Challenges and Opportunities for Large Landscape-Scale Management in a Shifting Climate: The Importance of Nested Adaptation Responses Across Geospatial and Temporal Scales

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***Abstract**: The Yellowstone to Yukon Conservation Initiative (Y2Y) was established over 20 years ago as an experiment in large landscape conservation. Initially, Y2Y emerged as a response to large scale habitat fragmentation by advancing ecological connectivity. It also laid the foundation for large scale multi-stakeholder conservation collaboration with almost 200 non-governmental organizations working together. In recent years, the Yellowstone to Yukon Conservation Initiative has taken on the issue of climate adaptation as climate impacts span large landscapes. Yet, these impacts are highly variable across 25 degrees of latitude and various local topographies. This presents a challenge to climate adaptation implementation methods as the response mirrors the complexity of the impacts. As such, climate adaptation approaches at large scales may require nested landscape methods that vertically coordinate smaller to larger areas of ecological concern, in combination with considerations of multiple temporal scales for specific spatial scales. In the Southwestern region of the Crown of the Continent Ecosystem in the vicinity of the Bob Marshall Wilderness of Montana, the US Forest Service, the Wilderness Society, and their many partners are prototyping large scale resilient forestry through the Collaborative Forest Landscape Restoration Program. Working across 1.5 million acres (600,000 hectares), the Southwestern Crown Collaborative seeks to test various hypotheses about forest conservation and management in the age of changing climate, uncertain futures, and shrinking economies. Drawing from our experience in collaborative forest restoration and management, here we examine the challenges and opportunities relating to climate adaptation implementation and larger scale conservation by focusing on specific lessons learned from a landscape-scale, on-the-ground project within the Yellowstone to Yukon region.*

INTRODUCTION

With the Holocene epoch giving way to a newly described Anthropocene, the ecological balance of the planet stands at the precipice of wholesale change. There is great concern that the Earth's biosphere is approaching an ecological state shift (Barnosky and others 2012; Brook and others 2013). As a result, the operating space for human livelihoods and conserving biodiversity is narrowing as the expanding human footprint pushes toward 10 billion people by the year 2050 (Rockström and others 2009). More than 77 percent of the Earth's land surface is now composed of new ecosystem configurations as large scale land conversion is increasingly evident through agricultural enterprises, massive urban sprawl and infrastructure development, invasive species, and freshwater system eutrophication (Ellis and Ramankutty 2008; Ellis 2013). If global climate models and human population predictions prove correct, the planet and people will be pushed to the edge of sustainability. In this period, two global trends will reach critical inflection points—a plateau and downward trajectory of human population growth and a parallel response of decreasing greenhouse gas accumulation in the atmosphere and oceans. A few lucky infants born today may stand witness to this planetary challenge over the next one hundred years. Our call to arms now is to ensure that today's future centenarians prioritize human action to restore ecological balance of the planet and, with it, human well-being.

The emergence of large landscapes as a focus for conservation and management

In the face of global threats, large landscape conservation has emerged over the past three decades as a science-based response to increasing large-scale habitat fragmentation and degradation by advancing the concepts of ecological integrity, ecological connectivity, wildlife corridors and comprehensive landscape matrix conservation. More recently, large landscape conservation approaches have been embraced as a strategy to facilitate the adaptation of biodiversity to the impacts of climate change. In one sense, large landscape conservation is the evolution of the "beyond parks" conservation approach (Minteer and Miller 2011) in which species and ecological processes cannot be satisfactorily sustained within most circumscribed protected landscape parcels.

Conserving nature's parts and processes requires working at a landscape, ecosystem, or even bioregional scale. Hansen and DeFries (2007) demonstrate how even the vast spatial scales of our largest national parks are insufficient to fully support many ecological processes or prevent cross-boundary effects of surrounding human-dominated landscapes. Size does matter in ecology because of the scale of processes and impacts, and, in general, the larger the scale of focus, the better chance of conserving critical ecological processes, such as hydrologic function, natural disturbance regimes, species life cycles and functional trophic interactions (Lindenmayer and others 2008). Conservation at such large scales increases the complexity of decision making as collaboration and consensus among diverse stakeholders, with diverse values, is required. These processes not only sustain nature but provide vital ecological services that support human livelihoods.

Since the establishment of Yosemite and Yellowstone as protected areas in the 19th century, our knowledge of ecology and the practice of conservation have advanced substantially and are reflected in both policy and management. One insight included greater understanding of animal movement ecology. For instance, the Migratory Bird Treaty Act between US and Canada in 1918 set the stage for protecting large scale avian flyways and the eventual design of the North American Waterfowl Management Plan in 1986, which has facilitated the conservation of millions of hectares of wetlands and other bird habitats. In Yellowstone in the 1950s and 1960s, the concept of ecosystem-scale research gained traction through radio-collar research of scientists such as the Craighead twins, who studied grizzly bear home range size and bear movement ecology. The Greater Yellowstone Coordinating Committee was established in 1964 to foster ecosystem scale collaboration among government agencies in the region, the same year that the Wilderness Act was passed. Further research of species movement ecology in later years led to the design of even larger conservation efforts such as the Yellowstone to Yukon Conservation Initiative, which recognized the inter-ecosystem movement needs of the region's medium-sized and large mammals, migratory birds and cold water fish within the Rocky Mountain Cordillera (Tabor 1996; Locke and Tabor 2005).

Since its inception in 1993, the Yellowstone to Yukon effort - through its network of 200 or so public and private organizations - has protected roughly 23 million acres (nine million hectares) of existing public lands through enhanced designations and roughly one million acres (400,000 hectares) of private lands through conservation easements and acquisitions. This includes one of the largest private land deals in the US: the wholesale purchase of Plum Creek timberlands within the railroad legacy checkerboard landscape, including nearly 50,000 acres (20,234 hectares) of the Swan and Blackfoot Valleys in the Crown of the Continent Ecosystem.

Yellowstone to Yukon was the first among a series of subsequent large scale efforts initiated in Canada, many facilitated by First Nations engagement, such as the Great Bear Rainforest in British Columbia, Plan Nord in Quebec and the Canadian Boreal Initiative. The latter effort stretches across six provinces and three territories and represents one of the largest landscape conservation initiatives in the world. In recent years within the US, various government-led large landscape responses have come to the fore. One of the more notable efforts was the 2008 Western Governors' Association initiative on crucial wildlife habitat and wildlife corridors, initiated in response to large scale energy planning and development. All 17 western states within the Western Governors' Association unanimously agreed on a shared policy framework to address the scale and scope of habitat and wildlife movement areas across their jurisdictions in the face of potential conflicts with planned development. This was a milestone event as states recognized the need to conserve their resources at a regional scale through interstate collaboration. Soon thereafter, in 2010, the US Department of Interior embraced a new landscape partnership program, the Landscape Conservation Collaboratives, which designated 22 large scale cooperative landscape management areas across the nation and adjoining transboundary regions in Canada and Mexico as part of a Department-wide coordinated adaptation response to climate change. At the same time, the All Lands Initiative and the US Forest Service's Collaborative Forest Landscape Restoration Program were established to more effectively address conflicts in natural resource management planning and development at large scales.

There has been an exponential growth of large landscape efforts in the past ten years, which, for the most part, reflects a growing conservation interest in maintaining ecological connectivity and wildlife corridors as an approach to address habitat fragmentation and heightened concerns about climate change impacts on species and habitats (McKinney and others 2010, Regional Plan Association 2012; McKinney and Johnson 2013). Large landscape efforts promote resilience to large scale stressors such as climate change, provide a range of potential climate refugia, and support species that can respond to changing environmental conditions with the opportunity to shift their geographic distribution. In reality, the story is more complex. Species interactions are likely to change as individual species respond differentially to climate stressors, and present day trophic structures may give way to novel species interactions and ecosystems in the future.

Moreover, not all species have the ability to shift their distributions to keep pace with the relatively rapid rate of climate change, and current understanding of the extent to which genetic plasticity may allow or prevent species from responding to climatic shifts in their current habitat is poor.

Within the Yellowstone to Yukon region at the international boundary between Canada and the US is the Crown of the Continent Ecosystem. This 18 million acre ecosystem surrounds Waterton Lakes and Glacier International Peace Park, the first international peace park, which was established in 1932. This landscape also bears the physical evidence of climate change as all remaining 25 glaciers in Glacier National Park are predicted to disappear within two decades after surviving for more than 7,000 continuous years (Hall and Fagre 2003). Triple Divide Peak within Glacier National Park connects three major continental river basins—the Columbia, the Missouri and Saskatchewan. The Crown of the Continent not only serves as a focal point for landscape impacts of climate change, it also serves as a focal point for US and Canada landscape collaboration and innovation. Within the southwestern portion of this ecosystem, a new large scale restoration effort is being prototyped, and this case study will inform the ideas for managing in the Anthropocene that are further elaborated in this paper.

A CASE STUDY OF COLLABORATIVE, LARGE LANDSCAPE MANAGEMENT

The CFLRP began in August 2009 upon passage of the Public Lands Omnibus Bill. This Congressional Act established an annual budget of $40 million to finance 10 collaborative, large landscape projects on Forest Service land across the United States. Thirteen additional CFLRP projects were added to the program in 2012 due to strong, bi-partisan support for the program (USDA Forest Service 2012). The goal of CFLRP is to carry out ecological restoration and fire management treatments in priority landscapes by encouraging collaborative, science-based ecosystem restoration projects.

Here, we provide one example of the many challenges, opportunities, and lessons learned related to landscape-scale management in a shifting climate: the Southwestern Crown of the Continent (SWCC) Collaborative Forest Landscape Restoration Program (CFLRP) project in Montana. The SWCC has been working to test various hypotheses about forest conservation and management in the age of changing climate, uncertain futures, and shrinking economies. This work falls under the auspices of a large landscape, forest restoration program initiated by Congress in 2010 and administered by the US Department of Agriculture's Forest Service. Spanning 1.48 million acres (600,000 hectares) of forested, mountainous habitat in three adjacent Forest Service (FS) Ranger Districts (Lincoln, Seeley Lake and Swan), the SWCC CFLRP project (one of 23 nation-wide CFLRP projects) includes portions of three of Montana's National Forests (the Helena, Lolo, and Flathead National Forests, respectively). Four years into the project, project partners are beginning to share lessons learned to identify best management practices for the Anthropocene in this landscape.

Under the CFLRP model of community forestry on our public lands, each project is expected to: (a) demonstrate the degree to which various ecological restoration techniques achieve ecological and watershed health objectives; (b) facilitate the reduction of wildfire management costs through re-establishment of natural fire regimes in back-country areas while simultaneously reducing the risk of uncharacteristically severe wildfire near rural communities; and (c) encourage the use of forest restoration by-products (e.g., small-diameter timber) to offset treatment costs and support local, rural businesses and economies.

Through intensive, long-term work to improve forest health and resilience in an era of shifting climate, CFLRP projects are intended to sustain ecological, economic, and social benefits in rural communities that have traditionally relied on natural resources locally for their livelihoods, drinking water, and recreational opportunities. The Act strongly encourages a shift to adaptive management in these landscapes by requiring all 23 CFLRP projects to develop and implement a large scale monitoring program; a baseline inventory of natural resource conditions, coupled with short- and long-term evaluations of the effectiveness of restoration projects, is expected to create critically important information-feedback loops for managers in an increasingly uncertain future (Hutto and Belote 2013; Larson and others 2013b).

Through its selection for funding in 2010, the SWCC in Montana (http://swcrown.org) combined several existing local collaboratives into a new coalition comprised of U.S. Forest Service agency staff, university faculty, conservation organizations, and citizen groups. The SWCC is sited within the larger 18 million acre (7.28 million hectare) Crown of the Continent, renowned for its unusually high degree of ecological integrity. No known extinctions of plant or animal species have occurred since Lewis and Clark's travels through the region 200 years ago (Prato and Fagre 2007). In addition to the prime habitat provided for grizzly bear, elk, wolverine, deer, gray wolf, Canada lynx, forest birds and waterfowl within the forested mountain landscapes, the cold, clear streams of the Crown are home to a variety of native salmonid species.

Nonetheless, major restoration needs exist. Noxious weeds and exotic fish species have invaded terrestrial and aquatic ecosystems across the landscape, thousands of miles of old logging roads fragment key wildlife habitat and lead to increased sedimentation in blue ribbon trout streams through erosion, and mining activities from an era gone by necessitate focused and expensive clean-up efforts in several places. Decades of fire suppression—a management response to catastrophic wildfires in Montana and Idaho during the "Big Burn" of 1910—have dramatically altered the ecology of Western forested ecosystems and resulted in unnaturally high accumulations of forest fuels (Arno and Fiedler 2005; Egan 2009).

While many of these restoration needs identified are common to Western landscapes of the United States and Canada, CFLRP project partners within the southwestern Crown of the Continent face further management opportunities and challenges associated with the Montana Legacy Project: an historic conservation deal in which 273,000 acres (110,479 hectares) of Plum Creek Timber Company-owned land was sold to a consortium of conservation organizations led by The Nature Conservancy and the Trust for Public Land, before being transferred into public ownership through the U.S. Forest Service. The checkerboard ownership pattern associated with the Montana Legacy Project (Figure 1) began a century ago when the lands were initially purchased by the transatlantic railroad, but remains visible from space today given major differences in the management of these and adjacent lands through time. The absorption of these commercial timberlands into the public domain highlights the significant, and often dynamic, challenges of developing conservation projects across jurisdictionally-fragmented lands.

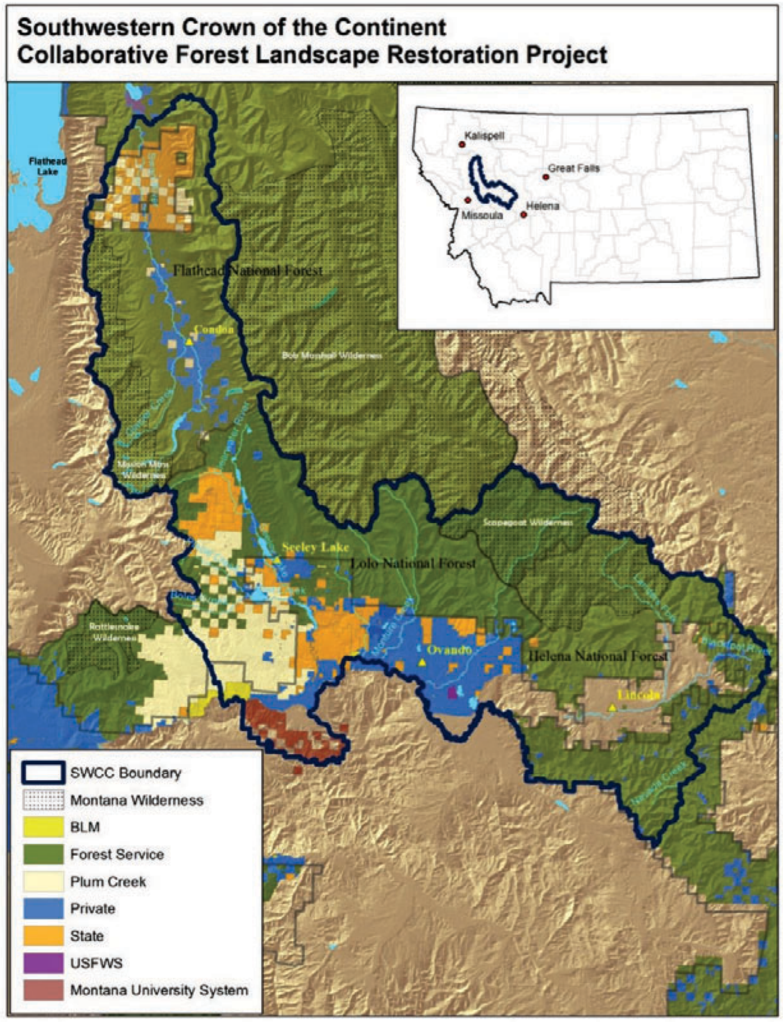

Figure 1. Public/ private pattern of land ownership within the 1.5 million acre SWCC CFLRP project. Nested scales of partnership and coordination are critical to the work of any conservation management project in the continental United States given the degree of jurisdictional fragmentation typically found across all large landscapes, including those that remain relatively intact ecologically. For example, note the checkerboard pattern of land ownership associated with the Montana Legacy Project (green squares), a project in which approximately 500 square miles of former commercial timberland is being transferred from the Plum Creek Timber Company to public ownership under the jurisdiction of the U.S. Forest Service and the State of Montana beginning in 2010. Map courtesy of Cory Davis.

Prior to 2010, the SWCC had identified a detailed list of ecological restoration needs across 1.48 million acres (600,000 hectares) of the SWCC region. Proposed restoration included 43,000 acres (18,600 hectares) of forest land, removal of 400 miles (650 kilometers) of roads, restoration treatments influencing 937 miles (1,500 kilometers) of streams, treatments to reduce erosion on ~650 miles (1,000 kilometers) of roads, upgrading of 150 stream-crossing structures, reduction of non-native distributions in area lakes and streams, and noxious weed treatments on 81,000 acres (33,000 hectares). This projects simultaneously create 170 full- and part-time jobs each year, and contribute $9.2 million annually in direct labor income to local communities in the southwest Crown (SWCC CFLRP proposal 2010; SWCC CFLRP landscape strategy 2010). Regional experts have worked to develop and implement the accompanying monitoring program required for the SWCC through collaborative "think tanks" on socioeconomics, aquatic ecosystems and fisheries, wildlife, and vegetation (a category that includes forest structure, noxious weeds, and fire) (SWCC CFLRP Annual Report 2012). In addition to the nested spatial scales of conservation work needed in the Anthropocene, the SWCC provides an excellent example of the nested temporal scales of planning and implementation required for landscape-scale projects; Figure 2 depicts the results of the SWCC's collaborative planning processes across the landscape for the decade-long project.

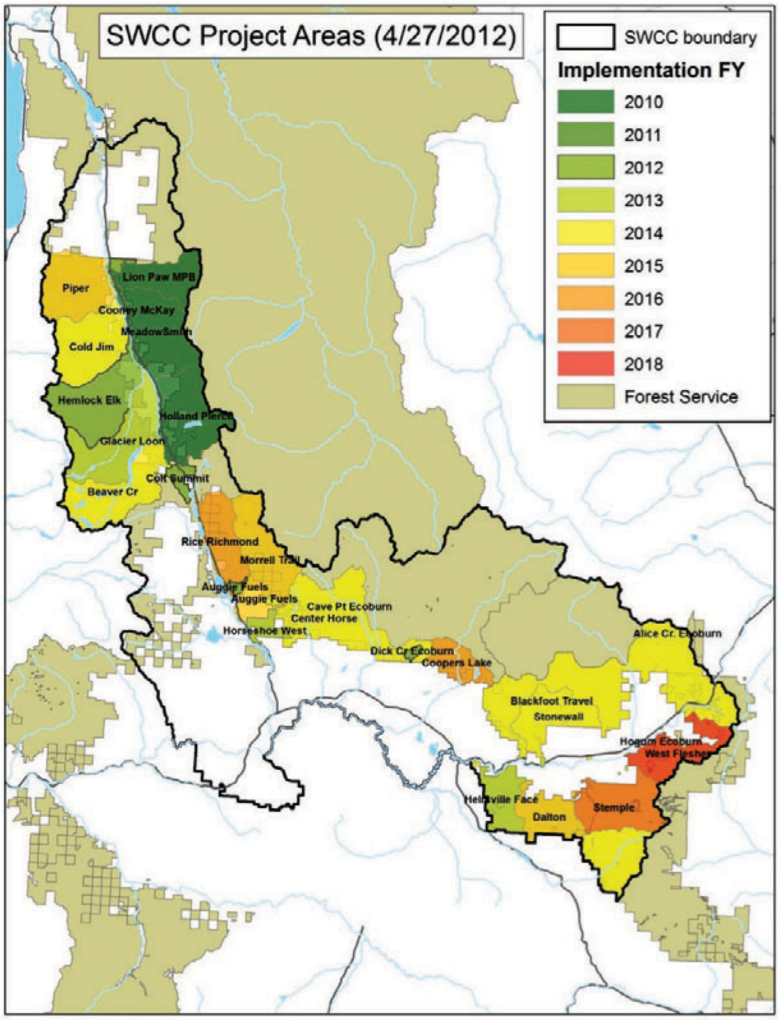

Figure 2. Map of SWCC CFLRP forest restoration projects depicted across space and time for the ten-year, large-landscape restoration project. The design and implementation of each project requires years of coordinated work across nested scales of partnership. Map courtesy of Cory Davis.

While the focus of "restoration" assumes management will attempt to return ecosystem composition, structure, and function to historical ranges of variability, we suggest here that ongoing changes in climate in the region challenge the notion that a return to historical range of variability is the best approach to conserving the ecological values. Climate change may exacerbate existing stressors and disturbance agents on the landscape (such as pine bark beetle outbreaks), while simultaneously acting as a powerful new environmental stressor by itself (Pederson and others 2010). Years of intensive research and monitoring in the Crown have greatly expanded our knowledge of the impacts of a warmer, drier climate thus far: disappearing glaciers, shallower snowpacks, more rain on snow events each winter, earlier peak snow runoff events in the spring, and longer annual summer droughts. These effects have contributed to longer, more severe wildfire seasons, the creation of more suitable habitat for pernicious noxious weed species (e.g., cheatgrass) and novel pathogens (e.g., West Nile virus) as well as range distribution shifts by numerous wildlife species (see summary by Bay and others 2010). Yet, these impacts are highly variable across 25 degrees of latitude and various local topographies that span elevational gradients of 1,000 to more than 3,000 meters (Prato and Fagre 2007), further complicating the design and implementation of management responses across the landscape.

COMING TO GRIPS WITH THE REALITIES OF LANDSCAPE-LEVEL WORK

Addressing restoration and climate adaptation challenges in the region requires explicitly dealing with the challenging issue of scale. Ecological processes operate across spatial scales where large scale patterns (e.g., climate regimes) govern small scale processes (e.g., seedling recruitment), while small scale patterns (e.g., stand-level structure of forest patches) also scale up to large scale processes (e.g., fire behavior and resulting emergent properties of landscape composition and arrangement, Hessburg and others 2013). Policy and management responses to coupled ecological pattern-processes span vast spatial scales as well (Table 1; Ban and others 2013). Understanding cross-scale patterns and mechanisms of linkages across spatial scales will be critical to sustain ecological systems in the Anthropocene. Given uncertainty surrounding the impacts of climate change across scales, how do policy makers and managers sustain ecological and social values? In the following sections we outline those approaches that we believe are needed to sustain ecological processes across scales through strategic and coordinated efforts to work across nested scales. When possible, we provide specific examples of ways the SWCC considers scale as it confronts challenges of forest management and restoration in the age of climate change.

Table 1. Examples of nested scales where key patterns and processes occur in ecological and socio-political realms. Understanding impacts of global changes at each scale and mechanisms that operate across scales is needed to sustain ecological services and conserve biodiversity in the Anthropocene.

Spatial scale	Area (hectares)	Ecological process example	Socio-political example
Global	51,000,000,000	Water, carbon, and energy cycling; global climate variability	G8 Global Summits on Climate Change and carbon emissions; geopolitical treaties and trade agreements
Bioregional	100,000,000	Long distance animal migrations, river basin hydrology, continental-scale climatic influences	River basin compacts, Canadian Boreal agreements, Landscape Conservation Cooperatives; Yellowstone to Yukon
Regional	1,000,000	Regional populations and genotypes of species	Forest Service Planning under new Planning Rule
Landscape	100,000	Habitat composition; contagious landscape processes (fire, insects, spread of invasive species); Large animal (e.g., grizzly bear) home ranges	Collaborative Forest Landscape Restoration Program
Watersheds	1,000	Hydrologic function; home range for small animals	Watershed Condition Class Framework
Stand-level	100	Local habitat for animal foraging and nesting; maintenance of tree diversity and local disturbance dynamics; seed dispersal	Local forest service districts and local restoration committees
Local-level	0.1	Regeneration niche; interactions between individuals (e.g., competition, mutualisms)	Contractor decisions and work; monitoring common stand exams; local restoration committees field trip visits

Work across nested scales of space and time

Working across scales requires an appreciation for different processes—both ecological and social—that operate at scales spanning orders of magnitude (Table 1). Managing ecosystem components with the best available understanding of interactions across scales will also be critical as climate change forces coupled patterns and processes at each scale. Project implementation and monitoring should consider various spatial scales that operate to sustain the things we value from nature (e.g., regenerating trees after disturbance and landscape composition and structure).

The Southwestern Crown of the Continent effort provides a concrete example of the necessity of collaborating and coordinating across nested scales to sustain ecological functions across geospatial scales. The SWCC continues to prototype much of the science and implementation for climate adaptation throughout the entire ecosystem (Figure 3). Consider, for example, the largest landscape-scale collaboratives in the region—Yellowstone to Yukon Conservation Initiative, the Great Northern Landscape Conservation Cooperative, and various Crown of the Continent coalitions. These groups generate much of the regional, scientific vision for sustained ecological functions across 25 latitudinal degrees of topographically-complex, mountainous ecosystems. They work collaboratively to establish and share data about the impacts of climate change and other stressors. Attributing phenomena to climate change impacts may only be detectable at regional scales (e.g., van Mantgem and others 2009). Regional monitoring programs—and their associated costs—may necessitate science consortia (e.g., Climate Science Centers) or national programs (e.g., National Phenology Network). Opportunities to attract and match funding are often highest at very large scales and most challenging at the smallest scales. Funding for the SWCC first came from the U.S. Department of Agriculture's Forest Service, but has since attracted financial support from the corresponding Department of Interior large landscape initiative, the Landscape Conservation Cooperatives, while private foundations have been enthusiastic about the opportunity to leverage their private funding with public funding. Altogether, reasons for coordinating and collaborating across nested geospatial scales abound, although appreciation and funding for this vital function is often lacking.

At the other end of the spectrum are those projects and groups operating at smaller geospatial scales than the SWCC (e.g., local restoration committees, the Montana Legacy Project, Forest Service Districts, and individual timber contractors). Despite the significant amounts of time and effort required to coordinate with each group, these collaborative efforts have turned out to be absolutely critical given that management control is highest at local scales. From stand-level treatments to district level project planning, this is the scale at which extremely detailed knowledge of the threats and opportunities for treatments exists, and at which managers subsequently implement treatments on the land or intervene to manage wildlife populations that range across both public and private lands.

In the SWCC, treatments are still designed as traditional Forest Service-led projects conducted within one of three Forest Service Districts. Project boundaries are typically ~250-2,500 acres (100 to 10,000 hectares) in size, though not all areas are treated in the larger project boundaries. Treatments are still typically applied to stands ranging in size from ~5-250 acres (20 to 100 hectares), and projects are still designed by agency specialists. However, collaborative input has become more influential in designing projects and their treatments. While projects are still designed with "stands" as the primary unit of treatment, placing treatments in the context of

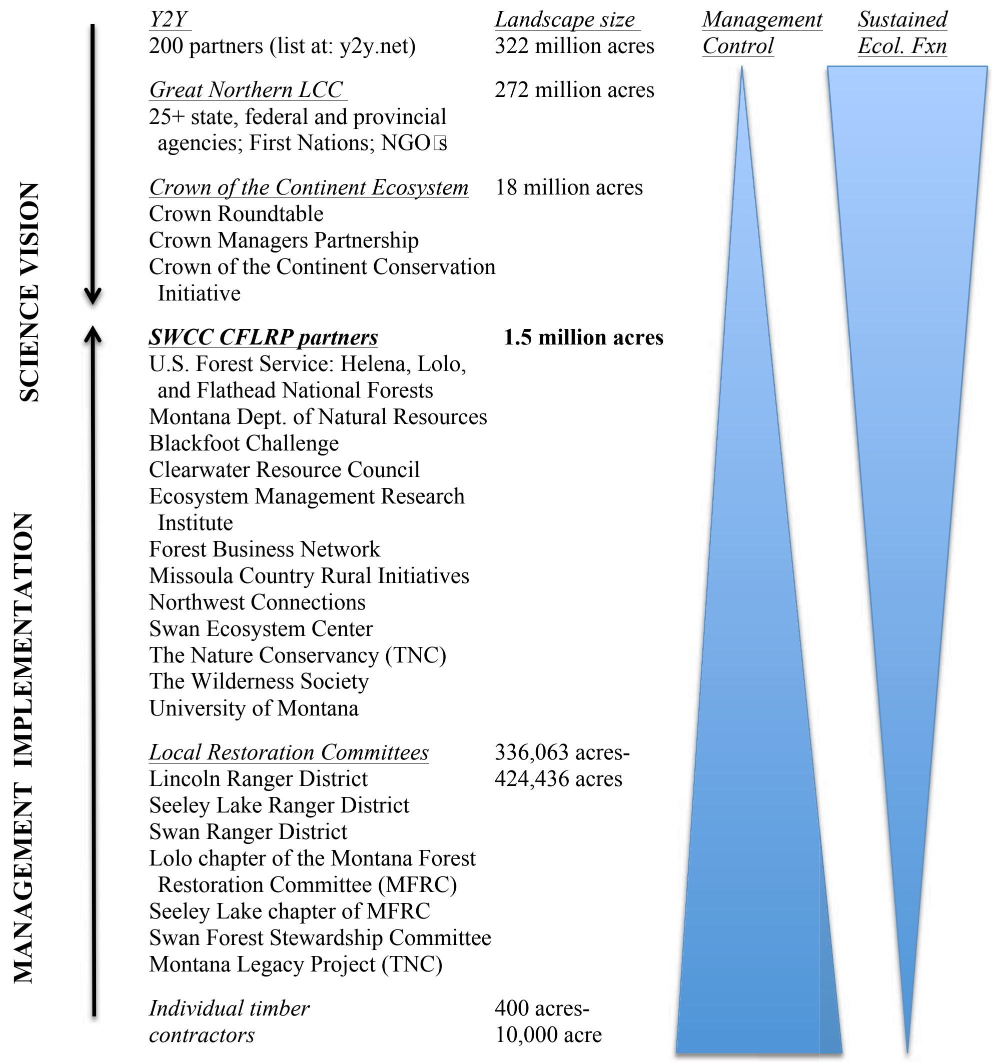

Figure 3. Levels of partnership and coordination required across nested geospatial and temporal scales for one large landscape project in Montana. The SWCC CFLRP provides a real-world example of the types of capacity and coordination required to successfully manage large landscapes in the Anthropocene, given that management control is highest at small geospatial scales, while sustained ecological function and connectivity are most effectively addressed at extremely large geospatial scales.

landscape processes is increasingly applied. Landscape modeling tools have provided both an idea of landscape characteristics within a historical range of variability as well as predicted landscape level effect of treatments on fire behavior and resulting landscape composition and arrangement. More work is needed to connect scales from <250 acres (100 hectare) patterns in stands to processes (e.g., fire, wildlife movement) operating at much larger (e.g., 2,500 acre or 10,000 hectares) scales, but the collaborative continually revisits the question about landscape function, rather than mere stand-level structure and composition.

Consideration of nested spatial scales may help move forest management beyond stands, but climate change also requires a consideration of temporal scales beyond traditional harvest rotation and schedules. A consideration of the “lifespans of treatments” now being implemented similarly should be factored into economic and ecological decisions, including plans for adjusting management decisions following monitoring and evaluation of data. Re-entry into stands and landscapes may be required to sustain initial restoration and adaptation investments. Implementation of adaptive management strategies usually implicitly considers time, because *future* decisions should be adjusted as new information and understanding become available. Global changes require that actions and policies implemented today consider an uncertain future marked by altered climatic regimes and shifting species ranges, while anticipating ecological surprises (Williams and Jackson 2007). Perhaps most importantly, it is becoming apparent that some 'work' may be best addressed at very large scales (e.g., long-term planning, development of scientific datasets or tools for assessment of connectivity, monitoring of climate change impacts, funding) while other 'work' may be best coordinated at much more local scales (e.g., prioritization of on-the-ground projects, decisions about which scientific datasets and tools to use in informing project development, etc.).

Work across jurisdictional boundaries

As described above, conservation biologists have understood for decades that protected areas with boundaries may not sustain biodiversity because (1) global changes impact "protected" areas, and (2) populations of animals and plants need room to move and maintain genetic diversity. Addressing the second issue by working across land management jurisdictions remains one of the most challenging elements of landscape conservation. Lands adjacent to conservation reserves may enhance core regions for sustaining biodiversity or serve as regions of connectivity, especially as climate change shifts the geographic distribution of habitat.

Ecologically compatible land use approaches across patterns of land ownership have been labeled 'matrix conservation' (Noss 1983). In other words, matrix conservation considers protected areas to be embedded in a landscape matrix of land uses. UNESCO's Man and Biosphere Program recognized this issue beginning in the early 1970s by advancing the implementation of landscape-scale conservation with ecologically intact core areas surrounded by gradients of increasing human use buffer zones. Noss and Cooperrider (1994) and Soulé and Terborgh (1999) improved on this design by advancing the concept of ecological connectivity or corridors between core protected areas—thus creating an interconnected ecological network of protected areas.

Ecological connectivity has become a major element of large-scale landscape conservation and is defined as the degree to which the landscape facilitates movement processes across habitat patches on multiple spatiotemporal scales (Taylor and others 1993). Over individual lifespans, daily and seasonal movements among patches ensure access to required resources (Dingle 1996); over generations, dispersal maintains metapopulation structure and provides rescue effects from population extinction (Harrison 1994); and, over multiple generations, long range dispersal sustains genetic diversity and the ability to respond to long-term trends, including climate change. Connectivity is now a major element in many revised State Wildlife Plans, the Western Governors' Association Wildlife Corridors initiative, the U.S. Forest Service's Planning Rule and the new national Fish, Wildlife, and Plans Climate Adaptation Strategy.

Connectivity is an ecological characteristic of landscapes, but achieving connectivity requires that conservation scientists and practitioners work across political boundaries. Connecting people to connect landscapes is the only approach that can sustain conservation outcomes through the vagaries of political and fiscal cycles. Conservation across jurisdictions requires time-consuming, facilitated collaboration processes to bring key conservation stakeholder interests together. For instance, the Yellowstone to Yukon Conservation Initiative began as a bottom-up non-governmental organizational effort to connect conservation efforts with similar goals across an ecologically defined and relatively intact region. Today, there are nearly a dozen Crown of the Continent-wide ecosystem-scale initiatives that span the U.S.-Canada border and bring various stakeholder groups together from tribal nations, government, private land owners, businesses, watershed groups, local communities, universities, environmental educators and the non-profit conservation community.

A landscape-scale network of all the ecosystem-wide initiatives, known as the Roundtable of the Crown of the Continent (www.crownroundtable.org), was established in 2007. The Roundtable has created an informal governance structure based on a charter of common principles and shared goals that establishes a framework for multijurisdictional landscape conservation and land management collaboration; its purpose is to facilitate multi-jurisdictional, large scale, climate adaptation implementation across all major land ownership communities across the entire ecosystem.

Even at the smaller nested scale of the SWCC, cross-jurisdictional work is required. Ecological (e.g., fire and animal movement) and social (e.g., fire management, recreation) processes operate across diverse ownership boundaries in the region (Figure 3). Communication and collaboration among diverse jurisdictions from federal agencies to state lands to local land owners can be a challenge, but also offers great opportunity. Partnerships between groups, facilitated by local conservation groups, create the kind of information exchange needed for land stewards of various affiliations to respond to ecological impacts as climate changes (Figure 4; see also Wyborn and Bixler 2013 for another regional example of partnerships across scales). Without cross-jurisdictional partners, social responses to conservation challenges and threats across spatial scales would be stymied.

Work across cultural and social ideologies

Moving beyond historical ideological and social barriers is a necessity for effective conservation in the Anthropocene. The old rhetoric of "us versus them" should give way to embracing uncertainty and humility, trust building, and development of visions based on common values. In the SWCC, diverse stakeholders co-authored a landscape vision and proposal that articulates shared ecological, economic, and social values among diverse groups including conservationists, scientists, and loggers (see, for example, the SWCC charter: http://www.swcrown.org/committee/committee-charters). Achieving consensus on every issue has its challenges. However, time spent articulating desired outcomes builds trust and establishes common ground among individuals representing diverse interests.

We have found that two activities have been of particular use in building the trust required to work across cultural and social ideologies for SWCC partners: first, the group agreed to use a 'zone of agreement' developed by the Montana Forest Restoration Committee to guide forest restoration projects in western Montana from 2007 onward (http://www.montanarestoration.org/restoration-principles); this framework allowed individuals, organizations and agencies alike to work within the zone of agreement rather than having to evaluate every conversation, proposed

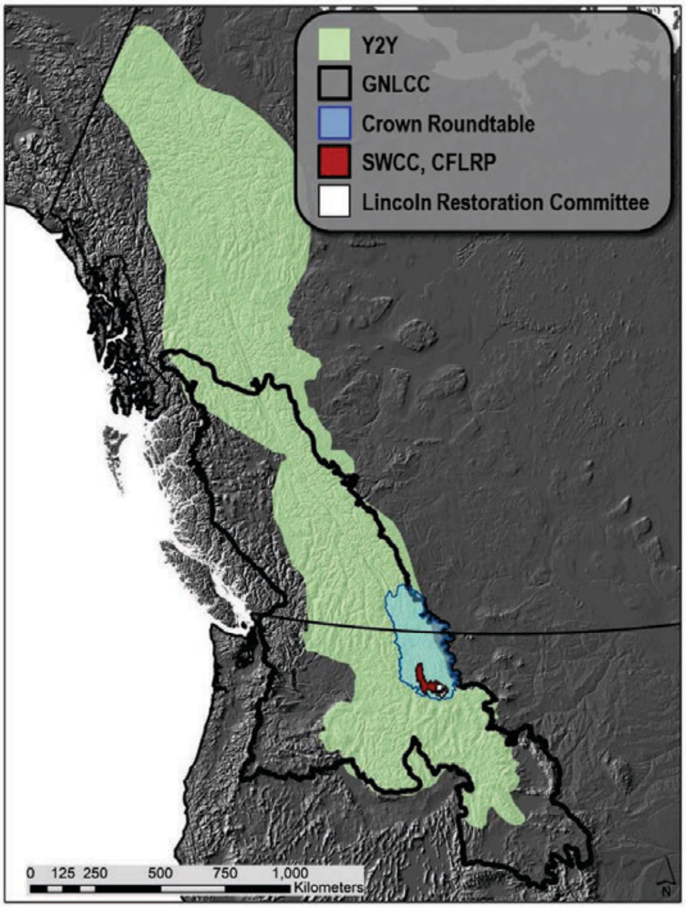

Figure 4. Map illustrating the geospatial scales associated across vertical nested conservation scales. Yellowstone to Yukon (Y2Y) connects conservation planning across bioregions. The Great Northern Landscape Conservation Cooperative (GNLCC) networks federal agencies and non-profits to handle complex conservation challenges across large regions. The Roundtable of the Crown of the Continent coordinates all stakeholders in the region. The Southwestern Crown of the Continent works to coordinate collaborative design and monitoring of landscape forest restoration. Nested with the SWCC, the local Lincoln Restoration Committee helps design on-the-ground projects, including use of experimental design of treatments as a way of implementing a science-based portfolio approach to restoration forest planning.

action, etc. against their own perspectives, missions or mandates. Rather, all of our missions and mandates were well represented within the zone of agreement, freeing partners to focus on the work at hand. Second, the partners have spent significant amounts of time out on the ground discussing proposed and completed restoration projects over the years, which has led to extremely honest and productive conversations that are firmly rooted in our values for the land and its resident wildlife: we recommend this approach whenever possible.

Reducing fuels in the wildland urban interface to reduce the risk of unmanageable crown fires near communities, sustaining populations of iconic wildlife species, and restoring landscape function and fire regimes are characters of the land that most individuals and groups agree are important to sustain or restore. The specifics on *how* to accomplish these goals and *what* science to rely on—especially when there is competing science—are sources of significant discussions and uncertainty. However, a common landscape vision that builds trust, embraces uncertainty, and moves beyond old ideological tensions has created an atmosphere that facilitates experimentation.

Work across scientific disciplines and industries

Collaboration across scientific disciplines is increasingly recognized as important to understanding complex socio-ecological systems (e.g., National Science Foundation's Coupled Human Natural Systems Program; Resilience Alliance). This cross-disciplinary science should not be limited to academe, but can also be used as a framework for implementation and monitoring of collaborative forestry projects. In the SWCC, we have developed a multidisciplinary monitoring program that bridges economic, social, and ecological disciplines.

The monitoring program consists of scientists and management partners that together discuss and plan monitoring to address ecological and social questions. For instance, SWCC monitoring efforts collect data on vegetation responses to treatments in terms of crown fire risk, understory vegetation, and soil impacts, and will couple these ecological responses with economic and social questions. How much economic return is generated from projects; what are the perceptions of the collaborative work; and will reduced crown fire risk equate to less fire-fighting costs in the future? The Forest Landscape Restoration Act of 2009 calls for a coupled socio-ecological perspective. In response, the SWCC monitoring program has been designed to address diverse, collaboratively-generated questions on ecological, economic, and social fronts (see http://www.swcrown.org for annual SWCC project and monitoring program reports as examples).

Adopt a portfolio approach that uses experimental design to learn and adapt more rapidly

Uncertain impacts of climate change require new approaches and strategies. A nested portfolio approach using elements of experimental design continues to build trust, sets up resilient landscapes by focusing on diversity and heterogeneity at various spatial scales, and may be a way of hedging against uncertainty (see below; Millar and others 2007). The value of this approach is that it (1) is science-based and will allow management adjustments to be conducted with strong inference and understanding; (2) spreads risk by not doing the same thing everywhere; (3) honors various perspectives and empowers collaborative stakeholders; (4) confronts uncertainty head-on through the use of multiple treatments or experimentations; and (5) embraces uncertainty through humility. In the SWCC, we have designed two projects with a rigorous approach to experimental design (Figure 5; Larson and others 2013b).

Using a robust experimental design, several projects of the SWCC will be implemented by turning diverse management perspectives into replicated treatments (Larson and others 2013b). For instance, the best method for restoring and sustaining forested values in lodgepole pine (*Pinus contorta*) landscapes where mountain pine beetle has caused significant mortality is a controversial topic. Lodgepole pine forests are typically considered to have been maintained historically by stand replacing fires. Whether mountain pine beetle, climate change, fire exclusion, or their convergence have altered landscape structure and composition, putting ecological and social values at risk of regime shift-inducing fires, remains an active area of research and controversy. Competing science and social perspectives have suggested that lodgepole stands and landscapes are either a very low or a very high priority for active management to restore structure and function. In situations of high scientific and social uncertainty, the SWCC and local restoration committee have begun designing a subset of projects as replicated experiments where various management options are viewed as experimental treatments (Figure 5).

Experimental approaches using stands and even small watersheds to replicate various treatments and monitor ecological responses helped move ecology from a descriptive to an experimental science (Bormann and Likens 1979). Additionally, nesting experimental applications of a

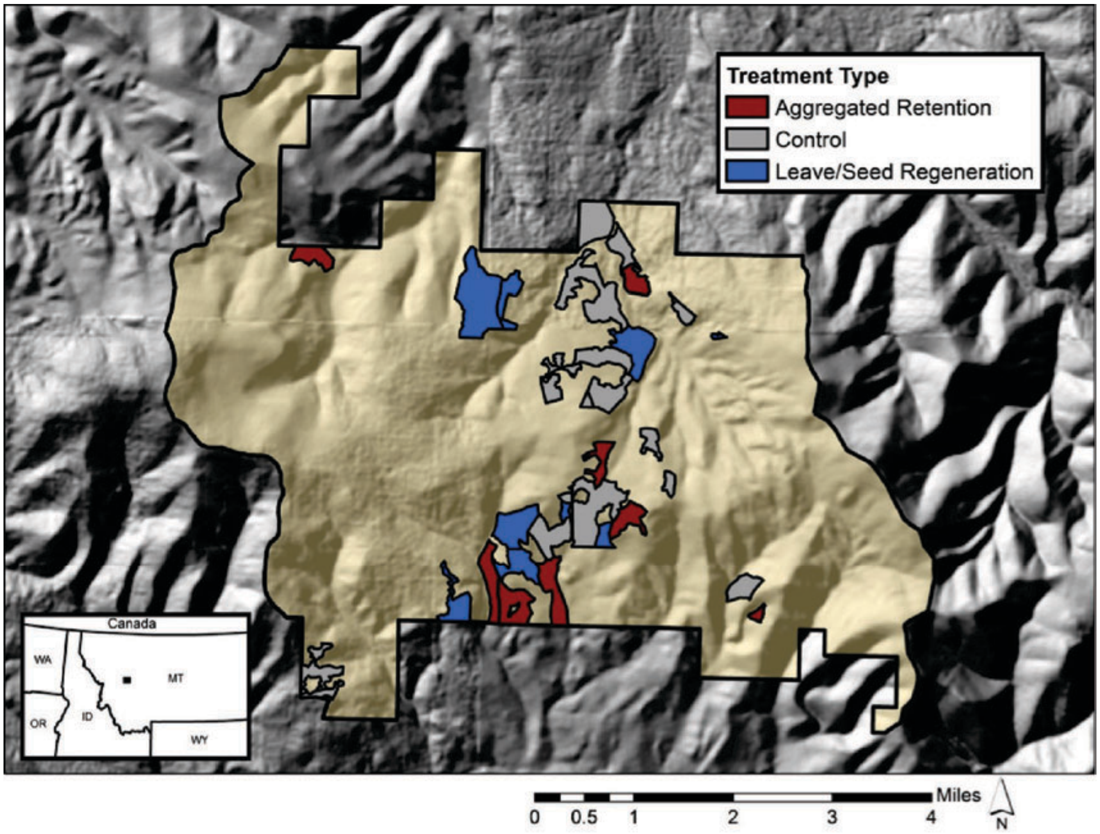

Figure 5. Map of the Dalton Mountain project area of the SWCC CFLRP where elements of experimental design (e.g., use of untreated controls, replication, and unbiased assignment of treatments) were collaboratively incorporated into treatment plans for 30 stands of lodgepole pine-mixed conifer forests. Figure courtesy of Larson and others, 2013.

portfolio of approaches can be accomplished across spatial scales ranging from 0.1 ha to entire landscapes (Figure 6), while simultaneously accommodating the legal framework associated with different land designations (e.g., Wilderness areas, roadless areas, etc.). This approach is consistent with a portfolio approach to managing climate risk (sensu Aplet and Gallo 2012). Such an approach would consider designated wilderness areas "observation zones" where managers can both accept and learn from climate-induced impacts. "Restoration zones" are areas managers resist climate-induced changes by working to restore resilience to degraded lands in the face of climate change. Existing lands administered by federal, state, and local agencies outside of wilderness would be good candidates for assignment to the restoration zone. Finally "innovation zones" would allow managers to attempt to facilitate transition to novel ecosystems given expectations that these ecosystems will undergo large scale, climate induced regime shifts (Aplet and Gallo 2012). The SWCC CFLRP project, for example, offers the opportunity to incorporate two of these three portfolio approaches at the landscape scale: the Bob Marshall Wilderness (in red, Figure 6 part C) is an "observation" zone in which managers are legally required (by virtue of the Wilderness land designation) to manage this area minimally, while the SWCC CFLRP project area (outlined in black, Figure 6 part C) is a "restoration" zone in which substantial intervention by managers could help reverse environmental degradation associated with a range of historic stressors and land use—thus sustaining key ecological values into the future.

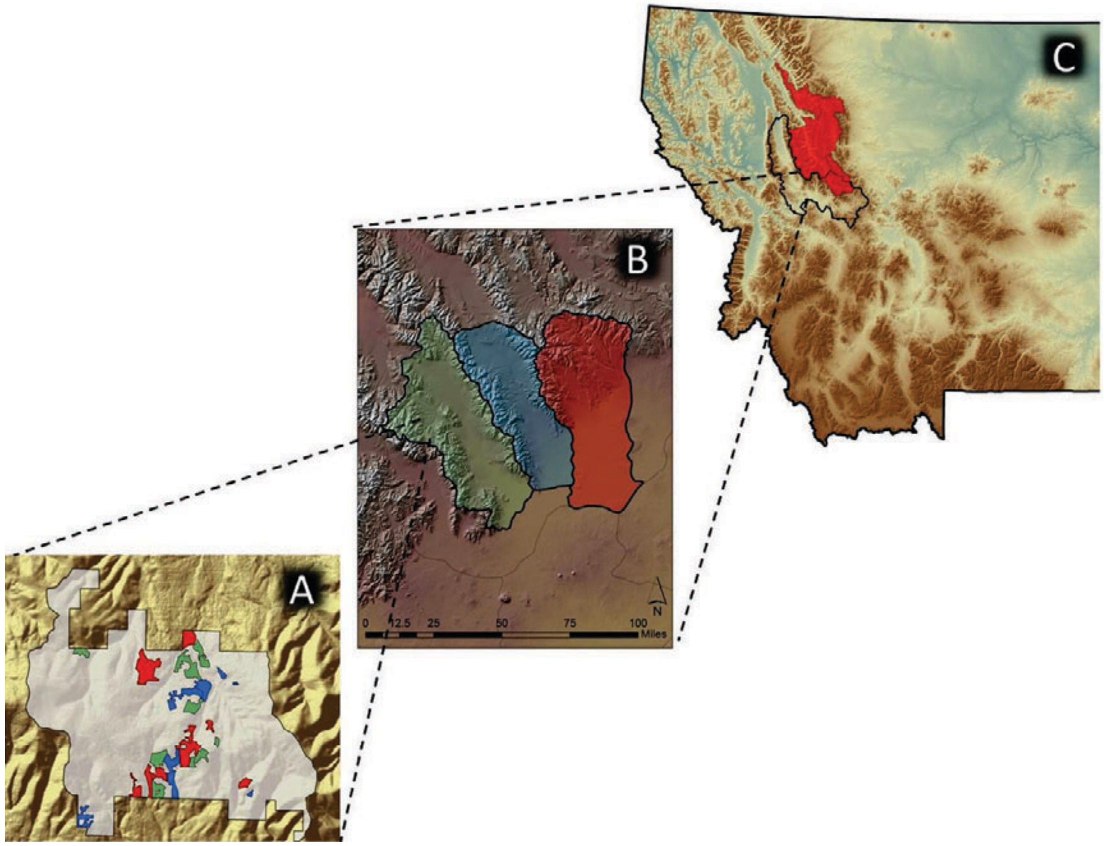

Figure 6. A nested experimental approach to applying various treatment alternatives could be applied from stand scales (A), to watersheds (B), and landscapes (C). Each colored zone within a panel represents an approach or treatment intended to meet objectives at various scales with an eye toward the next highest and lowest spatial scales, and is consistent with a portfolio approach to managing climate risk (sensu Aplet and Gallo, 2012). That is, wilderness areas comprise "observation zones" where managers can both accept and learn from climate-induced impacts; "restoration zones" are areas where managers resist climate-induced changes by working to restore resilience to degraded lands in the face of climate change; and "innovation zones" would allow managers to attempt to facilitate transition to novel ecosystems given expectations that these ecosystems will undergo large scale, climate induced regime shifts (Aplet and Gallo, 2012). The SWCC CFLRP project, for example, offers the opportunity to incorporate two of these three portfolio approaches at the landscape scale: the Bob Marshall Wilderness (in red, Figure 6C) is an "observation" zone in which managers are legally required (by virtue of the Wilderness land designation) to manage this area minimally, while the SWCC CFLRP project area (outlined in black, Figure 6C) is a "restoration" zone in which substantial intervention by managers could help reverse environmental degradation associated with a range of historic stressors and land use.

Nesting experimental treatments of stands (Figure 6 part A) within treated watersheds (Figure 6 part B) and landscapes (Figure 6 part C) could help create a resilient landscape by implementing diverse approaches across scales while simultaneously creating a landscape set up to contribute to our understanding of best approaches in the Anthropocene. While not yet intentionally implemented by the SWCC, CFLRP projects offer a rare opportunity for pairing treated watersheds and landscapes with untreated controls.

Continue to emphasize role of protected lands and wilderness core areas as a viable conservation strategy

Untreated lands—where nature is left untrammeled—have come under increasing fire in recent years, as pernicious threats of global change (altered climate, invasive species, altered nutrient loadings, acidification, etc.) have impacted ecosystems once regarded as pristine. A hands-off approach to ecosystem management was once held as the preeminent conservation strategy. In the Anthropocene, it may be important for managers to intervene at the expense of untrammeled lands, but for the benefit of sustaining ecological patterns and processes upon which we depend. Does this new era called the Anthropocene render those reserves where nature is left untrammeled passé?

Here, we join Caro and others (in press, this volume) in arguing that wilderness and protected lands still constitute a viable conservation strategy in an age of shifting climate, as unmanaged wild lands serve many ecological and social purposes in rapidly changing conditions. Wilderness lands provide a benchmark by which to assess managed lands and various management strategies implemented in the nested portfolio approach described above. In fact, untreated control landscapes of ~250,000 acres (100,000 hectares) may be regarded as part of the experimental portfolio approach to climate adaptation project design. Uninterrupted or re-established fire regimes and top predator trophic interactions exist primarily within large un-managed wild lands, and the presence of large predators on the land is strongly correlated with significantly higher levels of biodiversity in ecosystems around the world (Stolzenburg 2009; Terborgh and Estes 2010). Wilderness therefore remains extremely important to managing in the Anthropocene.

In the SWCC, the unlogged forests in the Bob Marshall Wilderness where fire regimes have been re-established in recent years provide a compelling case study of how untrammeled (or untreated) "control" lands can provide insights into appropriate restoration strategies in a managed landscape (Figure 6 part C). Fire has returned to ponderosa pine, western larch, and mixed conifer forests of gentle terraces above the South Fork of the Flathead River. Effects of fire in terms of mortality, recruitment and composition of new trees, fuel loadings, spatial arrangement of tree clumps and gaps, and woody debris loads are currently being studied. These data indicate that some forest types may be more resilient to re-established fire than once perceived (Larson and others 2013a), while also providing insights into appropriate restoration treatments that could mimic nature's patterns.

Embracing diversity and heterogeneity at multiple scales to sustain resilience

Sustaining nature's parts and processes in the Anthropocene requires maintaining biological diversity across life's hierarchy of organization. Growing numbers of studies link ecological function across scales of biodiversity from genetic diversity (e.g., Crutsinger and others 2006), to heterogeneity in the spatial arrangement of organisms (Larson and Churchill 2012), to landscape heterogeneity within and among ecosystems (Turner and others 2013). Therefore, to sustain these processes requires maintaining sufficient biological diversity across scales and levels of biological organization.

Biophysical diversity sets the stage for ecosystem and species diversity (Beier and Brost 2010), which occurs at various spatial scales (from diverse climatic regimes and landforms within and among continents to local edaphic and topographic effects). Local and landscape processes, such as species interactions and disturbance, further govern habitat and species diversity across more local scales. Understanding the patterns and processes that give rise to and sustain species diversity across spatial scales has been a cornerstone of ecology for over a century and remains an important research theme of the science. Shifting climatic regimes, altered atmospheric chemistry, and introduced species may profoundly influence patterns of biodiversity distributions and ecosystem function. Basic understanding of the mechanisms that govern distributions and abundances of species and patterns of biodiversity should still provide important insights into best conservation approaches to sustain biological diversity—in all its forms—in the Anthropocene.

NETWORKED SCIENCE AND GOVERNANCE ACROSS SCALES

The benefits of large landscape conservation lie within its inspirational vision and contextual management perspective, but these are countered by the realities of on-the-ground practice and socio-political constraints. The challenge of large landscape conservation is marrying the scale of how nature works with the scale of human decision making (Table 1). Landscapes are shaped by the decisions of multiple stakeholders. With this in mind, efforts to engage local stakeholders in landscape efforts and connect them through nested scales of conservation decision making and action are essential but often neglected in conservation investments. Similar to ecological trophic pyramids, there is a parallel land use decision making hierarchy in the United States (see Figure 7). Successful large landscape efforts need vertically integrated governance structures that link the scales of human decision making. Social agreement on shared goals and operating guidance is an essential element of landscape governance, as discussed in the SWCC example.

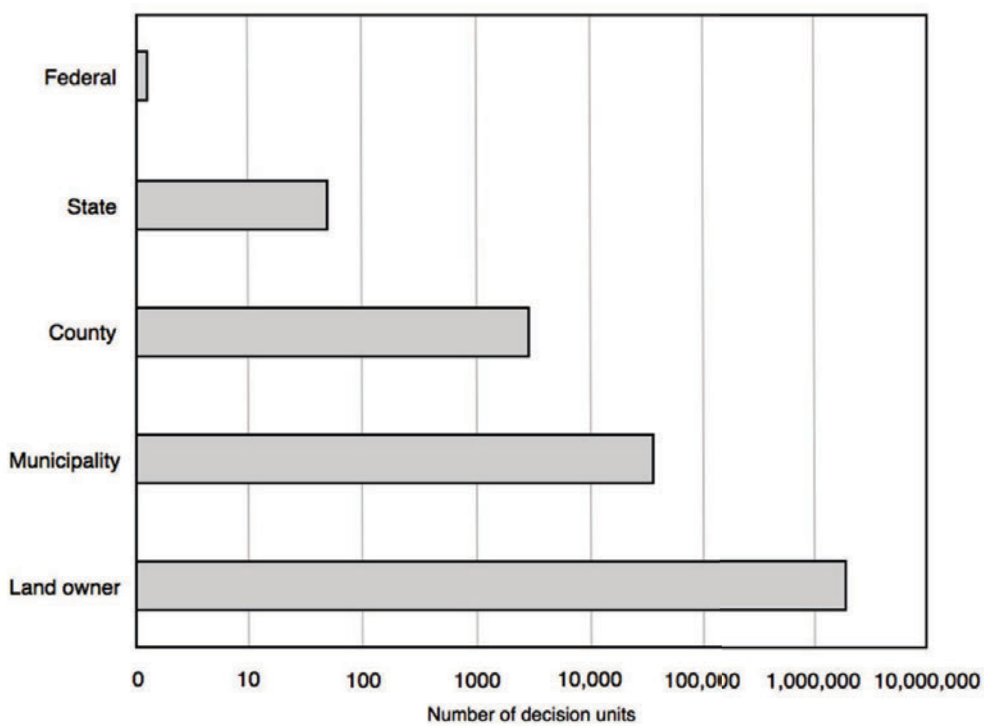

Figure 7. Land use decision-making hierarchy in the United States. This shows the number of jurisdictions (decision making units) with legal authority for making local land use decisions. Land owner is the number of large acreage agricultural land owners, a reasonable approximation of the potential number of land use decisions in the United States, which assumes that agricultural conversion is the primary form of land use change in the U.S. (from Theobald and others 2000).

There is an opportunity to bridge societal organizational scale with ecological scale through emerging network governance models. Equally so, information to assist large scale management efforts can be supported through networked science and monitoring approaches. If one critical goal of large landscape conservation is conserving ecological processes, the human response is similarly process oriented. Wise investments in stakeholder collaboration, trust building and connective organizational/community capacity will achieve this cooperative future. If information is the currency of social action, then the science community needs to engage stakeholders in research and monitoring from project inception. The technology and facilitative skill sets exist to link people and communities at large ecological scales. These collaborative efforts require long term vigilance and incentives for cooperative human action. The opportunity to establish long term conservation finance mechanisms to serve these enduring collaborative efforts have yet to be realized. Resilience funding mechanisms, similar to endowed conservation trusts, could support social engagement in large landscape conservation and leverage private and other public resources in order to sustain landscape efforts over the next century or longer.

CONCLUSIONS AND RECOMMENDATIONS

Large landscape conservation is an emerging approach to address large scale impacts to the ecological integrity of the planet. Conservation within a landscape context sustains ecological processes across an array of land jurisdictions and helps to align diverse land management approaches so that ecosystem benefits and services are optimized. All land has ecological potential depending on how it is managed. Restoration practice is a key element of resilient land management. Wilderness and protected areas enhance the resilience potential of lands, especially in the face of climate change. Like some of our other colleagues in this volume (Caro and others in press), we argue that protected lands and wilderness areas continue to constitute an important conservation strategy in an era of shifting climate.

"How much is enough?" is a question that has vexed conservationists since the beginning of the modern conservation era. This question has little meaning in the Anthropocene as the planet edges towards an ecological regime shift. Ecological processes that sustain nature and humanity are dependent on functional ecology and the species interactions they depend on. The planet is now the scale of consideration and planning, and the solutions need to mirror the global impact of humanity.

Large landscape conservation requires local societal efforts to reach toward management scales that are novel and often challenging. While vision may guide these large scale efforts, social glue is required to maintain and cement them over time. New approaches to conservation need to be prototyped. In the Southwestern Crown of the Continent Ecosystem, a 1.5 million acre landscape within the much larger Yellowstone to Yukon region, we are prototyping such an approach. While relatively young in its inception, the Southwestern Crown of the Continent Collaborative is testing the following elements of large landscape conservation:

First, large landscape conservation is an approach nested within larger and smaller scales of science and implementation. Vertical integration of scales of action is needed and requires intensive work to connect individuals, institutions, and resources to perform this function. All land has ecological potential, even though the land has mixed ownership. For instance, the

Southwestern Crown of the Continent Collaborative is represented at larger scales of action through the Roundtable of the Crown of the Continent, the much larger U.S. Great Northern Landscape Cooperative, and the even larger Yellowstone to Yukon Conservation Initiative. At the same time, the SWCC embodies smaller scale initiatives such as the Blackfoot Challenge, three US Forest Service Districts and various local communities.

Second, large landscape conservation is a fusion of the spatial and temporal aspects of ecology and those of human society. Multijurisdictional facilitated processes are the new norm for conservation. Collaborative approaches to science and management that include stakeholder engagement and participation is essential. Professional conservation approaches need to empower stakeholders as conservation practitioner partners. Mechanisms that foster societal trust are essential to the success of these efforts.

Third, large landscape conservation will have a broad array of governance designs ranging from formal to informal approaches. The work in the Crown of the Continent suggests the role of network governance among stakeholder groups. The Southwestern Crown of the Continent Collaborative has developed a multi-stakeholder project implementation roundtable structure. A larger Roundtable structure exists in the Crown of the Continent to bring all ecosystem-wide efforts and stakeholders together. While a common set of principles and an organizing charter serve as collaborative touchstones for this coordination, these roundtable efforts are an example of network governance.

And finally, large landscape conservation science and monitoring integrates formal and informal information processes from rigorous experimental methods to traditional ecological knowledge. Interdisciplinary science is an essential element of this work. Science and monitoring should embrace a networked science approach where science, monitoring, metadata and local information is handled in a transparent and accessible fashion. This includes enlisting all stakeholders in the practice of science and monitoring.

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