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Applying Climate Adaptation Concepts to the Landscape Scale: Examples from the Sierra and Stanislaus National Forests

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Introduction

In 2010, The Wilderness Society produced a report exploring the challenge of climate change adaptation planning on the national forests of the Sierra Nevada (Aplet et al. 2010). In that report, we argued that the advent of climate change requires a new approach to national forest management. The prospect of climate-driven increases in invasive species, altered disturbance regimes, decreased snow cover, altered phenologies of tightly linked species, and the break-up of long-established plant and animal communities all threaten the future productivity and diversity of ecosystems and the goods and services we expect from them. Under such conditions, the sustainability of ecosystems cannot be assumed, and the focus of planning must change from the scheduling of natural resource outputs to the management of risk to ecosystem diversity and productivity from climate change.

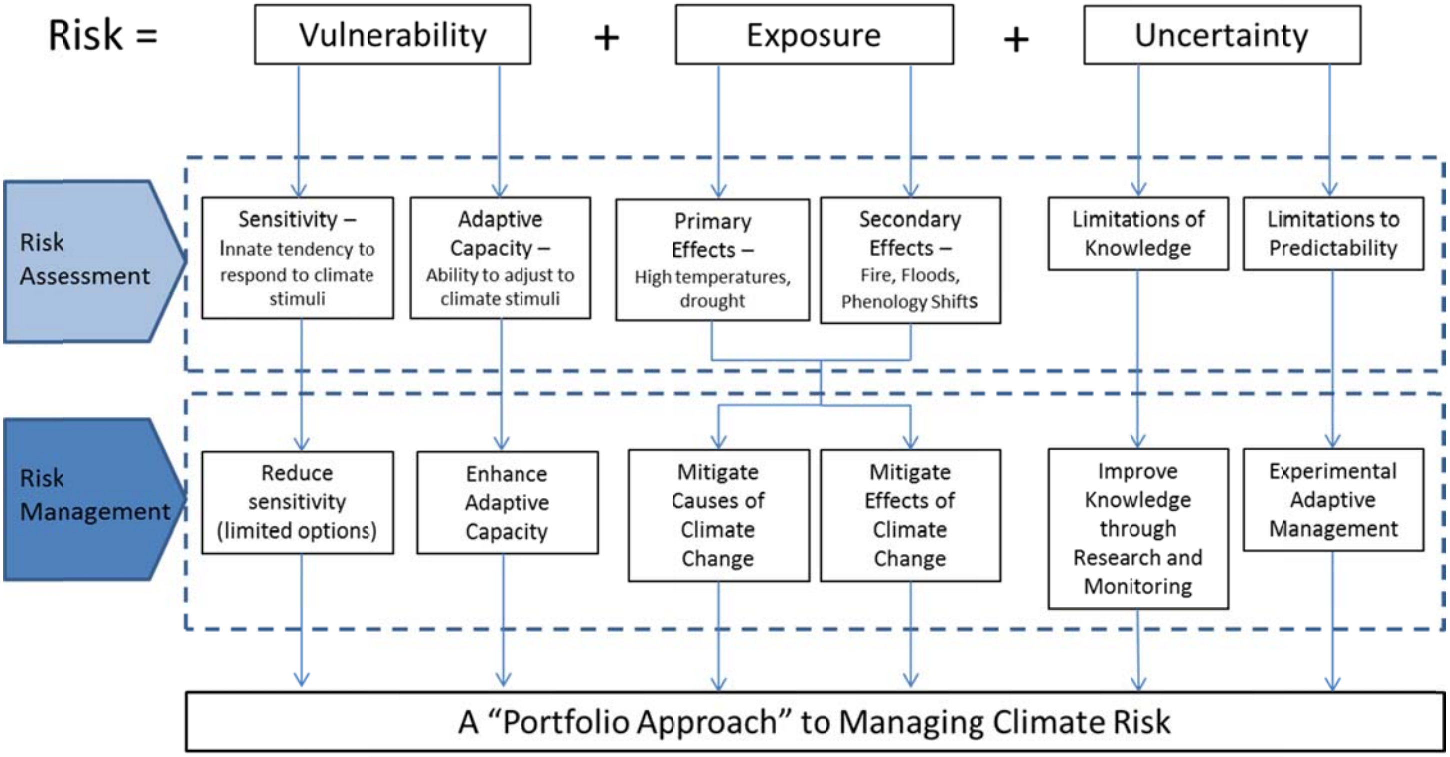
We argue further that risk can be managed by breaking it down into its fundamental components of vulnerability, exposure, and uncertainty, assessing the status of each, and developing strategies to reduce them (Figure 1). Vulnerability refers to the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change and is affected by both the innate sensitivity, or intolerance to climate change, of system components (*e.g.,* species) and their capacity to adapt through changes in behavior (*e.g.,* migration) or genetics (*i.e.,* evolution). Exposure refers to both the direct effects of climate change (*e.g.,* average temperature, extreme events, frequency, intensity, and duration of drought) and the indirect effects (*e.g.,* fire activity, flooding, phenological shifts). Uncertainty is a general term encompassing both the known variation in probabilities of anticipated events and the limitations to our knowledge that derive from poor data, inadequate science, and unforeseen circumstances.

The first step in the risk management process is to identify “key vulnerabilities,” the term used by the IPCC (2007) to describe the specific focal elements (*e.g.,* species and habitats) of the ecosystem that will be emphasized in the assessment. Key vulnerabilities possess characteristics that make them especially worthy of management attention: susceptibility (affected by such qualities as rarity, longevity, isolation, dependence on special habitats, and sensitivity to climate-driven disturbance), value to the public, availability of information, and influence on the ecosystem. An open public process should be used in the identification of key vulnerabilities, as throughout the risk assessment and development of management strategies.

The next step is to assess the vulnerability, exposure, and uncertainty associated with each key *vulnerability*. This will involve assembling the best available science on the sensitivity and adaptive capacity of the species and ecosystem elements identified as key vulnerabilities, projecting likely (or evaluating scenarios of) climate change and its effects, and explicitly investigating sources of uncertainty, including limitations of data and critical researchable questions (Figure 1).

Managing to reduce vulnerability will require the development of strategies to reduce the sensitivity of species to climate change by protecting them from environmental stressors (*e.g.,* habitat loss and degradation, noise, pollution) through the establishment of reserves protected from the influence of those stressors, by managing human behavior and recreational use (*e.g.,* ORVs), and by restoring the quality of habitat and enhancing the condition of vulnerable elements (*e.g.,* old growth). Vulnerability can also be reduced by enhancing the ability of vulnerable elements to adapt to climate change by preserving and restoring habitat connectivity, by promoting the diversity of genes, species, and landscapes, and, where species are blocked from moving in response to climate change, by helping species transcend barriers to movement.

Figure 1. A Framework for Adaptive Management of Climate Risk



Reducing exposure requires both mitigating carbon emissions and reducing exposure to the effects of climate change. Mitigation can be achieved by protecting and enhancing carbon storage in wildlands and reducing activities that add carbon to the atmosphere. In some cases, short-term increases in carbon release (*e.g.,* from prescribed fire) may be necessary to achieve long-term increases in carbon storage (*e.g.,* old growth resilience to fire). The first step is to assess the status of ecosystem carbon stores and sinks and understand what drives changes in those systems. Next, greenhouse gas implications of traditional resource management activities, such as logging, energy development, and transportation and recreation, must be understood. Last, steps must be taken to reduce emissions caused by such activities by eliminating forest conversion, reducing energy development and the use of fossil fuels, and restoring low-severity fire. In addition to mitigating greenhouse gas emissions, exposure can be reduced by addressing the effects of climate change through activities such as watershed restoration, fuel reduction near communities, mitigating disturbances that favor invasive species, and the protection of climate refugia.

Uncertainty can be reduced by enhancing our understanding of ecosystems and climate dynamics. One of the simplest ways to improve understanding is to increase knowledge of current conditions and the effects of management through comprehensive monitoring. In addition, managers need to encourage and facilitate research. Adaptive management combines monitoring and experimentation to increase the speed of learning. Where unknowns cannot be overcome in time, scenario planning can be used to explore wise responses to a variety of possible future conditions.

Finally, learning can be enhanced by experimenting with different approaches on different parts of the landscape. In some places, restoration should dominate, and the emphasis should be on sustaining ecosystems and all their parts. In other places, new, creative approaches to building ecosystem resilience in the face of climate change must be tried, albeit with great care to avoid unintended consequences. In still other places, we will simply want to observe change and learn from it. The conservation effectiveness of protected reserves is well established, but just as important, the need for experimental “controls” will only become greater under adaptive management in the future. These different approaches should be tried across the landscape on different types of protected areas, from strict nature preserves to actively managed sustainable use areas. We suggest that the ideal adaptive landscape consists of large blocks of different protected area categories well represented and connected across the environmental gradients of elevation and latitude to facilitate the movement of species within each category in response to climate change.

In the 2010 paper, we argued that if all of these steps are taken, forest planning can yield a robust approach to managing the risk of climate change. In this paper, we describe how these concepts apply at the scale of a landscape relevant to forest planning: the Sierra and Stanislaus National Forests. We discuss the process of identifying key vulnerabilities, assessing the risks to those ecosystem elements, and devising strategies to manage down each element of risk. We conclude by describing how such strategies can be developed in the context of adaptive management that treats the landscape as an experiment that tests a portfolio of approaches.

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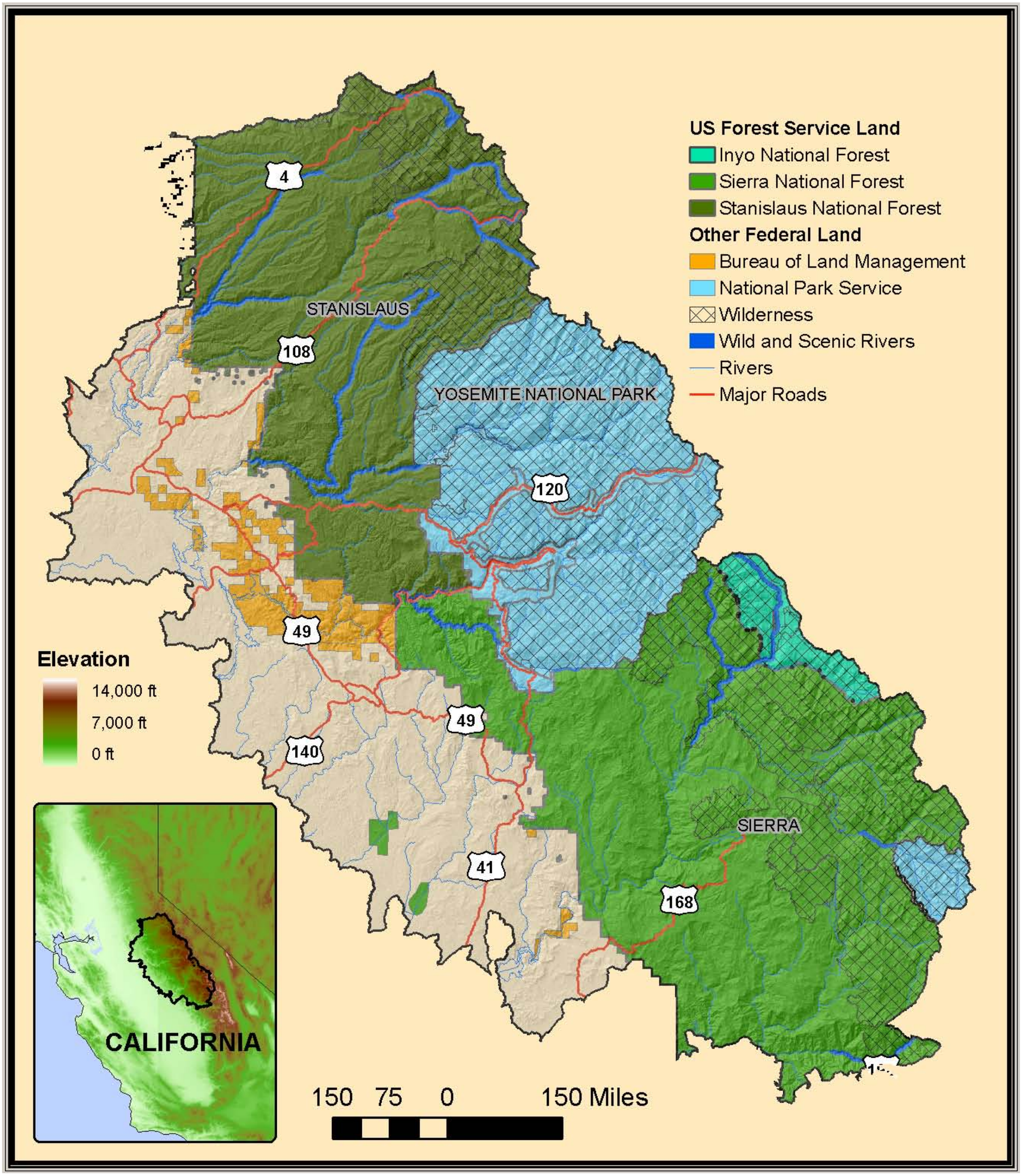
Study Area

We chose for further analysis the landscape of the Sierra and Stanislaus National Forests. It consists of the western slope of the Sierra Nevada from the Mokelumne River south to the Kings River, essentially the area defined as the Central Sierra Ecoregion by the Sierra Nevada Ecosystem Project (1996) modified to include all of each Forest. It is characterized by high elevation lakes, towering coniferous forests, deep river valleys, and granite monoliths. Strong elevation gradients result in diverse vegetation from low-elevation grasslands to subalpine meadows. It includes all of Yosemite National Park and the northern tip of Kings Canyon National Park, as well as a significant amount of BLM land at low elevations and abundant wilderness along the Sierra crest (Figure 2).

This 4.7 million acre area encompasses a number of issues expected to be the focus of planning under a changing climate, including such iconic species as giant sequoia, rare species like the California Spotted Owl, Pacific fisher, and American marten, issues of fire management and forest restoration, and maintenance of the Sierra’s legendary water quality.

Figure 2. Land ownership in the Sierra-Stanislaus landscape



In addition, the study area fills a gap not covered by two other assessments examining conservation in the face of climate change, the Northern Sierra Partnership (http://www.northernsierrapartnership.org/) and the Southern Sierra Partnership (http://databasin.org/connectivity-center/features/SSP).

Key Climate Vulnerabilities in the Sierra and Stanislaus National Forests

The first step in the assessment process is to identify the "key vulnerabilities" that will be the focus of further analysis. Identification of key vulnerabilities does not require a thorough evaluation of every species or ecosystem element in the region, as that would be extremely impractical. Rather, it needs to focus only on those elements about which there is already acknowledged reason for conservation concern. Identification of these elements should follow a scientific review of the state of the ecosystem, such as a bioregional assessment. Such a review should be based on science but should be open to the participation of all stakeholders.

In the absence of an up-to-date assessment, we suggested in the 2010 paper that a relevant distillation of conservation concerns for the region can be found in Appendix E of the 2000 Sierra Nevada Framework (http://www.fs.fed.us/r5/snfpa/library/archives/feis/vol_4/appn_e.pdf). Appendix E contained an adaptive management strategy for implementing the Framework that included not just the process and rationale for conducting adaptive management, but a set of "topic areas" that expands on the five "problem areas" addressed in the Framework EIS. These topics, which derived from considerable scientific review and public scoping, include old forest ecosystems; fire and fuels; aquatic, riparian, and meadow ecosystems; lower westside hardwoods; noxious weeds; air quality; soil productivity; and sociocultural conditions; as well as a number of species of conservation concern to be monitored as part of the adaptive management strategy. A similar set of issues has been raised by a coalition of conservation organizations in a Sierra Nevada Conservation Strategy, including additional topics of forest structural diversity, habitat connectivity, the effect of roads, and special designations (Britting et al. 2012).

It is not our intent here to conduct the evaluation of key vulnerabilities for the study area; indeed, it should be done through an open public process. However, we have selected a few that appear to meet the criteria for key vulnerabilities for further evaluation to demonstrate concepts of risk assessment and management in the context of climate change. Among the topics that appear most relevant to the Sierra and Stanislaus landscape are: conservation of Pacific fisher, fire and fuels management, and the use of special designations in adapting to climate change. In the following pages, we will use these issues to explore how risk assessment and management may be employed to facilitate climate change adaptation on the Sierra and Stanislaus National Forests. Our intent is for this paper to illustrate some simple steps that can be taken to incorporate climate change adaptation into the forest planning process.

Assessing Vulnerability

In the 2010 paper, we suggested criteria that may help in the selection of key vulnerabilities, but we did not suggest a particular process for evaluating vulnerability, as we were unaware of the existence of any well-vetted approach at the time. Since then, a number of sources have come available describing the process of vulnerability assessment (Association of Fish and Wildlife Agencies 2009, Foden et al. 2008, Game et al. 2010, Game et al. 2011, Glick et al. 2011, Swanston et al. 2010). One of the most useful is *Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment* published by the National Wildlife Federation with the support of a host of federal agencies, including the U.S. Forest Service (Glick et al. 2011). That publication treats vulnerability, exposure, and uncertainty all within the framework of a vulnerability assessment. Our approach keeps vulnerability (the combination of sensitivity and adaptive capacity) separate from exposure and uncertainty for purposes of risk assessment, but the two approaches are fundamentally similar (Table 1, Figure 1).

Table 1. Key risk management terms

Risk assessment	A review of the factors causing risk to a system or system components (*i.e.,* key vulnerabilities). The assessment systematically breaks down risk into its component parts of vulnerability, exposure, and uncertainty and evaluates each. Though vulnerability may be assessed separately from exposure and uncertainty, a full evaluation of risk is often called a "vulnerability assessment."
Key vulnerability	The system elements (*e.g.,* species, glaciers, fire) evaluated in the risk assessment. The IPPC (2007) recommends identifying key vulnerabilities based on an initial assessment of the magnitude, timing, probability, reversibility, and geographic scope of impacts, as well as the value of the system or system element to people and its potential for adaptation.
Vulnerability	The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. The IPCC (2007) defines vulnerability as "a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity." Because we believe exposure is worthy of attention in its own right, and because we believe a system may be considered "vulnerable" even if it is never exposed, we limit vulnerability to a function of sensitivity and adaptive capacity and evaluate exposure separately.
Sensitivity	The degree to which a system is affected, either adversely or beneficially, by climate variability or change (IPCC 2007). The effect may be direct (*e.g.,* lower productivity due to temperature change) or indirect (*e.g.,* loss of a pollinator due to changes in phenology).
Adaptive capacity	The ability of a system to adjust to climate change (including variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007).
Exposure	The nature and degree to which a system is exposed to significant climate variations (Glick et al. 2011). As with sensitivity, exposure may be primary/direct (*e.g.,* exposure to drought) or secondary/indirect (*e.g.,* increased predation due to invasion by warm-water predatory fish).
Uncertainty	An expression of the degree to which a value (*e.g.,* the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior (Glick et al. 2011).

Glick et al. begin the vulnerability assessment process with a consideration of various "elements of sensitivity" for each key vulnerability:[1]

- Hydrology (changes in the amount or timing of runoff)
- Fire (increased frequency and/or severity)
- Wind
- Physiological factors (temperature, moisture, CO_2 concentrations, pH, or salinity)
- Dependence on sensitive habitats

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[1] Actually, the first step in their process is equivalent to the selection of key vulnerabilities, above, a procedure they call "Determine objectives and scope":
- Identify audience, user requirements, and needed products
- Engage key internal and external stakeholders
- Establish and agree on goals and objectives
- Identify suitable assessment targets
- Determine appropriate spatial and temporal scales
- Select assessment approach based on targets, user needs, and available resources.

- Ecological linkages (relationships with other species that may themselves be vulnerable)
- Phenological changes (timing of various ecological phenomena)
- Population growth rates (species with slow population growth rates are more vulnerable)
- Degree of specialization (as with ecological linkages, highly specialized species, communities, and ecosystem processes that depend on the existence of particular species are more vulnerable)
- Reproductive strategy (species with long lifespans and few offspring are more vulnerable) and
- Interactions with other stressors (stressors like pollution or grazing may have greater effect in an altered climate)

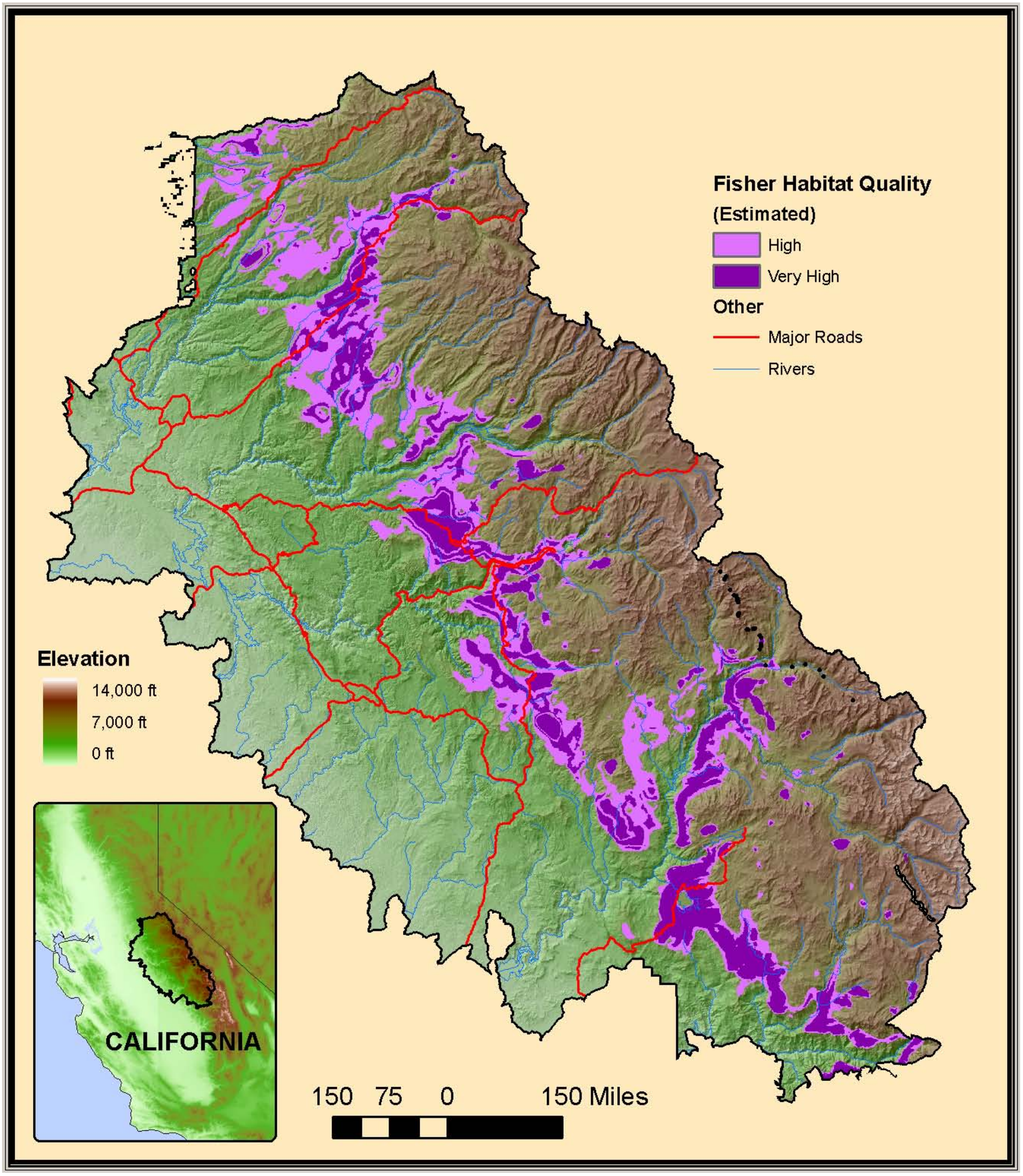
All key vulnerabilities, whether species, habitats/communities, or ecological processes, should be evaluated as to the degree to which they are likely to be affected by these factors. In addition to the sensitivity of these elements, a vulnerability assessment should evaluate their potential to adapt. In practice, since key vulnerabilities are likely already to be elements of conservation concern, a climate vulnerability assessment adds to the picture of vulnerability for those elements. A good example in the Sierra Nevada is the Pacific fisher, whose "elements of sensitivity" with regard to climate change are considered in Table 2:

Table 2. Climate vulnerability assessment (after Glick et al. 2011) of Pacific fisher (based on information in CDF&G 2010, Conservation Biology Institute 2007, Powell et al. 2003, Safford 2006; Truex and Zielinski 2005, Sierra Forest Legacy 2010).

Hydrology	Pacific fisher utilizes riparian zones but does not depend on aquatic habitats and is therefore not likely to be dramatically affected by changes in flow regimes.
Fire	The multi-layered canopy and presence of surface woody debris that make for good fisher habitat also make fisher vulnerable to the loss of habitat from the larger, more frequent, and more intense fires expected to result from climate change in the Sierra. Safford (2006) used a forest growth simulator to derive that increased fire frequency and severity could result in decreased canopy cover and down wood, resulting in long-term degradation of fisher habitat by mid-century. Fire likely does not pose a direct threat, as fishers, like most animals, move away from fire.
Wind	To the extent that more frequent windstorms destroy habitat, fishers may be considered vulnerable to wind; however, wind is also an important factor in the creation of multilayered canopies, and increased wind activity may actually help convert single-layered forest stands into suitable habitat. If a fisher happens to be occupying a tree at the time it goes down, it may cause direct harm. This kind of rare event demonstrates better the risk posed by small population sizes (see below) than the direct threat of wind itself.
Physiological factors	Very little is known about the likely physiological responses of fishers to climate change. Fishers are known to prefer cooler locations within landscapes (*e.g.,* north-facing slopes and deep canyons) and to rest in shaded locations (witches brooms, cavities) to avoid heat in the summer, suggesting that warmer temperatures may cause direct harm. Fishers also seek shelter from extreme weather in both summer and winter, suggesting that increased climatic extremes expected under climate change may also negatively affect population status.
Dependence on sensitive habitats	Pacific fisher is considered a habitat specialist, dependent on complex forest structure, especially rare old-growth. While old growth may not be sensitive *per se* (having shown the ability to survive climate changes of the recent past), high quality fisher habitat is uncommon in the southern Sierra and is limited to 545,268 acres in the 4.7 million acre Sierra-Stanislaus region (Figure 3). Long-term availability of fisher habitat is threatened both by fire and by treatments to mitigate fire severity, both of which may open and simplify the forest canopy and reduce surface cover and complexity.
Ecological linkages	Pacific fisher depends on a number of ecological linkages beyond its dependence on

	complex forest structure. It depends for resting and denning habitat on structures (cavities, brooms, etc.) that are created by a host of species from fungi to woodpeckers. How climate change will affect these species is not known. Similarly, the health of the fisher's prey base is a key driver of fisher population status. Even without keen understanding of the effect of climate change on these species, the strength of these ecological linkages increases fisher's vulnerability to climate change.
Population growth rates	The intrinsic rate of population increase of Pacific fisher is considered to be very low, decreasing its ability to recover from population set-backs or to take advantage of short-term resource availability. The current population size in the southern Sierra is not well understood but is considered by the California Department of Fish and Game to be "small enough that it could be impacted by substantial events affecting fisher range," such as bad weather and extreme fire years, as well as genetic effects and reproductive challenges associated with small populations. The slow population growth rate extends the duration of these vulnerabilities.
Degree of specialization	Pacific fisher is highly dependent on complex forest, but its prey base is broad, and it does not seem to prefer particular canopy species within its habitat. While fisher cannot be considered a true generalist, as different habitats appear to be sought for breeding and non-breeding seasons, specialization may not contribute to vulnerability for fisher as much as for other species.
Reproductive strategy	Pacific fisher is considered a "K-selected species," with a low annual reproductive capacity (a single litter per year of 1-6 kits), which increases the vulnerability of the population to changing conditions. Species with high reproductive outputs and short generation times may be better able to respond to novel conditions.
Interactions with other stressors	The west coast population of the Pacific fisher is currently at risk due to habitat loss and fragmentation, small population sizes and isolation, and human-caused mortality. Climate change promises to interact with habitat loss and fragmentation through increased drought and wildfire activity. Also, as fuel treatment to protect communities and forests from wildfire results in simplified forest structure, habitat can be degraded and further erode population status.

Figure 3. Modeled distribution of Pacific fisher habitat in the Sierra-Stanislaus landscape. High (top 40%) and very high (top 20%) habitat quality estimated from continuous data from Conservation Biology Institute. Fine scale habitat variability with classes is not mapped.



In addition to the analysis of these sensitivities, a vulnerability assessment should consider the adaptive capacity of the target element. Glick et al. suggest that adaptive capacity derives from four sources: 1) plasticity, or the ability of the individual organisms to change, either physically or behaviorally, in response to climate change; 2) dispersal ability, or the capacity of the key vulnerability to move to a favorable location in response to climate change; 3) evolutionary potential, or the ability of the population to respond favorably to climate change through the expression of latent or novel genes;

and 4) the “permeability” of the landscape, or the degree to which the landscape allows movement or range expansion in response to climate change.

Pacific fisher, being a mammal, is not capable of physically changing in response to climate change. It cannot, for instance, grow new appendages that are better adapted to dry conditions the way a plant can. It does have the ability to disperse (move) to suitable climatic conditions, but it is not clear how rapidly fisher can expand its range, and it is not clear that suitable habitat would await at the end of the journey. Like any species, Pacific fisher populations can evolve. However, as a “K-selected” species, its rate of evolution is limited by long generation times and low reproductive output. Its small population size could facilitate rapid genetic change in the population, but it also would not tolerate high mortality. Habitat fragmentation is already recognized as a cause of population decline, so habitat permeability should be considered low. Considering these factors collectively, it appears that Pacific fisher’s adaptive capacity is severely limited. With relatively high sensitivity and low adaptive capacity, Pacific fisher seems to be highly vulnerable to climate change. Assessments conducted for other key vulnerabilities can be expected to reveal similar information useful to the crafting of conservation strategies under an altered future climate.

Assessing Exposure

Understanding the probability of exposure is a critical part of the risk assessment process. Glick et al. (2011) include analysis of exposure as part of their vulnerability assessment process, but we recommend it be kept separate. Both the meaning of exposure and its analysis are fundamentally different from vulnerability. Vulnerability applies to the biological and physical qualities of the key vulnerability, and exposure applies to the environment that the key vulnerability is likely to experience. A target species or ecosystem element may possess qualities that make it vulnerable to a stressor, whether or not it is ever exposed to the stressor. Similarly, exposure will happen, whether or not any elements of the ecosystem are vulnerable. It is when the two are brought together – in the presence of uncertainty – that risk occurs.

Another difference between our recommended approach and that of Glick et al. (2011) is in the reliance on downscaled climate models to assess exposure. Glick et al. assert:

> Assessing the exposure of species to climate change requires the ability to peer into the future and identify likely or potential changes in ecologically relevant variables…[M]ost vulnerability assessments will not involve running sophisticated and complex global climate change models, but will instead rely on existing scenarios and make use of available downscaled climate projections.

Alternatively, we have found that the uncertainties that attend downscaled climate models limit their usefulness in assessing exposure. The variety of scenarios, model behaviors, and other uncertainties makes it difficult to describe future climate in any but the most general terms. As Overpeck et al. (2005) conclude, the “lesson for conservationists is not to put too much faith in simulations of future regional climate change” (as quoted in Beier and Brost 2010). Rather than invest substantial portions of limited budgets on downscaled climate models, we recommend planners rely on information that already exists to describe regional trends. Anticipated trends associated with climate change at the regional scale can be sufficient to facilitate exposure assessment. In describing how climate change is likely to affect the Pacific fisher, Safford (2006) cogently summarizes:

> It is impossible to say with certainty what future climates will look like in California. That said, there is nearly unanimous agreement that atmospheric CO_2 levels will more than double and temperatures will rise by at least a few degrees C by the end of the 21st century… Most regional modeling efforts suggest that mean annual precipitation across California will remain similar to current values or increase (with strong regional differences), rain: snow ratios will increase, and the seasonality of precipitation in the state will become more pronounced…
>
> It is also impossible to say with certainty how climate change will impact the California fisher or its habitat. This is due to a number of factors, chief among them: (1) differing GCM predictions with respect to future precipitation patterns in California; (2) the broad spatial scale of current GCM and derivative models, which cannot properly model the relatively fine-grained topographic and forest structural landscapes that support fisher populations in California; and (3) a lack of information as to the likely direct impacts of climate change on fisher metabolism. As with climate, however, it appears we can make a few useful generalizations about the probable future state of fisher habitat in California…

Safford goes on to describe what is understood about future climate in California in terms that are relevant to the fisher. He notes that the modeling that has been done suggests that hardwoods, especially deciduous hardwoods that are important to creating multilayered structure in fisher habitat, are expected to increase. Also, fire is expected to increase in frequency, which can be expected to increase snags and the amount of down woody debris and aid in the creation of tree cavities, especially where severities are low or patchy. On the other hand, he warns, increased severity may decrease surface wood and canopy cover, which may cause a tertiary exposure to diminished prey populations. As Safford shows, a meaningful qualitative assessment of exposure can be conducted even where quantitative information is lacking – and without detailed downscaled climate modeling.

Assessing Uncertainty

As mentioned, a critical component of risk is uncertainty, and a good risk assessment takes a hard look at that uncertainty. Table 3, below, from Aplet et al. (2010) describes some of the many sources of uncertainty that contribute to climate risk.

For the Sierra Nevada, there is no better consideration of relevant uncertainties than the monitoring framework proposed in Appendix E of the 2000 Sierra Framework. For each of the conservation issues addressed there, the document explicitly considers uncertainties, poses monitoring questions to reduce the uncertainties, and identifies “key information gaps.” As a result of research conducted in the past decade, many of these uncertainties have been addressed, including concerns about effects of fuel treatments, Pacific fisher status and ecology, and the conduct of adaptive management. While climate change was not an explicit consideration in the design of the adaptive management program described in Appendix E, all of the primary topic areas – fire and fuels; old growth forests; lower westside hardwood forests; aquatic, riparian and meadow ecosystems; air quality; soil productivity; and noxious weeds – are likely to be affected by climate change. The research, monitoring, and adaptive management protocol described in Appendix E serves as an excellent starting place for consideration of uncertainties associated with climate change in the Sierra and Stanislaus National Forests. We recommend a similar review be conducted as part of the forest plan revision process.

There is, of course, much more to a climate risk assessment than has been described here. It is not our intent to provide a comprehensive assessment of climate risk to the Sierra and Stanislaus landscapes, but rather to demonstrate the value of systematic consideration of that risk. By breaking risk into its component parts and evaluating each according to a comprehensive set of factors, understanding of climate change risk can be improved.

Table 3. Sources of uncertainty in understanding future climate change and its effects

Classes of uncertainty	Sources of uncertainty
Data limitations	• Poor records of past climate surfaces • Poor records of species occurrences
Limitations in ecological knowledge	• Habitat/range models ("climate envelopes") • Limited understanding of species response to climate change • Mortality rates and thresholds of mortality and recruitment • Dispersal • Species interactions • Behavior of novel ecosystems • Effects of interacting stressors
Model limitations and variability	• Limited understanding of the climate system • Intermodel variation in model output • Intramodel variation in model output • Downscaling coarse resolution global output to generate higher resolution future climate (especially in topographically diverse terrain)
Vagaries of human behavior	• Future emissions scenarios • Institutional resources • Public support • Planning horizon • Shifting decision processes and loci

Managing Vulnerability

Following the assessment phase, strategies should be developed to manage the vulnerability, exposure, and uncertainty revealed by the assessment (Figure 1). Managing vulnerability can be achieved either by reducing the sensitivity of key vulnerabilities or by enhancing their adaptive capacity. Unfortunately, for species, unlike vulnerable aspects of the built environment, there is little that can be done directly to reduce innate sensitivity of individuals. One of the few ways is to reduce non-climate stressors that can interact to increase sensitivity to climate change (*e.g.,* noise, pollution). Another approach is to work to keep population levels high to reduce the probability that climate (and non-climate) disturbances reduce population levels below a threshold of recovery. A time-honored strategy to protect populations is to increase the amount of habitat available by preventing erosion of existing habitat and increasing the number and size of habitat reserves. This will have the added benefit of reducing exposure to non-climate stressors, as well.

While options to reduce sensitivity are limited, adaptive capacity can be enhanced through a host of management strategies. As mentioned above, adaptive capacity is a function of the plasticity of individual organisms, their ability to disperse, their potential to evolve, and the "permeability" of the landscape. With the exception of the plasticity of individuals, each of these can be affected by management. For example, a species that is incapable of dispersing in response to climate change can be assisted into suitable habitat. Of course, this "managed relocation" must be undertaken with extreme caution so as to avoid the well-known negative consequences of species invasions into novel habitat, but the management option does exist. Evolutionary potential can be enhanced by conserving subpopulations with high genetic diversity and protecting a population structure that facilitates evolution. Last, landscape permeability can be managed by protecting connected habitats where they exist and by restoring connectivity where it has been broken, such as through the removal of roads and dams and the construction of passageways where removal is not possible.

Returning to the Pacific fisher for example, there are a number of ways in which the vulnerability assessed earlier can be addressed through management. Habitat loss (and population reduction) can be addressed by protecting existing habitat from development, destructive logging, and harmful fuel-reduction projects while treatments are undertaken to restore old-growth forest structure without increasing fire hazard. Barriers to movement, such as highway medians, can be re-engineered, and culverts and other passageways can be installed. Where vehicles contribute directly to mortality, traffic can be managed to reduce the probability of collision, and where suitable habitat exists but cannot be reached by individuals dispersing from existing populations, animals can be translocated, as has been done elsewhere in the species' range (CDF&G 2010). Finally, landscapes can be managed to provide appropriate habitat connectivity to ease movement and interaction among subpopulations that facilitate both evolution and range shifts in response to climate change.

Managing Exposure

In *Managing Risk* (Aplet et al. 2010), we described a number of strategies for reducing both exposure to climate change and exposure to its secondary effects. Strategies for mitigating climate change itself include both curtailing activities that emit carbon (*e.g.,* including silvicultural conversion of old to young forest, development of new sources of fossil energy [*e.g.,* oil and gas leasing], and carbon emitting recreational and administrative activities) and facilitating the storage of carbon through forest protection and the restoration of low-severity fire and fire-tolerant forest structure. The carbon storage benefits of fuel treatment and forest restoration are only beginning to be understood and may not be realized everywhere (Hurteau and Brooks 2011, Campbell et al. 2011) but are nevertheless worth considering, as they represent one way in which national forests can actively participate in mitigating climate change.

For the time being, though, restoration may better be thought of as a means of addressing exposure to the *effects* of climate change, including fire, drought, and invasive species. Forest restoration can help ensure that fires made more probable by climate change burn as low- and moderate-severity surface fires, rather than as crown fires, thereby reducing damage both to communities and to forest ecosystems. Similarly, restoration may reduce the influence of drought on tree mortality and, though it should not be considered a primary benefit, may help maintain stream flow in dry years (Baker 2003). Control of invasive plants, which are expected to increase as a result of climate change, can also be undertaken as part of a forest restoration program (Sieg et al. 2003). Another means of reducing exposure is to protect sites such as canyons or steep north-facing slopes that may provide refuge from a warming climate.

Fire is an effect of climate change that is particularly amenable to exposure reduction. Typically, reducing the exposure of human communities to wildfire effects is undertaken by identifying a "buffer" around a community and managing fuels within it to reduce the probability of flame spreading into (and out of) the community (Healthy Forests Restoration Act 2003, Stewart el al. 2009, Platt 2011). There is no standard, scientifically derived appropriate buffer width, and the choice of buffer width depends on the objective (preventing home ignition from radiant heat, reducing the probability of firebrands reaching the community, providing "defensible space" within which firefighters can work safely, etc.) One thing is clear: the definition of "community," as well as the width of the fire protection "buffer" around that community, has a dramatic effect on the amount of land considered part of the wildland-urban interface (Wilmer and Aplet 2005, Platt 2010).

Figure 4. Location of wildland-urban interface communities in the Sierra-Stanislaus study area and the effect of buffer width on the area considered for community protection treatments

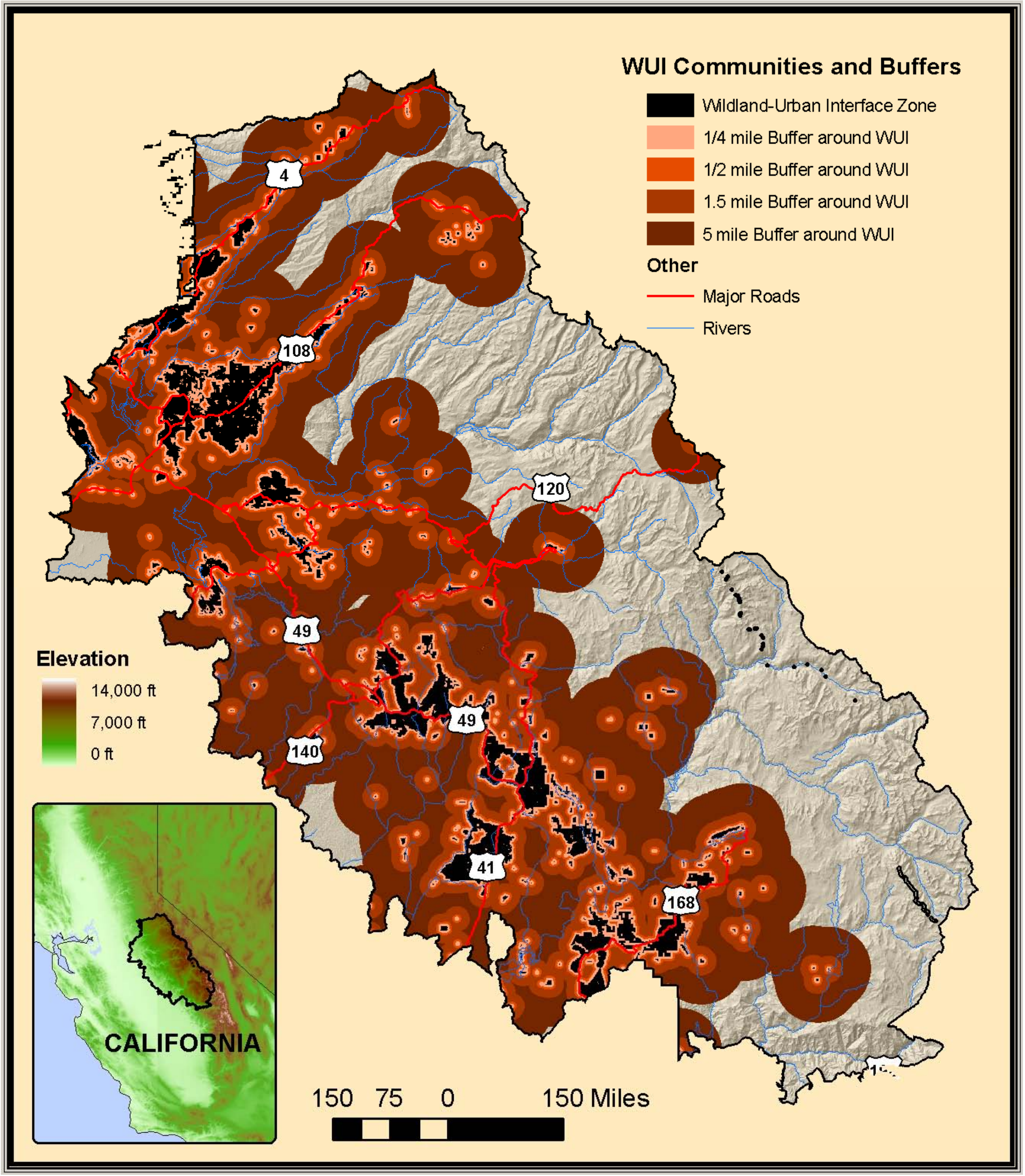


Figure 4 demonstrates the effect of various buffer widths on the size of the Community Fire Planning Zone (see Wilmer and Aplet 2005) in the Sierra/Stanislaus landscape. As buffer width is increased from the area of communities alone to a quarter-mile, a half-mile, a mile, and five miles, the size of the area under consideration for fuel treatment increases from less than a quarter million acres to over 3 million acres (Table 4). Obviously, as more area is considered for treatment, the cost of treatment increases as well. Similarly, as treatment acres increase, so do long-term maintenance costs of the areas treated (Aplet and Morton 2003). In an era of limited budgets, it is essential that the area treated for community protection be determined strategically – and not opportunistically – in order to ensure that resources are spent wisely to ensure community protection well into the future.

Table 4. Acreage of WUI defined by different buffer distances from communities within Sierra-Stanislaus study area

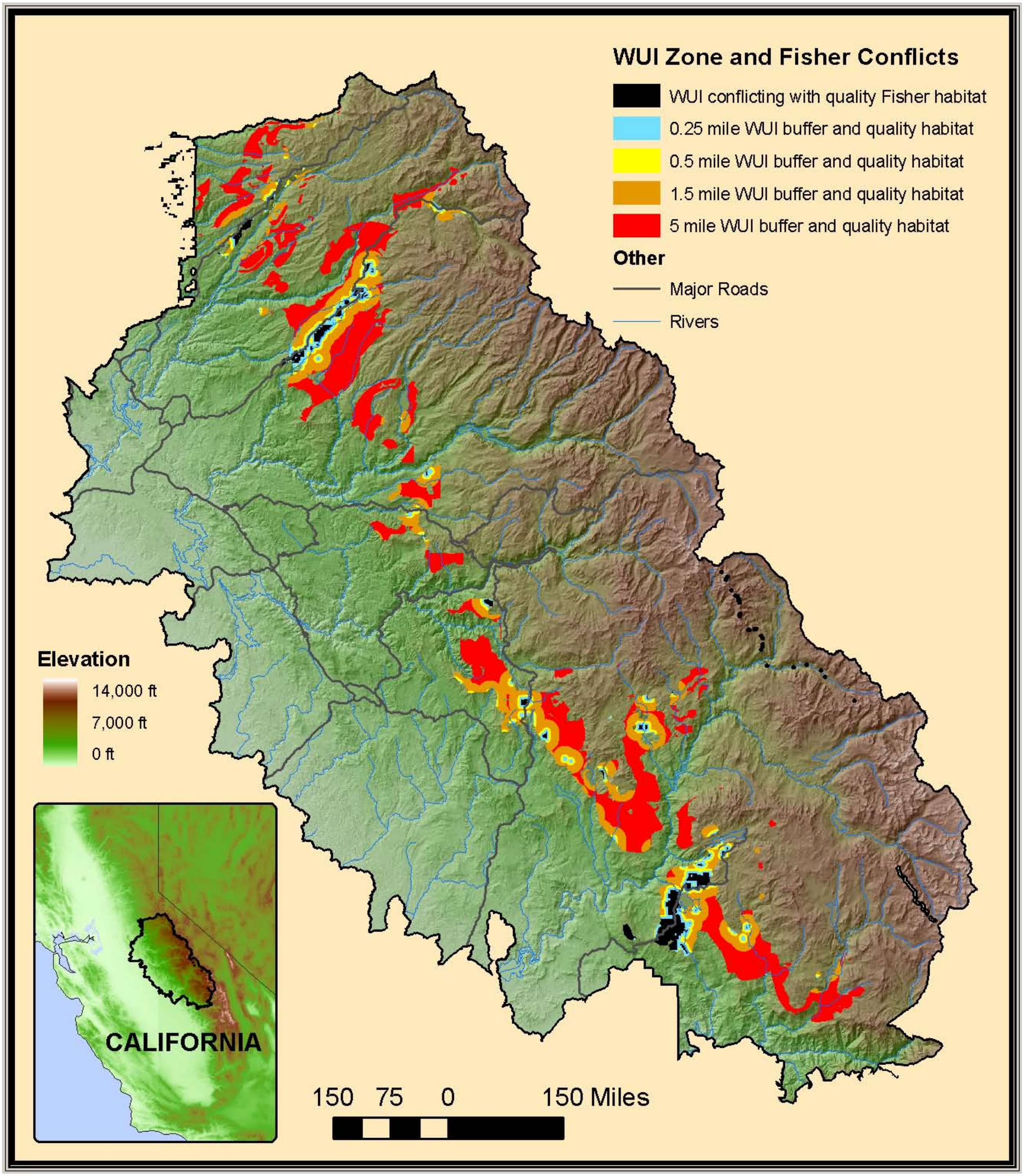
Community area	Within ¼ mile	Within ½ mile	Within 1.5 miles	Within 5 miles
246,827 acres	468,703 acres	679,703 acres	1,467,239 acres	3,102,751 acres

In addition to the challenge of strategic and budget realities, the placement of fuel treatments may conflict with other resource management objectives. Table 5 and Figure 5 illustrate the potential for increased conflict as the wildland-urban interface pushes farther and farther out into the habitat of Pacific fisher. For example, increasing the width of the WUI buffer zone from a half-mile to 1.5 miles increases the zone of potential conflict by more than 100,000 acres, encompassing more than one-quarter of the high quality fisher habitat in the region. Because high quality fisher habitat depends on a complex, multi-layered forest canopy and abundant surface cover and woody debris, and these features are often what are reduced in fuel treatment projects, potential for conflict exists. In practice, conflict may be reduced by focusing community-oriented fuel treatments as close as possible to communities where they will provide maximum protection, by modifying more remote prescriptions to achieve sufficient reduction in fire behavior with minimum effect on habitat quality, or both. If fire itself can be managed in such a way as to increase snags and the production of cavities and down wood, it could ultimately benefit the fisher.

Table 5. Area of overlap between high quality fisher habitat and various definitions of the wildland-urban interface

Community area	Buffer = ¼ mile	½ mile	1.5 miles	5 miles
21,143 acres	43,775 acres	68,414 acres	177,508 acres	412,943 acres

Figure 5. Overlap between high quality fisher habitat and the wildland-urban interface defined at various distances from communities



Managing Uncertainty

In the 2010 paper (Aplet et al. 2010), we argued that both monitoring and research are important ways to reduce the uncertainty that attends climate change. Even better would be if the two are combined in a formal program of adaptive management. Further, we suggested that Appendix E of the 2000 Sierra Nevada Framework should be consulted in the development of an adaptive management plan. In this document, we have demonstrated Appendix E to indeed provide a wealth of information, and we recommend it provide the starting point for development of a similar approach to adaptive management for the current round of Sierra Nevada plan revisions.

In addition to the suggestion of an adaptive management strategy, Aplet et al. (2010) recommended that national forests be divided into a set of landscape zones to facilitate rapid learning during adaptive management. The approach embraces the uncertainty that attends climate change and accepts that no single approach to management can be assumed to best sustain the values of the national forests; rather, management will have to test different approaches at the landscape scale. This requires allocation, one of the most fundamental aspects of forest planning.

The idea is rooted in a conceptual model of wildland character discussed in Aplet (1999) whereby the nature of any landscape can be described in terms of its ecological condition and its degree of human control. The model represents all lands as existing in the space created by two axes, one describing ecological condition along a gradient from novel to "pristine" (or intact with respect to its historical composition, structure, and function)[2] and the other defined by the degree of intentional manipulation from controlled to "self-willed" (Figure 6). In the upper right corner of this space occur the most uncontrolled, unaltered places -- the large, ecologically intact landscapes where historical conditions have been maintained without much human intervention. The Arctic National Wildlife Refuge is a prime example. Its antipode, the highly altered, highly controlled environment of the city, occurs in the lower left corner. Still other landscapes, such as the historically accurate but highly manipulated prairie restoration project at the University of Wisconsin Arboretum, belongs in the lower right-hand corner, and the C&O Canal, an artificially constructed waterway parallel to the Potomac River, overgrown with exotic species, might reasonably be called ahistorical and highly altered, yet self-willed and untrammeled, as it is largely left alone by managers (though it is no doubt influenced by the condition of its surroundings). Landscapes can express any combination of human control and historical fidelity.

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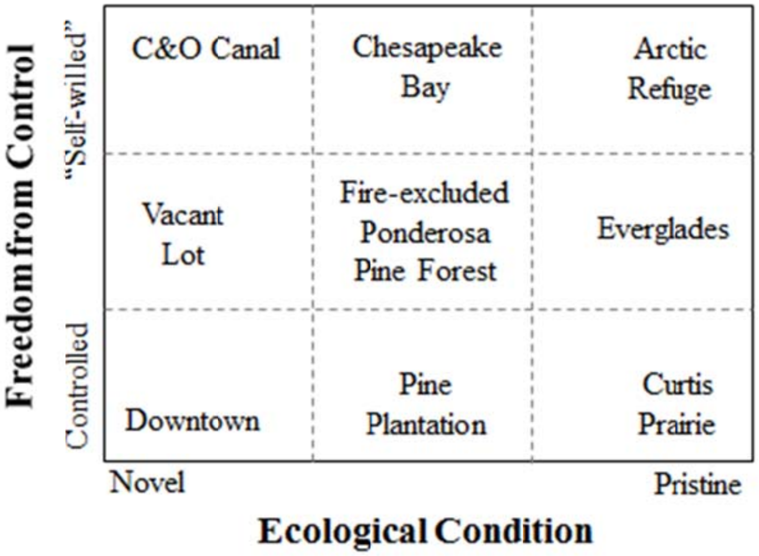
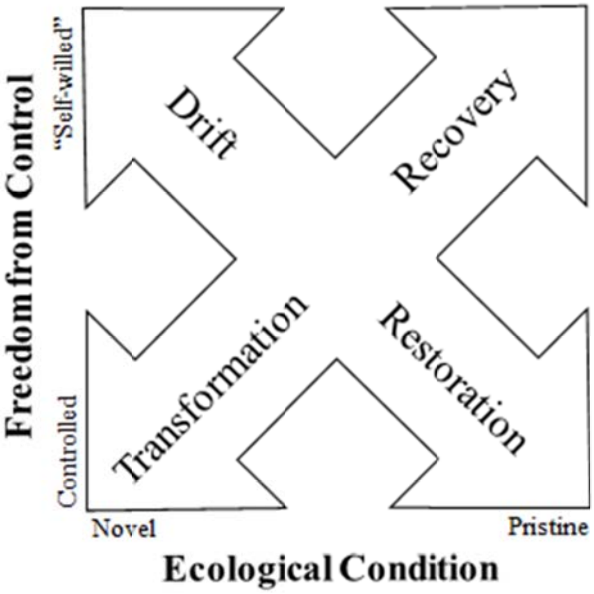
[2] For some people, "pristine" conveys notions of freedom and untouched nature that are not intended here and so might better be replaced with "historical," "primeval," or "intact," but it is the word used by Aplet (1999) and so appears here.

Figure 6. Any landscape can be represented in the two-dimensional space created by ecological condition and freedom from human control (from Aplet and Cole 2010).



This conceptualization can be used to contemplate the role of human agency in shaping landscape character (Figure 7) (Aplet 1999). Increased human effort can drive systems away from pristine conditions through *transformation*, as has typified the progress of civilization. Or, human effort can be exerted to increase historical fidelity and mitigate human impacts, through the process of *restoration*. In the absence of active management, land freed from human control can either *recover* toward the pristine or *drift* toward a more novel condition. Franklin and Aplet (2002) assert that, for wilderness, recovery is always the ideal trajectory; however, they recognize that there will be cases in which recovery from an altered state is impossible without active restoration. In these cases, the decision to intervene “will hinge on whether the potential for [recovery] outweighs the ecological uncertainties and the magnitude and duration of the required trammeling” (Franklin and Aplet 2002: 278).

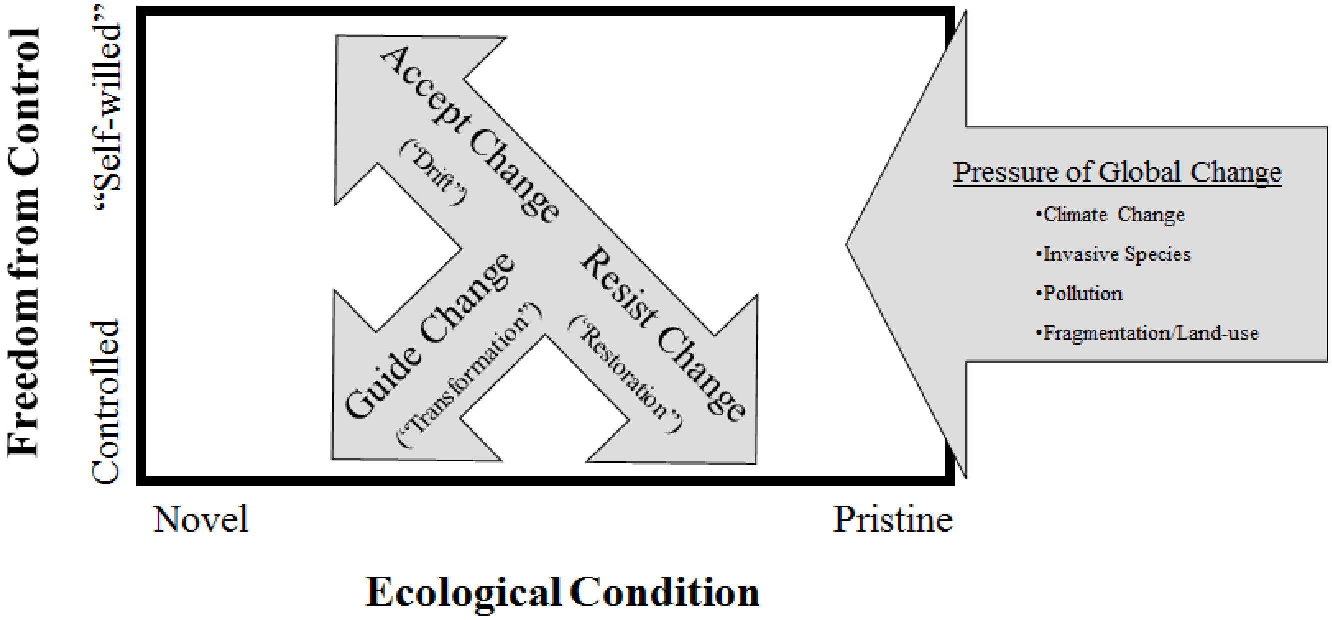
Figure 7. The same axes that describe land describe the "direction" of management options (from Aplet and Cole 2010)



Zoning the Forest for Learning: An "Adaptation Portfolio Approach" to Managing the Risk of Climate Change

Having explored these four potential "directions" of management (recovery, drift, transformation, and restoration), Aplet and Cole (2010) consider the implications of global change for the future of each and conclude that factors like climate change, species invasions, and atmospheric pollution are so pervasive and powerful that it is unrealistic to expect a particular place to recover to historical conditions if freed from human control over the long term. The ideal of wilderness management – the perpetuation of whole historical ecosystems through passive "untrammeling," is no longer tenable in the long run. In the short run, of course, there will still be places where passive restoration ("recovery") is possible through the removal of existing ecosystem stressors (*e.g.,* regrowth and succession of cutover or agricultural land, relief from overgrazing, dam removal). When such recovery results in a system that is more resistant to change or resilient to disturbance, recovery can be an important short-term strategy. Over the long term, however, global change can be expected to drive ecosystems away from historical conditions. The only management options remaining for the long haul are 1) to *accept change* by allowing ecosystems to "drift" into conditions novel to the place, 2) to *guide change* by actively transforming systems into forms capable of sustaining their most valued aspects and ecosystem services, and 3) to *resist change* and try to retain the composition, structure, and processes of complete, historical ecosystems through the process of "restoration" (Figure 8). Hybrids of these "directions of change" may also occur, such as when managers anticipate climate change and seek to guide an ecosystem into a condition that occurred historically somewhere else on the landscape, or where accepting change results in the "migration" of an historical ecosystem into a new location. This latter possibility must be considered unlikely, however, as paleoecological evidence suggests that ecosystem members (*i.e.*, species) rarely, if ever, migrate together in response to climate change (Williams and Jackson 2007).

Figure 8. Global change can be thought of as a pressure on ecosystems driving them away from historical conditions. In the future, degraded sites cannot be expected to "recover" to their historical condition in the absence of human influence (though some short-term recovery is possible upon relief from existing stressors).



At the same time that these realities are presenting themselves, other authors are arguing that the uncertainties associated with climate change require that a range of alternative approaches be tried to conserve the values and services we expect from ecosystems. For example, the IPCC (2007) concluded, "A portfolio of adaptation and mitigation measures can diminish the risks associated with climate change," a judgment echoed by Millar et al. (2007), who stated, "Managing in the face of uncertainty will require a portfolio of approaches, including short-term and long-term strategies, that focus on enhancing ecosystem resistance and resilience…as climates and environments continue to shift." Managers will have to try different approaches in different places, some with an emphasis on restoration, some on transformative activities, and some places we simply leave alone and observe. These three management options encompass many of the climate adaptation strategies that have been described in the literature. Strategies of reserve establishment, protection of old growth and corridors, and monitoring align well with the option to accept change. Reestablishing fire and flood regimes and reconnecting flood plains are familiar restoration actions, whereas more aggressive activities, such as assisted migration and the establishment of "neo-native forests," (Millar et al. 2007) fit in the vein of transformation. The problem is that we just don't know which of these options will best serve adaptation. Some are well-established, traditional conservation methods, while others entail significant risk, due to the lack of a track record, but may nevertheless be worth testing (Lawler et al. 2010).

Each national forest should allocate lands to three categories that emphasize restoration, observation, and innovation to match the options in the management portfolio

Given these realities, we recommend that forest planning result in the designation of management zones dedicated to these three purposes. Each national forest should allocate lands to three categories that emphasize restoration, observation, and innovation to match the options in the management portfolio (Table 6). In making these allocations, zones should be as large and contiguous as possible to minimize negative "edge effects" and facilitate monitoring and evaluation of the different strategies. Land units (*e.g.,* watersheds) of each zone should be connected, to the maximum extent feasible, across climate-relevant environmental gradients of elevation and latitude to facilitate movement and range shifts in response to climate change. Plans should connect congressionally designated wilderness, often occurring at the highest elevations of planning areas, with lower-elevation land units through the designation of research natural areas and other management areas where change is to be observed without manipulation. Such reserves are not guaranteed to sustain all valued elements and services of ecosystems, but their historical "track record" is excellent, and they ought to be part of any strategy to sustain ecosystems in the face of climate change. Landres (2010) identifies a host of benefits of the "hands-off approach," including sustaining non-focal species and hedging risk.

Designation of the other two classes of land should be handled in the same way. Parks, monuments, wildlife refuges, and other land classes that are managed to preserve valued elements of historical ecosystems should be connected, to the maximum extent feasible, across gradients of elevation and latitude by allocating land units of the national forests to a similar purpose. Such allocation of a "restoration zone" would make explicit which parts of any planning unit will be dedicated to restoration of historical conditions. Historical range of variability may ultimately prove to be a poor model of sustainability in the face of climate change, but it remains the only model we have of the dynamics that sustained ecosystems in the past.   Sustaining the whole ecosystem while "swimming upstream" against the current of climate change may ultimately prove impossible (Millar et al. 2007), but it may also "buy time" for certain species, communities, and processes that might be eliminated in the short term without such human intervention. In the case of fire-prone ecosystems, or aquatic communities at risk due to altered hydrology, restoration may result in ecosystems that are themselves more resistant to change.

Table 6. Summary of the three zones of the Adaptation Portfolio Approach

Zone	Response to Change	Purpose	Suitable lands
Restoration	Resist Change	To sustain historically "whole" ecosystems within their historical range of variability. Such lands may have been degraded by past management but can be restored to high ecological integrity through management.	Non-wilderness national parks, monuments, wildlife refuges, and other lands set aside specifically to sustain scenery, natural and historic objects, and wildlife are especially appropriate for inclusion in this zone.
Observation	Accept Change	To sustain the building blocks of future ecosystems without intervention.	Designated wilderness, research natural areas, and other lands likely to sustain ecological integrity without intervention (*e.g.,* areas of high genetic diversity, absence of invasive species, and/or late-seral forest).
Innovation	Guide Change	To sustain viable populations and other historical legacies in the face of climate change. Populations, soils, and streams, for example, may be manipulated into a condition that is more resilient to climate change, even if the ecosystem diverges from that which dominated historically.	Lands best suited for the Innovation zone may have undergone substantial change but are capable of supporting valued ecosystem components under management. Here, heavy-handed activities, such as the artificial cultivation of endangered species, may be appropriate if necessary to sustain wildland values identified by society.

The third class, the "innovation zone," would consist of the remainder of the forest, also set up to maximally connect across environmental gradients. Here, the desired future condition would be less constrained to achieving historical conditions, allowing the testing of new approaches to achieving resilience in the face of climate change. The objective here would not be "business as usual" or "anything goes." Instead, "resilience thinking" (sensu Zavaleta and Chapin 2010) would apply, where preferred ecosystem services would be identified through an open, collaborative, public process focused on ecosystem function, rather than states, and on linkages between ecological and human communities. As Zavaleta and Chapin (2010) note, "Managing for resilience ultimately means managing for the long-term adaptability and functioning of a regional system, even if that means allowing major reshuffling of the ecosystem's parts to take place (without losing parts altogether)."

In Figures 9a, 9b, and 9c, we have illustrated these concepts in a hypothetical diagram that uses the Sierra-Stanislaus landscape as a template. (Note: It is important to keep in mind that the figure represents only a conceptual diagram and not a recommendation, which will depend on incorporation of public values and other information not represented here.) Because the objective is to connect each of these zones across climate-relevant environmental gradients, we sought to connect the highest elevation subwatershed in each zone with the lowest elevations on the national forests. We began by identifying the highest elevation subwatershed in existing wilderness (*i.e.,* the legislated "observation zone") and connected it to the next lower elevation watershed sequentially until we reached the low-elevation boundary of the national forest. To this central watershed "corridor" we added adjacent watersheds to ensure that the zone contained intact upland ridges on either side of the central corridor. The resulting zone is a topographically diverse, contiguous landscape spanning the elevation gradient of the planning area.

To identify the "restoration zone," we located the highest elevation watershed within non-wilderness national park land. (We include national park lands in the restoration zone because they, like national monuments and wildlife refuges/management areas, were designated to preserve ecosystems or ecosystem elements [monumental trees, historic artifacts, wildlife species, scenery, etc.] for the future.) That watershed occurred near Tioga Pass in Yosemite National Park, where Tioga Road was excluded from park wilderness. We then repeated the same process as we did for the observation zone. To identify the "innovation zone," we identified the highest elevation subwatershed in the remaining unreserved national forest and repeated the process. The three resulting corridors are displayed in Figure 9a.

To identify the lands relevant to the forest planning process, we masked the three corridors with existing legislated uses, including wilderness and national parks and identified currently unreserved national forest within each category. Figure 9b shows that there is very little "restoration zone" above the eastern boundary of the national forest because of the abundant wilderness within Yosemite National Park, but the national forest itself provides ample opportunity to zone for such activity. In contrast, resulting "observation" and "innovation" zones are intact across a broad range of elevation. The rest of the national forest landscape can be allocated either by further expanding each zone in the manner already illustrated, by repeating the allocation process for unallocated watersheds, or by allocating watersheds to underrepresented zones to increase latitudinal connectivity, as illustrated in Figure 9c. Again, these figures are intended only to illustrate a concept, not to provide recommendations for specific allocations. In the "real world" of forest planning, other considerations will affect how land can be allocated to these zones. Objectives such as protection of communities in the wildland-urban interface, the need to protect spotted owl PACs and archeological sites, the presence of private inholdings, and the location of popular recreational destinations effectively "hardwire" certain uses into management plans, and allocations will have to take these into account. In addition, it should be noted that connecting zones across the elevation gradient works at cross-purposes with connecting across the latitude gradient in this landscape (and vice-versa). Ultimately, this process should be conducted with the full participation of the public. The point here is that allocation must be spatially explicit, taking into account the realities of the landscape. We will continue to work on methods for a realistic allocation and welcome the input and participation of others.

The primary benefit of this "three zone" management system is to explicitly address the uncertainty that attends climate change. It is not currently clear what the best approach will be to sustainability in the face of climate change. Some have argued that the pressure of climate change should lead to “designating new protected areas and undertaking low-level habitat management to reinforce species’ intrinsic dispersal and migration mechanisms” (Dawson et al. 2011), while others have suggested that “[a]ccepting that the future will be different from both the past and the present forces us to manage forests in new ways” (Millar et al. 2007). As a third alternative, restoration addresses Aldo Leopold’s still-relevant “first precaution of intelligent tinkering:” to keep all the parts (Leopold 1953). Ultimately, climate change will operate on what exists, and it makes sense to carry into the future a “portfolio of approaches,” where some areas are managed creatively and deliberately to promote certain ecosystem services and values, some are managed to conserve as much of our natural heritage as possible, and the rest is left for Nature to change on her own time, in case we’re wrong elsewhere.

To illustrate how this “adaptation portfolio approach” might affect forest management, we return to the example of the Pacific fisher and its need for complex forest habitat. In the “observation zone,” fisher habitat would be maintained simply by protecting existing old forest and complex forest recovering from decades-old logging activity. Such habitat has been shown to be suitable, despite the removal of fire from the system and the heavy component of shade-tolerant tree species. Here, no intervention appears necessary to provide adequate fisher habitat. In the “restoration zone,” managers would work to provide fisher habitat consistent with an historical habitat structure model. Activities like thinning and burning to favor understory oak would recreate a structure more consistent with the fire regime that dominated these sites for millennia. Elsewhere, in the “innovation zone,” managers might anticipate a drier, more fire-prone future, and manage to favor drought and fire-resistant species, like ponderosa pine, even if those species were not as abundant historically. Such intervention may not improve fisher habitat in the short term, but by trying these three different approaches, managers may “spread the risk” of climate change and improve the chances that high-quality fisher habitat will remain somewhere on the landscape into the future.

Similarly, rehabilitation of unnecessary roads might proceed along different paths. In the observation zone, roads would be allowed to recover without intervention, wherever catastrophic failure is not a concern. In the restoration zone, active management would seek to restore the slope to its original contours and reestablish native vegetation, and in the innovation zone, new techniques may be applied that look forward to a climate-altered future. Among the possibilities may be conversion of roads and adjacent buffers to shaded fuelbreaks to facilitate prescribed fire, establishment of drought-tolerant species that are poorly represented in the current vegetation, or even creating wetlands to mitigate reduced subsurface flow under future drought.

The purpose of the “portfolio approach” is to establish a landscape that is amenable to the management of vulnerability, exposure, and uncertainty while maximizing the probability of adaptation success. The risk assessment should reveal potential actions that can be applied according to coherent strategies of restoration, observation, and innovation. Not every potential action is appropriate in all three zones. It would be incoherent, for example, to apply forest thinning in the same place as management aimed at reducing soil disturbance or stress from noise. Ultimately, the portfolio of strategies should guide where to apply various actions and provides a “testing ground” where lessons learned from monitoring will reveal which actions are most effective at reducing risk.

Illustrating the process of allocating national forest lands to a 3-zone “adaptation landscape” to enhance connectivity and facilitate learning. *These graphics should not be interpreted as a preferred allocation in upcoming forest plan revision, but rather as an illustration of how a map of subwatersheds may be used to identify an adaptation portfolio.*

Figure 9a. Allocation of successively lower elevation watersheds to each zone, followed by allocation of adjacent watersheds to ensure inclusion of uplands

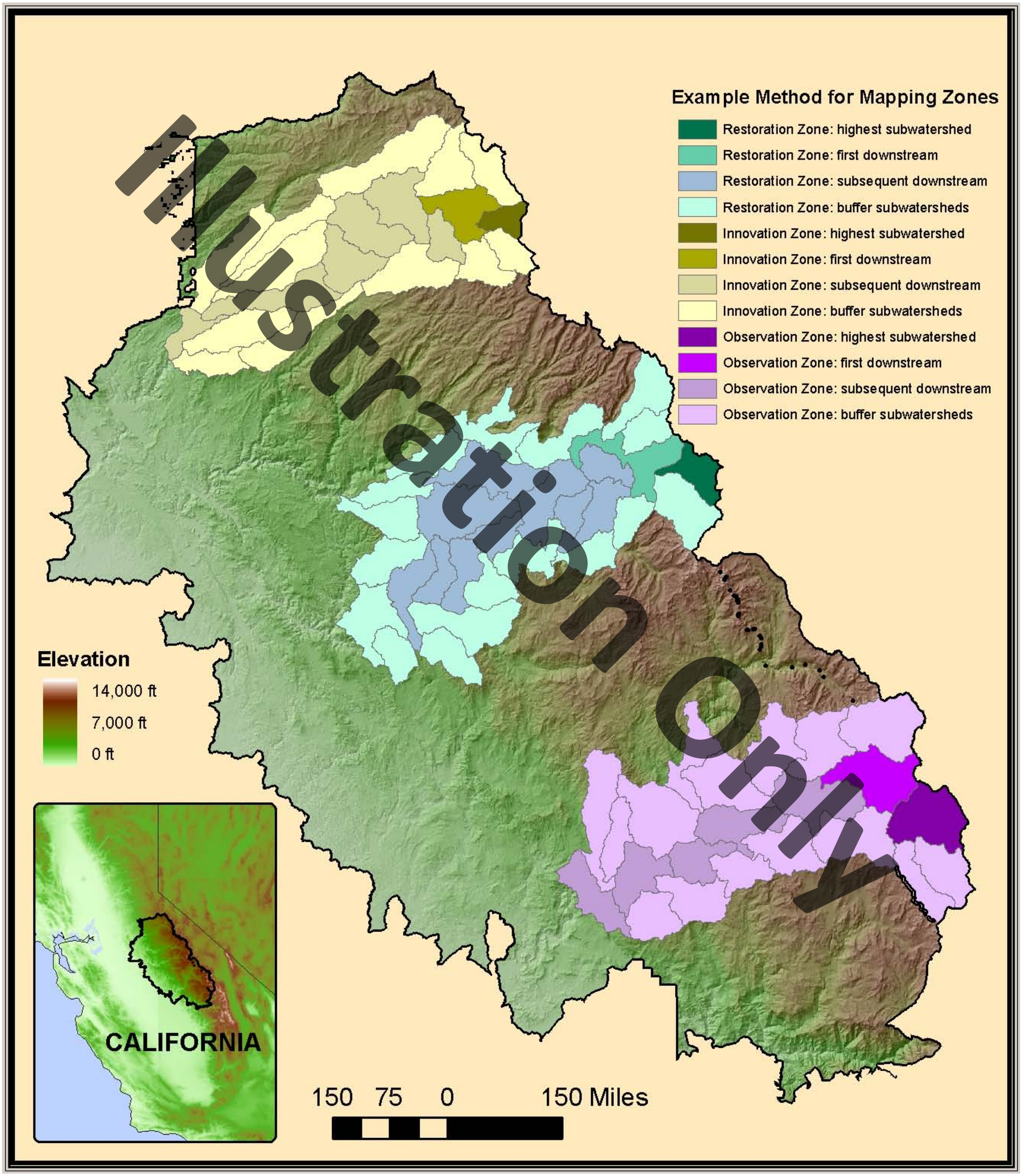


Figure 9b. Consolidation of non-wilderness national forest lands into management zones

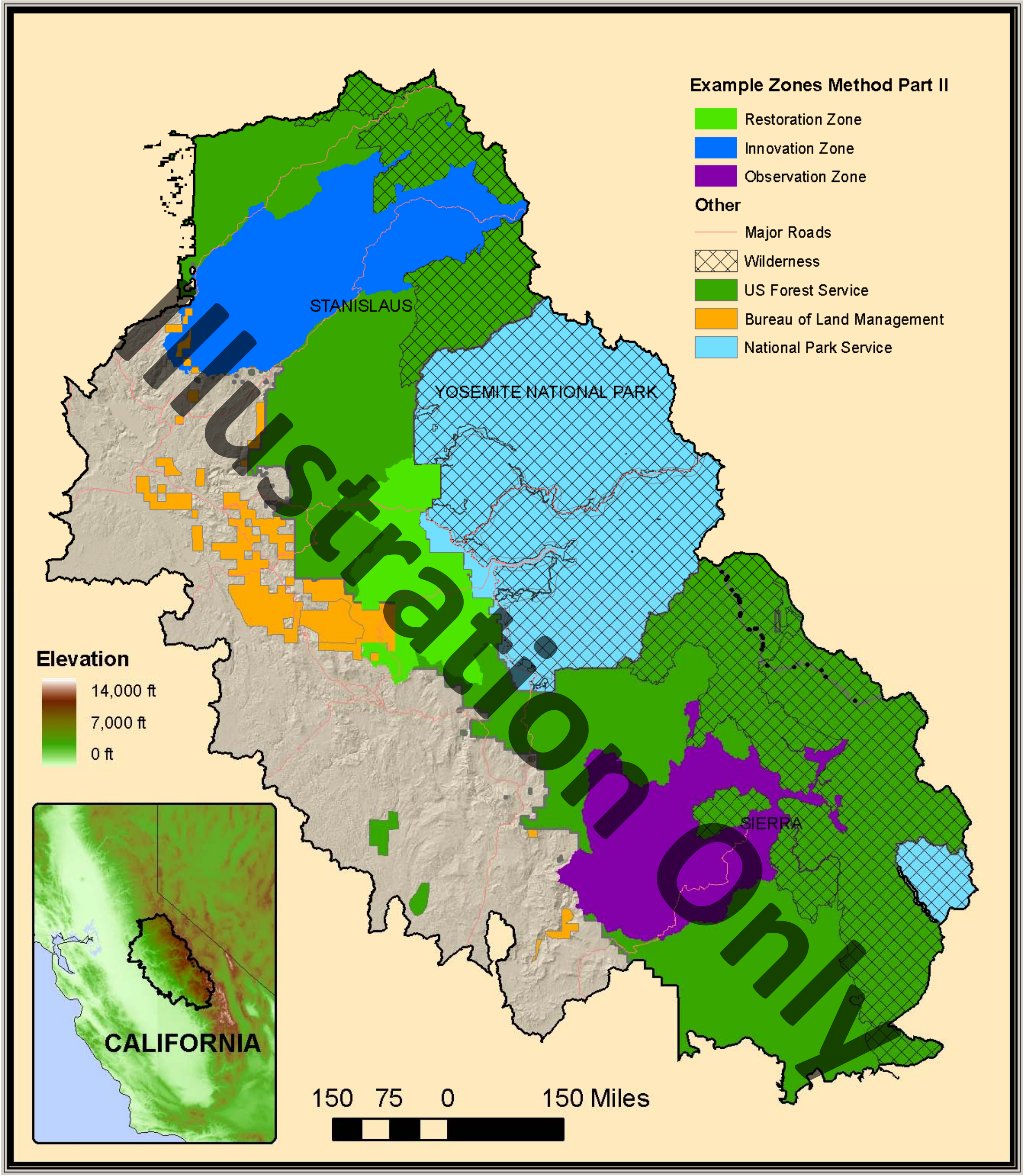
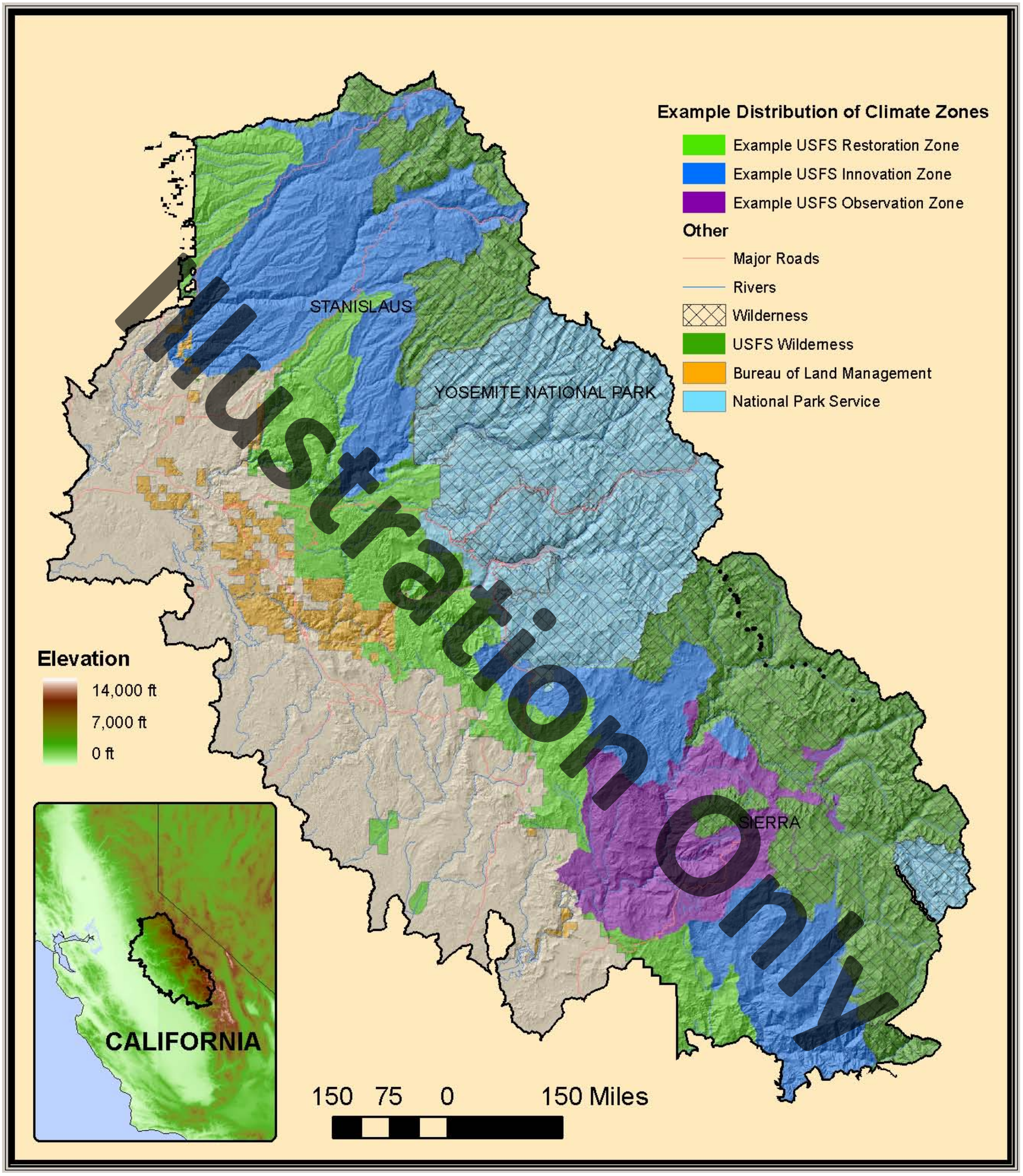


Figure 9c. Allocation of remaining watersheds to underrepresented zones (restoration and innovation) to enhance latitudinal connectivity



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Our mission is to protect wilderness and inspire Americans to care for our wild places

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