vitality and integrity of socioecological systems (Reid et al. 2010). During the past 30 years, as the US National Science Foundation (NSF)–sponsored Long Term Ecological Research (LTER) Network has grown from 6 to 26 research sites, ranging from Alaska to Antarctica and from urban ecosystems to forests to coral reefs. The LTER Network has increasingly used innovative approaches to connect science to society: from direct engagement with policymakers to educational programs in public schools and software applications that inform the public about the structure, function, and state of socioecological systems (Bestelmeyer et al. 2005, Driscoll et al. 2012 [in this issue], Robertson et al. 2012 [in this issue]). Scenario studies are one such approach and are emerging as a powerful tool for synthesizing the results of LTER science and for engaging with stakeholders to consider socioecological futures. There is a rich history involving the use of scenarios to encourage prescient thinking, largely born out of military and corporate planning (Kahn 1962, Wack 1985). Scenarios offer a framework for practitioners to integrate diverse modes of knowledge and to explicitly recognize those components of complex systems that are understood and those that are uncertain. In this way, scenario studies can describe multiple ways in which our shared socioecological future may unfold, sometimes including a *visioning* process that is focused on the specific attributes of one preferred future condition. Although the first type of scenario studies yield impartial descriptions of a range of *possible* future states, visioning describes *desirable* future states (or *visions*)—for instance, according to sustainability principles or stakeholder agreement (Swart et al. 2004, Carpenter and Folke 2006, Weaver and Rotmans 2006). Both types of scenario are contrasted with probability-based approaches to forward-looking research below.

We refer here to *scenario studies* in general as any strategy for describing plausible future conditions while explicitly incorporating relevant science, societal expectations, and internally consistent assumptions about major drivers, relationships, and constraints (Xiang and Clarke 2003, Iverson Nassauer and Corry 2004, Raskin et al. 2005, Bolte et al. 2007, Mahmoud et al. 2009). Unlike predictive modeling, scenario studies acknowledge the uncertainty inherent in socioecological systems and therefore do not attempt to forecast the precise or probable state of any variable at a given point in the future. Instead, comparisons among a set of contrasting scenarios are used to understand the systemic interrelation and dynamics of complex socioecological systems

BioScience 62: 367–376. ISSN 0006-3568, electronic ISSN 1525-3244. doi:10.1525/bio.2012.62.4.8

and to define a range of possibilities and uncertainties in quantitative and qualitative terms. The value of scenario studies lies in the process of embedding alternative states of the future into a transparent problem-solving framework (Swart et al. 2004). In this way, scenario studies may help to anticipate change in systems characterized by high levels of irreducible uncertainty and low levels of controllability (Bennett et al. 2003, Peterson et al. 2003a) and evoke new integrative perspectives and novel concepts of ecological change (Carpenter and Folke 2006, Carpenter et al. 2006). Although environmental scenarios are developed for a wide range of specific purposes, scenario studies can serve three widely accepted functions: education and public information, scientific exploration, and decision support and strategic planning (Alcamo and Henricks 2008, Henrichs et al. 2010).

In many large science- and environmental-assessment programs, scenarios have been used to describe and underpin analyses of alternative futures. The Intergovernmental Panel on Climate Change's (IPCC) emission scenarios (Nakićenović and Swart 2000) and the Millennium Ecosystem Assessment's scenarios (MA 2005) are perhaps the most well known, but there are many others (e.g., Sala et al. 2000, Raskin et al. 2005). Several LTER sites, for example, are deeply involved in scenario studies and even more plan to be. A recent LTER Network–sponsored workshop brought together 32 social and ecological researchers representing 16 LTER sites from around the United States that were actively engaged in some aspect of scenario studies for the region surrounding their sites (Thompson and Foster 2009). The participants reaffirmed what may seem self-evident: LTER-based science has several characteristics amenable to developing regional socioecological scenarios. Credible socioecological scenarios require a deep understanding of long-term environmental dynamics—a signature strength of LTER science—and a tight coupling of ecological and social research—an emerging strength of and direction for the LTER Network (Collins et al. 2011, Robertson et al. 2012 [this issue]).

Looking forward to the next 30 years of LTER—and, more generally, to other research programs concerned with understanding socioecological systems—we argue that the application of scenario studies can advance prescient thinking in an era of unprecedented rates of global change. For example, an overarching goal set forth in the LTER Network's Strategic and Implementation Plan is to use its deep understanding of complex socioecological systems to help anticipate ecological, evolutionary, and social responses to future environmental change and to inform societal strategies to adapt to this change (LTER Network 2011). This aligns seamlessly with the primary functions of scenario studies (i.e., underpinning decision processes, collaborative learning, and scientific exploration). More specifically, scenarios can enable site-based research programs to explore possible as well as desirable and sustainable future states of their respective regions. And through sustained partnerships with land managers, policymakers, and other stakeholders, participatory scenarios can increase the societal relevance of their research. Moreover, in scenario studies in which the socioecological future of their regions is formally considered, new research needs can be identified while research in temporal and spatial dimensions is scaled up. Finally, developing and analyzing future scenarios would provide a platform for working with many scientific networks, including the National Ecological Observatory Network (NEON) and Urban Long Term Research Areas (ULTRA).

Driscoll and colleagues (2012) explore the novel ways in which scientists have delivered their research findings to policymakers and managers where they can inform decisions. They describe several important communications approaches that allow new science to span boundaries and to address new challenges. In the present article, we examine scenario studies as one such boundary-spanning approach, using several examples of scenario studies from LTER sites in order to identify approaches that may be more broadly applicable. More specifically, we evaluate one emerging and four mature scenario studies in terms of three questions that address the value of scenarios for advancing socioecological science, programs, and outreach:

A science question: How do the scenario studies relate the past to the future? Related to this question are those of what attributes of the socioecological system will change a lot, what attributes will change a little, and why. To articulate a range of alternative futures in a plausible and credible manner, it is necessary to understand the relevant history and trajectory of environmental and social change of the system of interest and its component parts. Evaluating future scenarios in light of recent changes, then, leads to an understanding of system attributes that are more or less resilient or vulnerable to future change. This feature of scenario studies is especially valuable as socioecological change approaches "tipping points" and the need to anticipate and mitigate future change becomes acute (Scheffer et al. 2001, Rockström et al. 2009).

A programmatic question: How do the scenario studies relate to the more traditional long-term science occurring within LTER? Related to this question is how they can advance science synthesis. Scenarios take many forms and, as is shown below, they may have narrow or expansive thematic scope. But in all the case studies, scenarios are either informed by or are used as a platform for applying the core long-term research coming from the individual LTER sites. Consequently, scenarios can be a compelling approach to science synthesis and for cross-site comparative analyses.

An outreach question: How do the scenario studies affect the region and regional society through real-world changes or capacity building? Future scenarios draw together stakeholders affected by the hypothesized future changes. By engaging in scenario studies, scientists can place themselves in a new relationship with society. It can be a means for linking science and decisionmaking in order to support future and hopefully sustainable trajectories for socioecological systems, whether they are wild landscapes, natural resource lands, or urban areas.

Case studies

The case studies showcase diverse ways in which scenario studies are being employed as a vehicle to understand the drivers of socioecological change, to engage with regional stakeholders, and to consider shared socioecological futures. Each is distinct in its motivation, methodology, and outcomes. To provide a consistent organization for evaluation, we describe each using a seven-part conceptual framework (figure 1, table 1) that includes (1) a trigger or context (i.e., what precipitated the study and in what environment [e.g., academic, professional] it occured), (2) a goal (i.e., what the leaders and participants in the scenario study hoped to achieve), (3) construction or methodology (i.e., what scenario construction method was used), (4) collaboration (i.e., who was involved in scenario development [e.g., regional or national stakeholders, experts]), (5) scenarios (i.e., what scenarios [i.e., topics] were generated and what the mode or representation [e.g., narratives, visuals, maps] was), (6) use (i.e., in what ways the scenarios were used after they were completed [e.g., research, planning and decisionmaking, education and training]), and (7) impacts (i.e., what social impacts the application of the scenarios yielded [e.g., it improved the network, influenced policy decisions, changed professional practice, or increased capacity]).

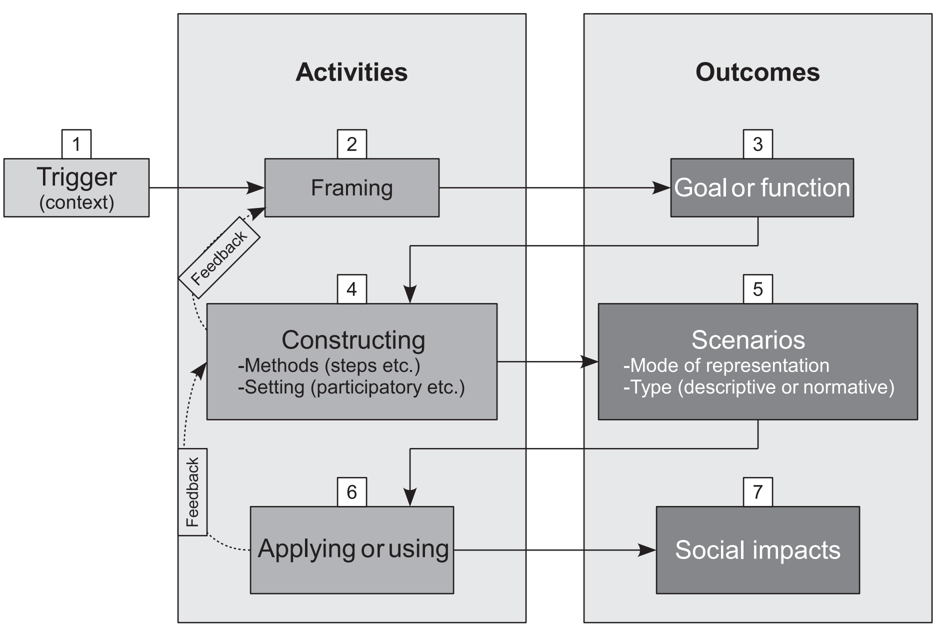

Figure 1. Analytical framework for evaluating diverse forms of scenario studies conducted throughout the US Long Term Ecological Research Network.

Northern Highlands Lake District scenarios: The North Temperate Lakes LTER site. The Northern Highlands Lake District (NHLD) is located in northern Wisconsin. During the past several decades, the population of the region has expanded significantly, which has resulted in the construction of new housing and infrastructure and a marked increase in tourism and recreation, which are important components of the region's economy (Peterson et al. 2003b). These developments have placed additional pressure on the lakes and surrounding forests, which has caused concern about the long-term sustainability of these resources and the economic activity they support. Partially on the basis of the social- and natural-science infrastructure developed by scientists at the North Temperate Lakes (NTL) LTER site, the NHLD was selected as one of a few pilot study regions for the Millennium Ecosystem Assessment Scenarios Working Group (Carpenter 2008). Participants in the working group were drawn from local businesses, nongovernmental organizations (NGOs), tribal organizations, and government, as well as technical experts from the NTL, to engage in wide-ranging conversations about the vulnerabilities and potential strengths of the region, as well as the fears and hopes for the landscape's future. Through an iterative process, facilitators distilled diverse storylines into four composite scenarios that portrayed alternative drivers of change over the coming 25 years. They commissioned an artist to develop illustrations for the storylines and allowed the stakeholders to refine the scenarios. The four scenarios represented very different pathways that the NHLD might follow with regard to future population trends, zoning requirements, and recreation policies. They were designed to be internally coherent, logically consistent, and plausible. In this way, it was possible to explore each scenario individually, as well as the similarities and differences among them. The scenarios were presented as illustrated stories in a short book and on a Web site. After the scenarios were settled, simulation modeling was begun in order to couple the qualitative stories to the anticipated quantitative changes in ecological systems. Together, the scenarios and outputs from simulations were used to spark conversations about the future in meetings with individual decisionmakers, in large public meetings, and in online forums. The facilitators also ran an online survey to gather public reactions to the scenarios. In subsequent years, the scenarios have been used in several university classes through role-playing adaptive-management games.

Table 1. Features of the US Long Term Ecological Research (LTER) Network sites and their associated projects discussed in this article.

Project Title, LTER site, space, and record length	Triggers and context	Goals	Method (1) and steps (2)	Collaboration	Scenarios: topic (1) and format (2)	Uses	Impacts
Northern Highlands Lake District LTER site: North Temperate Lakes (NTL) Space: 5300 square kilometers (km^2) Time: 25 years forward	1. Academic 2. Pilot scenario study for Millennium Ecosystem Assessment	1. Create contrasting scenarios 2. Stakeholder outreach and collaborative learning 3. Provide input for LTER	1. Workshops 2. Iteratively review scenarios and combine scenario elements	Input from regional stakeholders	1. Landscape change 2. Narratives (stories); artistic renditions; book; Web page	1. Role-playing adaptive-management games 2. Simulation models	1. Increased network 2. Influenced policy choices 3. Increased outreach capacity of NTL
Blue River Landscape Plan and Study LTER site: Andrews Forest (AND) Space: 23 km^2 Time: 500 years back 200 years forward	1. Professional (forest planning) 2. Alternative forest management	1. Create contrasting scenarios 2. Test history as management guide 3. Provide input for management and policy	1. Assess fire history 2. Write alternative scenarios 3. Formally analyze 4. Elicit feedback	Research-Forest Service managers collaboration	1. Forest landscape structure and function under alternative disturbance regimes 2. Narratives (technical); maps; report	1. Development of forest management plan 2. Begin plan implementation 3. Public demonstration project	1. Influenced forest practices in North America
2. Future Vision and Scenarios for Phoenix LTER site: Central Arizona Phoenix (CAP) Space: 1344 km^2 Time: 40 years forward	1. Professional (urban planning) 2. Revision of the city's general plan	1. Create sustainability vision and contrasting scenarios 2. Stakeholder outreach and collaborative learning 3. Provide input for General Plan	1. Review scenario literature 2. Elicit vision statements 3. Formally analyze 4. Elicit feedback	Input from regional stakeholders	1. Urban development (economy, environment, society, infrastructure) 2. Narratives (technical, stories); illustrations; graphs; report	1. Revision of general plan 2. Professional training, fundraising 3. Primary and university classes	1. Incorporated into general plan 2. Influenced policies 3. Built planners and citizens' capacity
Scenarios Network for Alaska/ Arctic Planning (SNAP) LTER site: Bonanza Creek (BNZ) Space: AK / 1.7 million km^2 Time: 20 years back 100 years forward	1. Academic 2. Societal need for regional information regarding climate change	1. Create contrasting scenarios 2. Stakeholder outreach and collaborative learning 3. Create research and communication tool on climate change	1. Downscale climate scenarios 2. Model biophysical parameters	Expert-driven	1. Climate and biophysical parameters 2. Reports; interactive Web mapping	1. Modeling of ecological impacts; planning 2. Energy projects 3. University classes	1. Incorporated into report to governor's panel on climate change 2. Informed decisions (communities)
North American Forest Scenarios LTER sites: Harvard Forest, Coweeta, NTL, AND, BNZ Space: 15 landscapes / 5600–27,000 km^2 Time: 50 years forward	1. Academic 2. Identify regional characteristics that alter continental-scale drivers of global change	1. Create contrasting scenarios 2. Provide input for cross-site LTER comparative research	1. Elicit narratives 2. Parameterize interactive simulation models	Input from national and regional stakeholders	1. Forest conversion, energy production, climate mitigation, conservation, etc. 2. Narratives (technical), maps, graphs, visualizations	This is an emerging project whose use and impacts have yet to be realized.	

Overall, the process of scenario planning increased the connectivity of the NTL group to other groups actively engaged in the region. The process also had the immediate effect of increasing the extent of networking among diverse stakeholders who had long histories in the NHLD but little prior interaction. This connectivity improved the outreach capacity of the NTL and introduced the science to more potential users.

Blue River Landscape Plan and Study scenarios: The Andrews Forest LTER site. In the early 1990s, forest policy in the Pacific Northwest abruptly shifted from several decades of management in which commodity (timber) production was emphasized to one that was focused on species conservation (Duncan and Thompson 2006). The Northwest Forest Plan (NWFP) was the policy instrument that codified this change. The NWFP was itself the product of a scenario approach in which scientists, including several from the Andrews Forest (AND) LTER site, prepared 10 management scenarios (alternatives) for the Clinton administration (FEMAT 1993), with one selected as the basis of the NWFP. Within the plan, 10 large parcels (40,000–200,000 hectares) of federal forestlands were delineated as adaptive management areas (AMAs), in which scientists and land managers were charged with examining alternative strategies to meeting conservation and timber-production goals. At the Central Cascades AMA, which contains the AND site, LTER scientists teamed with land managers of the Willamette National Forest to construct a landscape-scale forest-management plan. They used science-based visioning to describe an ecologically desirable but unconventional approach to long-term management that was informed by historic fire regimes and landscape dynamics rather than by standard reserve-design criteria. The resulting scenario, called the Blue River Landscape Plan and Study (BRLP; Ecoshare 2011), patterned timber harvests on the historical wildfire regime (Cissel et al. 1999). The BRLP's resulting "disturbance-based" or "historical range of variability" approach began with a dendrochronology-based fire-history study that spanned the previous 500 years (Weisberg 1998), which was used to semiquantitatively generate a map of three fire-regime types distinguished by fire frequency and severity and constrained in part by topography. A forest planner used this fire-regime map and a map of the then-present distribution of forest age classes to project harvests 200 years into the future. The plan included novel approaches to individual-tree and patch retention and to cutting-rotation length to emulate the historical wildfire severity and frequency. This disturbance-based approach to landscape management was contrasted with expected future management under the NWFP, which is based on the management of unharvested reserves and matrix land (i.e., actively harvested areas between reserves), for its conservation value for selected species (Cissel et al. 1999). Public reaction to the disturbance-based plan was assessed through surveys and field-tour discussions. The public had a significant level of acceptance, although the concept and vocabulary were unfamiliar to many (Shindler and Mallon 2009). The BRLP has since served as an actual management plan intended for implementation, as well as a demonstration project used for critical discourse within science, land-management, and public circles. The BRLP helped reveal to the various stakeholders that an understanding of natural-disturbance regimes can lead to a viable approach to harvesting and the conservation of biodiversity and ecosystem functions. Lessons being learned from the BRLP have been widely communicated and may be used for new applications as society charts the management of public lands through a dynamic future socioecological system (Spies and Duncan 2009).

Future vision and scenarios for Phoenix: Central Arizona–Phoenix LTER site. In autumn 2009, the city of Phoenix, the Central Arizona–Phoenix (CAP) LTER site, and the School of Sustainability at Arizona State University initiated a research project entitled "The Future of Phoenix: Crafting Sustainable Development Strategies." (Wiek et al. 2012). The purpose of the combined visioning and scenario study was to create—through a collaboration of expert facilitators, scientists, and stakeholders—a vision and contrasting scenarios that captured a spectrum of possible future developments of Phoenix. The vision described Phoenix as a desirable and sustainable socioecological system, as was determined by stakeholder agreement and sustainability principles (Gibson 2006). The contrasting scenarios described alternative—less desirable and less sustainable—future states and represented what might happen if the vision is not achieved (Withycombe and Wiek 2011). In the vision that resulted from this participatory research process, Phoenix was described as being comprised of vibrant communities, where healthy food, clean water, fresh air, excellent educational opportunities, satisfying jobs, and public transit options are available to all citizens; where strong local businesses take advantage of local assets to build a diverse and community-oriented urban economy; where governance is open and transparent and reflects the values of all people, regardless of their power or influence; and where the urban ecological system is preserved and cared for, so that it can be sustained for generations to come. In the contrasting scenarios, two alternative future states of Phoenix are described: *Phoenix behind the times*, in which the city acknowledges critical challenges from climate change to environmental degradation and social tensions but cannot seem to keep pace with other regions in creating a healthy socioecological system, and *Phoenix overwhelmed*, in which the city ignores long-term challenges, upholds the growth paradigm, and continues to overextend its capacities and to jeopardize sustainable future development pathways. The vision was presented in three formats: stories with photographs, a narrative, and a map of priorities. The scenarios were presented as newspaper cover pages with illustrations and as narratives. Visioning and scenario construction combined several methods, such as consistency analysis, diversity analysis, sustainability appraisal, and trade-off analysis

(Wiek et al. 2006, Withycombe and Wiek 2011). In the study, the knowledge, preferences, and values of a broad range of experts and regional stakeholders were elicited, deliberated, and integrated. The core stakeholder-engagement activities were 15 meetings in all parts of the city, designed to elicit vision statements, and a visioning workshop, in which the elicited vision statements were revisited, systemically linked, and reprioritized on the basis of potential conflicts. More than 100 citizens, city planners, business representatives, nonprofit organization members, and researchers participated in this workshop. The vision and the scenarios are now being used by the city administration in planning, training, and fund raising, as well as for teaching purposes in public schools and at Arizona State University. Overall, the project spurred a rich public discussion about the future directions in which Phoenix may be headed and about the degree to which these directions align with a desirable and sustainable future vision. The substance of the vision and scenarios has been incorporated into the current public-hearing draft of the city's general plan (City of Phoenix 2010), which is the city's most important guide for long-term planning and development. It provides direction for planning and allows researchers, policy analysts, and stakeholders to evaluate the effectiveness of policies and actions.

The Scenarios Network for Alaska Planning: The Bonanza Creek LTER site. Arctic and boreal forests are warming about twice as fast as the global average, creating widespread concern and interest in the patterns and consequences of climate change, especially among northern residents. At the Bonanza Creek (BNZ) LTER site, scenarios have been used as both a research and a communications tool to explore the consequences of recent and projected climate change in Alaska. Rapid change experienced in Alaska has focused public attention on these scenarios, which in turn has led to the establishment of a research partnership: the Scenarios Network for Alaska Planning (SNAP; *www.snap.uaf.edu*), which comprises the BNZ, the University of Alaska, and several state and federal agencies, local communities, and nonprofits. SNAP has developed scenarios of future climate as high-resolution maps of mean monthly historical and projected temperature and precipitation (between 1900 and 2100) that account for the known effects of topography and the movement of air masses. By downscaling the five global circulation models that were shown to perform best in the far north and by providing outputs for three emission scenarios defined by the IPCC, SNAP offers stakeholders a range of possible climate futures, rather than a single prediction. Moreover, discussion and interpretation of uncertainty play a large role in SNAP projects. The actual technical work of downscaling the climate scenarios is an expert-driven process. However, all SNAP projects are collaborations between SNAP researchers and land managers or other stakeholders. These stakeholders help determine how the data will be linked to landscape models, existing data sets, and local knowledge and how the resulting scenarios will be used and interpreted. For example, in collaboration with US Fish and Wildlife Service, The Nature Conservancy, and other partners, SNAP researchers have used climate-change scenarios to model potential biome shifts and changes in the ranges of endemic and invasive species. In the resulting report (Murphy et al. 2010), barren-ground caribou, Alaska marmots, trumpeter swans, and reed canary grass were used as indicator species to assess multiple possible futures, given the possible range of climate-change impacts. In addition, the climate scenarios have been used directly by Alaska communities in order to inform decisionmaking about the future sustainability of hydroelectric generation and other energy project plans (Cherry et al. 2010).

The American Forest Futures Projects: The Harvard Forest, Andrews Forest, Bonanza Creek, Coweeta, and North Temperate Lakes LTER sites. Scenario planning is the focus of American Forest Futures Projects, an emerging group of cross-site LTER projects that are being advanced across the major forested regions of the United States in collaboration with major NSF-sponsored programs (including, e.g., five LTER Network sites, NEON, ULTRA), the US Forest Service, the US Geological Survey, the Smithsonian Institution, and several NGOs (e.g., The Nature Conservancy, the Ecological Society of America, the Heinz Center). The projects were designed to address pressing scientific questions related to how and why forested regions vary in their socioecological responses to global change (*www.wildlandsandwoodlands.org/node/133*). In a parallel thrust, the researchers designed the projects as a means to advance several burgeoning network-level LTER Network priorities, such as national- and regional-scale stakeholder engagement, development of models and visualization tools, and communication with policymakers. The projects rely on tiered scenarios developed at national and regional scales to address at least four dominant themes: economic development, energy exploitation (e.g., bioenergy), climate mitigation and adaptation, and landscape-scale conservation.

The researchers have convened a national advisory board of experts, consisting of federal agency and national NGO representatives, to develop national-scale scenarios describing the anticipated drivers and the changes associated with each of the themes. After they are finalized, the suite of national-scale scenarios will be reinterpreted at regional scales around the country by engaging regional stakeholders (e.g., natural-resource managers, scientists, agency officials, conservation professionals) in the development of narratives in which the local manifestation of each of the national scenarios is described. This process of downscaling global scenarios to local scales can be an effective approach for participatory capacity building and for motivating behavioral changes in local stakeholders and decisionmakers (Shaw et al. 2009). The regional scenarios will, in turn, be used to define land-use assumptions and to parameterize spatially interactive landscape-simulation models (e.g., Thompson et al. 2011) within study a series of study landscapes

(5600–27,000 sqaure kilometers) dispersed throughout five forest regions: the Northeast, the Lake States, the Southeast, the Pacific Northwest, and Alaska. Using the scenarios and simulation outputs, the group plans to conduct a series of within- and across-region comparisons to evaluate how ecosystem attributes and services change in response to similar national scenarios of global change along multiple social and ecological gradients, including productivity and topography, land tenure and demographics, land-use history and policies, disturbance regimes, and climate. This approach for coupling qualitative and quantitative scenarios has informed prescient planning and policy and has generated a rich set of fundamental research questions (see, e.g., Spies et al. 2007, Schmitt Olabisi et al. 2010). Although it is still in its early stages, the American Forest Futures Projects have already spurred dialogue among dozens of agencies and stakeholder groups in an effort to describe an envelope of plausible futures for forested landscapes across the country.

Discussion of the case studies

From these case studies, we offer responses to our initial three questions:

How do the scenario studies relate the past to the future? Unlike predictive modeling, in scenario studies, no level of confidence is asserted that any particular changes will occur. Instead, several possible changes are integrated into a set of potential future pathways in which the major drivers are logical and consistent across scenarios. In doing so, scenario studies provide useful contexts for addressing questions about how past change may or may not help understand future change, given a range of possible societal dynamics (e.g., population growth, shifting demographics, land-use change) and possible environmental dynamics (e.g., climate, invasive species, major disturbance events). The BRLP, for example, was based on the concept that important elements of the future will represent an extension of historic trajectories of change and also incorporated a detailed understanding of historic landscape change over many centuries in response to disturbance by wildfire, flood, and landslides. The future landscape is expected to include continued responses of forest and stream systems to those past disturbance regimes, as well as future regimes resulting from direct and indirect human influences and natural processes. The vision of management based on historical ecosystem dynamics acted as a medium for discussing these complexities among scientists, land managers, and the public. By examining a range of plausible futures, scientists and stakeholders could consider the range of social and ecological uncertainty and learn about the attributes that drive change, even if they do not know exactly what level of change will occur. The value of considering how historical trends may diverge along multiple alternative pathways was also evident in the NHLD, where big shifts in the status quo were foreseen from both internal and external forces. Internally, concern was focused on political gridlock and a lack of capacity to make collective decisions. Externally, concern was focused on the demographic and economic drivers of massive development in the Northern Highland. These internal and external social drivers were thought to affect the resilience of the region to climate change and other biophysical drivers. In the NHLD scenarios that were seen as optimistic by most respondents, the social and political system of the region changed in ways that facilitated resilient responses to large-scale biophysical changes.

Evaluating multiple scenarios that are informed but not constrained by history can have great advantages over the predictive modeling of future conditions, which can pose serious challenges even in seemingly straightforward analyses and when long-term data exist. For example, we live in a period of high concern over climate change, yet in many cases, climate-change signals are difficult to interpret amid the temporal variability of climate at multiple temporal scales, even with 50-year historical records (Jones et al. 2012 [in this issue]). In Alaska, where the impacts of climate change have been felt by communities for many years, gathering information about how land managers and residents are experiencing and reacting to change offers crucial information about how to address future change. Those who are living with changes, such as increased fire risk, treeline shift, or severe coastal erosion, can offer information about how these changes are already being experienced and managed and can make specific requests about what kind of climate information and what models would be most useful. The SNAP scenarios span a range of potential climate futures, informed by the best available science, but without the false precision of predictive models. The climate scenarios can, in turn, be integrated into socioecological models and narrative stories that define potential futures in a way that managers and residents can relate to and plan for. The use of scenario studies is therefore a productive means for relating historical landscape change to forward-looking analyses of unpredictable socioecological systems.

How do the scenario studies relate to the more traditional long-term science occurring within the LTER Network? Scenario studies are often a form of synthesis of both biophysical and social science. Framing plausible alternative depictions of the future and evaluating them promotes highly integrative thinking. The social, political, and land-management contexts in which LTER sites are embedded increasingly demand a level of integrated analysis that is uncommon in traditional scientific research but that is central to scenario studies. In each of the case studies, the strengths of traditional LTER science—notably, monitoring and evaluating the impacts of long-term environmental change—were integrated into the scenario studies. For example, in the American Forest Futures Projects, the future response of forest ecosystems to climate and land-use change are evaluated over time using ecosystem-process models that are developed and constrained by LTER. National and regional stakeholders define the narratives that guide their assumptions about land use and other societal responses, thus linking the scenarios to the legacy of "hard science" traditionally upheld by LTER. Likewise, in Alaska, where climate change is a topic that has reached a relatively high level of public awareness, SNAP and the BNZ are already engaged in the type of synthesis that forges connections between LTER and exogenous social and economic pressures. In working with groups such as the National Park Service, the Fairbanks North Star Borough Climate Change Task Force (*www.investfairbanks.com/Taskforces/climate.php*), and Alaska's governor's Subcabinet on Climate Change (*www.snap.uaf.edu/projects/governors-subcabinet-climate-change-0*), SNAP has received input from partners who are concerned about the interplay among multiple ecological factors in the context of budgets, short planning cycles, and public criticism. Scenario planning has proven to be a useful tool in this context, because it allows scientists to offer the best available information in a way that incorporates uncertainty and that allows planners to assess risk on their own terms.

Importantly, in all of the case studies discussed here, knowledge transfer and syntheses flowed in both directions, whereby the science informed the scenarios and, in turn, the scenarios informed the science. For example, within the NTL program, the scenarios contributed to a shift toward explicit long-term thinking about socioecological change that has influenced research and the planning of site activities. Recent projects have been focused on thresholds for abrupt change in fisheries, food webs, and invasive-species dynamics, for example. Climate change has been a long-standing interest at the NTL that is also serving as an organizing focus for hypothesis-driven long-term research. Similarly, the Future Vision and Scenarios for Phoenix study serves as a pilot project and will be continued with even more emphasis on the integration of previous CAP work. To this end, a formal synthesis workshop will be conducted in order to make the links to the other CAP working groups explicit and to plan future contributions. The study has also been proven to stimulate collaboration between CAP researchers and other research groups at Arizona State University that are already engaged or interested in scenario studies in the CAP region (across different spatial levels and topic areas).

How do the scenario studies impact the region and the regional communities through real-world changes or capacity building? Scenario studies are a distinctive form of science engagement with society and one that has only recently been employed in LTER. They are much more participatory than traditional outreach that consists of a delivery of scientific findings to policymakers, managers, and the public. For example, the Future Vision and Scenarios for Phoenix study has served as a powerful medium to enhance the engagement between CAP researchers and regional stakeholders. Although CAP research has included stakeholder engagement since its inception in 1997, the dominant mode of operation has been one-way elicitation. The scenario study, in contrast, has demonstrated how more interactive engagement can enhance the interest and ownership for the challenges as well as potential solutions across different stakeholder groups. The ongoing scenario work further expands the participatory-research methodology through advanced collaborative visualization, walking audits, and exploration courses. Similarly, the BRLP scenario has proven to be very useful process for generating discussion among varied stakeholders—pro- and antilogging groups alike—of the dynamics of forest ecosystems and the relevance of natural variability for future management. Having a management scenario based on historic disturbance regimes has fostered public understanding of landscape dynamism at a time when some elements of the public seek to freeze components of the landscape as though it were a museum diorama.

LTER scenario studies have also led to novel uses of technology to engage the public. Taking just a few examples from the case studies, the American Forest Futures Projects are developing a Web-based course modeled after the highly successful LTER Network–sponsored "From Yardstick to Gyroscope" class (*http://news.lternet.edu/article170.html*), in which the science of scenario studies will be taught to university students and landscape planners. As part of the BNZ SNAP project, a Web-based community charts tool has been developed (*www.snap.uaf.edu/community-charts*) that allows Alaska residents to compare a range of possible future climate scenarios for their own village (from among more than 350 in the state) and a Google Earth interface (*www.snap.uaf.edu/google-earth-maps*) that lets users zoom in on their own region and define which models they would like to explore. At CAP, as part of the Future Vision and Scenarios for Phoenix study, the Decision Theater at Arizona State University is to be used to evaluate the effectiveness of those participatory processes for capacity building and decisionmaking.

Overall, the scenario studies presented here demonstrate how considering our shared socioecological future can motivate sustained engagement between science and society. We believe that the long-term dimension of the US LTER Network makes it a highly suitable venue for scenario studies. Indeed, the 30-year history of the LTER program provides time for development of social networks with key parts of society (e.g., decisionmakers, NGOs, government agencies with lands responsibilities, interested members of the public). Finally, members of the LTER Network's science community live and work in their studied landscapes and are themselves stakeholders with a deep personal stake in its future.

Conclusions

As the case studies show, scenarios can be an effective approach for synthesizing science in a major research program and can lead to an improved understanding of socioecological change. Scenario studies offer a flexible framework for integrating the best available ecological science with the myriad of uncertainties that are inherent in global change. Using scenarios, large ecological research programs, such as the LTER Network, NEON, and ULTRA, can lead societal discussion regarding the future of their landscapes. The core strengths of the LTER Network in particular—its history of long-term, place-based studies; its community of scholars committed to integrative research across disciplines and service to society; and its diversity of landscapes, stakeholders, and disturbance regimes—make it ideally suited to leading scenario studies in each of the landscapes in which LTER sites are present. As such, we suggest that scenario studies be advanced in collaboration with many other research groups and agencies as a network-wide activity to promote research in socioecological systems and cross-site comparative analyses across the network.

Acknowledgments

Support for this work was provided by US National Science Foundation Long Term Ecological Research Network awards to Harvard University, Arizona State University, Oregon State University, the University of Alaska, and the University of Wisconsin and by the US Forest Service.

References cited

Alcamo J, Henrichs T. 2008. Towards guidelines for environmental scenario analysis. Pages 13–35 in Alcamo J, ed. Environmental Futures: The Practice of Environmental Scenario Analysis. Elsevier.

Bennett EM, Carpenter SR, Peterson GD, Cumming GS, Zurek M, Pingali P. 2003. Why global scenarios need ecology. Frontiers in Ecology and the Environment 1: 322–329.

Bestelmeyer S, Dailey S, Elser M, Hembree P, Landis C, O'Connell K, Simmons B, Sommer S, Steiner S. 2005. Handbook for LTER Education. US Long Term Ecological Research Network.

Bolte JP, Hulse DW, Gregory SV, Smith C. 2007. Modeling biocomplexity: Actors, landscapes and alternative futures. Environmental Modeling and Software 22: 570–579.

Carpenter S[R]. 2008. Seeking adaptive change in Wisconsin's ecosystems. Pages 407–421 in Waller DM, Rooney TP, eds. The Vanishing Present: Wisconsin's Changing Lands, Waters, and Wildlife. University of Chicago Press.

Carpenter SR, Folke C. 2006. Ecology for transformation. Trends in Ecology and Evolution 21: 309–315.

Carpenter SR, Bennett EM, Peterson GD. 2006. Scenarios for ecosystem services: An overview. Ecology and Society 11: 29.

Cherry JE, Walker S, Fresco N, Trainor S, Tidwell A. 2010. Impacts of Climate Change and Variability on Hydropower in Southeast Alaska: Planning for a Robust Energy Future. University of Alaska, Fairbanks. (31 January 2012; *http://ine.uaf.edu/accap/documents/seak_report_final.pdf*)

Cissel JH, Swanson FJ, Weisberg PJ. 1999. Landscape management using historical fire regimes: Blue River, Oregon. Ecological Applications 9: 1217–1231.

City of Phoenix. 2010. Phoenix General Plan Update: Transitioning to a Sustainable Future. Public Hearing Draft. December 2010. City of Phoenix, Phoenix, Arizona. (8 September 2011; *http://phoenix.gov/citygovernment/planres/cityplan/planphx/index.html*)

Collins SL, et al. 2011. An integrated conceptual framework for long-term social-ecological research. Frontiers in Ecology and the Environment 9: 351–357.

Driscoll CT, Lambert KF, Chapin FS III, Nowak DJ, Spies TA, Swanson FJ, Kittredge DB Jr, Hart CM. 2012. Science and society: The role of long-term studies in environmental stewardship. BioScience 62: 354–366.

Duncan SL, Thompson JR. 2006. Forest plans and ad hoc scientist groups in the 1990s: Coping with the Forest Service viability clause. Forest Policy and Economics 9: 32–41.

[FEMAT] Forest Ecosystem Management Assessment Team. 1993. Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. US Forest Service.

Gibson RB. 2006. Sustainability assessment: Basic components of a practical approach. Impact Assessment and Project Appraisal 24: 170–182.

Henrichs T, Zurek M, Eickout B, Kok K, Raudsepp-Hearne C, Ribeiro T, van Vuuren D, Volkery A. 2010. Scenario development and analysis for forward-looking ecosystem assessments. Pages 151–220 in Ash N, et al., eds. Ecosystems and Human Well-Being: A Manual for Assessment Practitioners. Island Press.

[Ecoshare] Ecoshare: Interagency Clearinghouse of Ecological Information. 2011. Blue River Landscape Strategy. Ecoshare. (31 January 2012; *http://ecoshare.info/projects/central-cascade-adaptive-management-partnership/landscape-studies/blue-river-landscape-strategy*)

Iverson Nassauer J, Corry RC. 2004. Using normative scenarios in landscape ecology. Landscape Ecology 19: 343–356.

Jones JA, et al. 2012. Ecosystem processes and human influences regulate streamflow response to climate change at long-term ecological research sites. BioScience 62: 390–404.

Kahn H. 1962. Thinking about the unthinkable. Horizon Press.

[LTER Network] US Long Term Ecological Research Network. 2011. Strategic and Implementation Plan: Long-term Ecological Research Network (LTER): Research and Education. LTER Network. (31 January 2012; *http://intranet2.lternet.edu/sites/intranet2.lternet.edu/files/documents/LTER%20History/Planning%20Documents/LTER_SIP_Dec_05_2010.pdf*)

Mahmoud M, et al. 2009. A formal framework for scenario development in support of environmental decision-making. Environmental Modeling and Software 24: 798–808.

[MA] Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Scenarios. Island Press.

Murphy K, Huettmann F, Fresco N, Morton J. 2010. Connecting Alaska Landscapes into the Future. US Fish and Wildlife Service. (8 September 2011; *www.snap.uaf.edu/files/SNAP-connectivity-2010-complete.pdf*)

Nakićenović N, Swart R. 2000. Emissions Scenarios. Intergovernmental Panel on Climate Change.

Peterson GD, Cumming GS, Carpenter S. 2003a. Scenario planning: A tool for conservation in an uncertain world. Conservation Biology 17: 358–366.

Peterson GD, Beard TD Jr, Beisner BE, Bennett EM, Carpenter SR, Cumming GS, Dent CL, Havlicek TD. 2003b. Assessing future ecosystem services: A case study of the Northern Highlands Lake District, Wisconsin. Conservation Ecology 7 (3, Art. 1).

Raskin P, Monks F, Riberio T, van Vuuren D, Zurek M. 2005. Global scenarios in historical perspective. Pages 35–45 in Carpenter S, Pingali P, Bennett E, Zurek M, eds. Ecosystems and Human Well-being, Vol. 2: Scenarios. Island Press.

Reid WV, Chen D, Goldfarb L, Hackmann H, Lee YT, Mokhele K, Ostrom E, Raivio K, Rockström J, Schellnhuber HJ, Whyte A. 2010. Earth system science for global sustainability: Grand challenges. Science 330: 916–917.

Robertson GP, et al. 2012. Long-term ecological research in a human-dominated world. Bioscience 62: 342–353.

Rockström J, et al. 2009. A safe operating space for humanity. Nature 461: 472–475.

Sala OE, et al. 2000. Global biodiversity scenarios for the year 2100. Science 287: 1770–1774.

Scheffer M, Carpenter S, Foley JA, Folke C, Walker B. 2001. Catastrophic shifts in ecosystems. Nature 413: 591–596.

Schmitt Olabisi LK, Kapuscinski AR, Johnson KA, Reich PB, Stenquist B, Draeger KJ. 2010. Scenario visioning and participatory system dynamics modeling to investigate the future: Lessons from Minnesota 2050. Sustainability 2: 2686–2706.

Shaw A, Sheppard S, Burch S, Flanders D, Wiek A, Carmichael J, Robinson J, Cohen S. 2009. Making local futures tangible—Synthesizing, downscaling, and visualizing climate change scenarios for participatory capacity building. Global Environmental Change 19: 447–463.

Shindler B, Mallon A. 2009. Public acceptance of disturbance-based forest management: A study of the Blue River Landscape Strategy in the Central Cascades adaptive management area. US Department of Agriculture, US Forest Service, Pacific Northwest Research Station. Research Report no. PNW-RP-581.

Spies TA, Duncan SL. 2009. Old Growth in a New World: A Pacific Northwest Icon Reexamined. Island Press.

Spies TA, Johnson KN, Burnett KM, Ohmann JL, McComb BC, Reeves GC, Bettinger P, Kline JD, Garber-Yonts B. 2007. Cumulative ecological and socioeconomic effects of forest policies in coastal Oregon. Ecological Applications 17: 5–17.

Swart RJ, Raskin P, Robinson J. 2004. The problem of the future: Sustainability science and scenario analysis. Global Environmental Change 14: 137–146.

Thompson J[R], Foster D[R]. 2009. Report to the LTER Network Office on the Scenarios of Future Landscape Change Working Group Meeting April 1–2, 2009. (8 September 2011; *http://lno.lternet.edu/files/lno/Workship%20Report%20-%20Landscape%20Change_Thompson_Foster.pdf*)

Thompson JR, Foster DR, Scheller R, Kittredge D[B Jr]. 2011. The influence of land use and climate change on forest biomass and composition in Massachusetts, USA. Ecological Applications 21: 2425–2444.

Wack P. 1985. Scenarios: Uncharted waters ahead. Harvard Business Review 63: 73–89.

Weaver PM, Rotmans J. 2006. Integrated sustainability assessment: What is it, why do it and how? International Journal of Innovation and Sustainable Development 1: 284–303.

Weisberg PJ. 1998. Fire history, fire regimes, and development of forest structure in the central western Oregon Cascades. PhD dissertation. Oregon State University, Corvallis.

Wiek A, Binder CR, Scholz RW. 2006. Functions of scenarios in transition processes. Futures 38: 740–766.

Wiek A, Ness B, Brand FS, Schweizer-Ries P, Farioli F. 2012. From complex systems analysis to transformational change: A comparative appraisal of sustainability science projects. Sustainability Science. doi:10.1007/s11625-011-0148-y

Withycombe L, Wiek A. 2011. What if the future does not play out as imagined in the vision? Advances in sustainability planning and research through contrasting, non-intervention scenarios. Project Report. School of Sustainability, Arizona State University. (*http://start.lab.asu.edu/*)

Xiang W-N, Clarke KC. 2003. The use of scenarios in land-use planning. Environment and Planning 30: 885–909.

Jonathan R. Thompson (thompsonjr@si.edu) is affiliated with the Smithsonian Institution's Conservation Biology Institute, in Front Royal, Virginia. Arnim Wiek is affiliated with the School of Sustainability at Arizona State University, in Tempe. Frederick J. Swanson and Thomas A. Spies are affiliated with the US Forest Service's Pacific Northwest Research Station, in Corvallis, Oregon. Stephen R. Carpenter is affiliated with the Center for Limnology at the University of Wisconsin, Madison. Nancy Fresco is affiliated with the School of Natural Resources and Agricultural Science at the University of Alaska, Fairbanks. Teresa Hollingsworth is affiliated with the Boreal Ecology Cooperative Research Unit at the University of Alaska, Fairbanks, and with the US Forest Service's Pacific Northwest Research Station, also in Fairbanks. David R. Foster is affiliated with Harvard University's Harvard Forest, in Petersham, Massachusetts.