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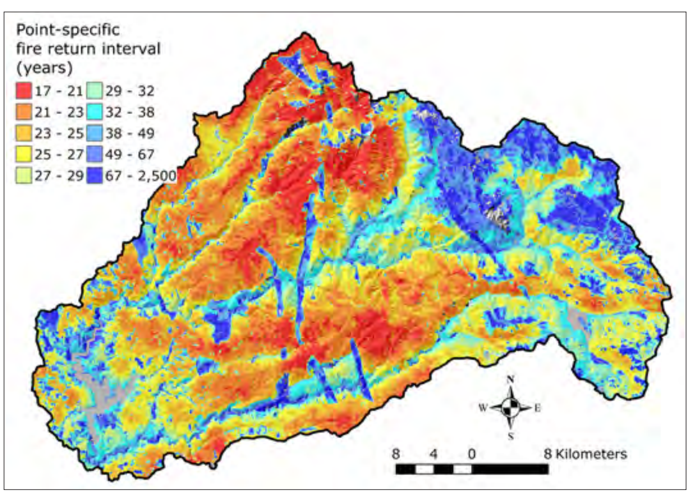
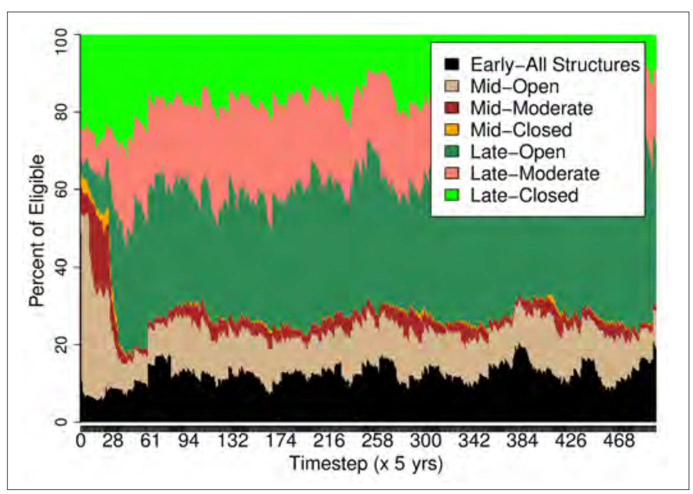
Modeling Historical Range of Variability and Alternative Management Scenarios in the Upper Yuba River Watershed, Tahoe National Forest, California

Kevin McGarigal, Maritza Mallek, Becky Estes, Marilyn Tierney, Terri Walsh, Travis Thane, Hugh Safford, Samuel A. Cushman





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Abstract

This report describes modeling of historical range of variability and alternative management scenarios in the upper Yuba River watershed, Tahoe National Forest, California. We discuss the need for this study with respect to the historical and contemporary context of the northern Sierra Nevada landscape, including background on the range of variability concept and the use of simulation modeling to quantify it. We simulated the dynamics in vegetation driven by wildfire during the historical reference period (ca. 1550–1850). Based on the output, we quantified the range of variability in composition and configuration of the landscape mosaic, and compared the results to the current landscape to quantify departure. We also created a set of eight alternative management scenarios reflecting different objectives and applying different treatment types and intensities. We conducted 20 replicate 100-year simulations of each of these management scenarios and quantified the range of variability in landscape composition and configuration, as before, for each scenario. We compared the range of variation in each landscape attribute among management scenarios and with the historical range of variability and current landscape to determine the potential for management scenarios to move the current landscape toward its historical range of variability. We provide a synopsis of the major findings or “take-home” messages of this study and their management implications. For example, our scenario analysis demonstrates that active vegetation management involving a combination of mechanical and prescribed fire treatments has the potential to emulate many aspects of landscape structure that would occur under a natural disturbance regime, but it would require a much higher intensity of treatment than we are accustomed to—perhaps as much as 10 times the current treatment rate.

Keywords: range of variability, historical range of variability, range of natural variability, natural range of variability, future range of variability, landscape disturbance-succession modeling, alternative management scenarios, northern Sierra Nevada

Cover images—top: Upper Yuba River watershed from Sierra Buttes (photo by: Becky Estes, USDA Forest Service); **bottom left:** simulated point-specific fire return interval for the simulated historical range of variability (ca. 1550–1850); **bottom right:** simulated trajectory in the percentage of the Sierran Mixed Conifer – Ultramafic cover type in each seral stage.

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INTRODUCTION

Purpose and Need

The upper Yuba River watershed project area (181,556 hectares, or 448,625 acres) on the Tahoe National Forest in northern California (fig. 1) is a spatially and temporally dynamic mosaic of ecological systems. This dynamic stems from a complex natural and human land use history that characterizes much of the northern Sierra Nevada ecological region. This dynamic is largely driven by the interplay of disturbance regimes, especially fire and vegetation succession. Cycles of fire and vegetation recovery occur variably over large extents, as well as over long periods of time, and produce a constantly shifting mosaic of ecosystem conditions. Understanding this dynamic is essential to the management of this landscape.

It is generally believed that prior to Euro-American settlement in the mid-1800s the Sierra Nevada landscape was shaped by a set of environmental conditions—including climate, topography, vegetation, and management by Native Americans—that over thousands of years had led to high resilience to major ecological change (Van Wagtendonk and Fites-Kaufman 2006). Although climate is always changing, the general outlines of modern Sierra Nevada ecosystems have been in place for approximately the last 4,000 years (Millar and Woolfenden 1999). Before Euro-American settlement, fire was the major source of disturbance in Sierran forests, shaping the composition and spatial configuration of vegetation communities (Safford and Stevens 2017). Fires were primarily lightning caused, although indigenous peoples set fires for a variety of purposes, especially at lower elevations (Safford and Stevens 2017). Fires during this period were exceptionally frequent, resulting in an overall fire rotation period (i.e., the time it takes to burn an area equivalent to the total area under consideration) of about 30 years (Agee 1993), although fire rotation varied considerably among vegetation types in relation to moisture and elevation gradients (Mallek et al. 2013). In general, regardless of

Figure 1— The upper Yuba River watershed project area on the Tahoe National Forest located within the North Sierran CALVEG mapping zone in the Sierra Nevada ecological region.

vegetation type, fires during the presettlement period are thought to have burned primarily at low intensities. High mortality (>75 percent overstory canopy mortality) fire was relatively uncommon (Collins et al. 2007; Safford and Stevens 2017) and, when it did occur, it most likely occurred as relatively small (<1 to several hectares) patches embedded within a mosaic of lower severity and unburned areas (Collins et al. 2007). When stand-replacing fire did occur, it initiated early-development conditions on the landscape. Most fires, however, were surface fires that removed only understory fuels and tree regeneration. In some cases, moderate overstory mortality opened forest canopies without resetting stand development, especially in more xeric parts of the forest or areas of dense patches of trees (Mallek et al. 2013; Safford and Van de Water 2014; SNEP 1996a,b). Where fires did not recur frequently or occurred only at very low severity levels, succession processes such as infilling and overstory growth led to a gradual closing of the canopy. For most of the ecological communities, high-severity fire rates were low enough to allow most stands to succeed into late-development and old-growth conditions characterized by a variety of (mostly open) canopy structures (Mallek et al. 2013; Safford and Van de Water 2014; SNEP 1996a,b). Thus, it is generally believed that during the presettlement period the landscape was in a dynamic equilibrium—a relatively stable shifting mosaic of vegetation conditions—and highly resilient to permanent change (Hessburg et al. 2005; North et al. 2009).

Since Euro-American settlement, grazing, logging, mining, and fire exclusion have interacted to greatly and rapidly alter the historical fire regime and vegetation patterns (Knapp et al. 2013; Stephens et al. 2015). Heavy grazing in the late 19th and early 20th century altered fine fuels and probably reduced understory flammability (Hessburg et al. 2005). Widespread timber harvest in the past, especially of fire-tolerant species such as ponderosa pine (*Pinus ponderosa*) and sugar pine (*P. lambertiana*), accelerated the increased cover of fire-intolerant species such as white fir (*Abies concolor*) and incense cedar (*Calocedrus decurrens*) and selectively removed most of the late-seral forests (Hessburg et al. 2005; McKelvey and Johnston 1992; McKelvey et al. 1996).

Timber harvesting continues today, but the emphasis has switched from commercial timber production to fuels management. Hydraulic mining in the past had a long-lasting effect on fire through the local removal of both vegetation (i.e., fuels) and soils, which prevented or dramatically altered the potential for vegetation development after mining ceased (Storer and Usinger 1963). For oak woodlands, yellow pine, and mixed conifer forest types, frequent fires (usually having low mortality) were historically common (Mallek et al. 2013; Safford and Van de Water 2014; Van de Water and Safford 2011). After large-scale fire exclusion in the second half of the 19th century, less fire-tolerant species such as white fir, incense cedar, and Douglas-fir (*Pseudotsuga menziesii*) have become more dominant in areas where they were once a minor part of the vegetation community (Beaty and Taylor 2007; Knapp et al. 2013; Safford and Stevens 2017; Stephens et al. 2015). In addition, fire exclusion has allowed the buildup of surface fuels and ladder fuels, which promotes larger and hotter fires when they do occur (Knapp 2015). Moreover, the lack of natural fires has increased the contiguity in fuel loading that allows fires to spread over very large areas under the right conditions (Beaty and Taylor 2007; Hessburg et al. 2005; Meyer et al. 2008). Thus, the current landscape is now dominated by fuel-rich, early- to mid-seral stage, overstocked forests composed disproportionately of less fire-tolerant species (Hessburg et al. 2005; Knapp et al. 2013; Stephens et al. 2015; Storer and Usinger 1963). Given the uncharacteristically high canopy cover, tree density, and continuity of abundant surface fuels, it is believed that the landscape has become less resilient to the occurrence of future fires and other disturbance agents and is especially susceptible to extensive and uncharacteristically severe fires (Beaty and Taylor 2007; Hessburg et al. 2005; Meyer et al. 2008).

The Tahoe National Forest is the principal land manager in the Yuba River watershed. Based on fire return interval departure mapping (which compares current fire frequencies versus historical frequencies), the Tahoe National Forest has one of the highest levels of departure among national forests in California, reflecting extremely effective fire suppression efforts (Safford and Van de Water 2014). In 1999, however, the Pendola fire burned 4,734 hectares (11,698 acres) around Bullards Bar Reservoir and west of Camptonville, California, in the upper Yuba River watershed. The final fire perimeter included a total of 1,565 hectares (3,867 acres) on the Tahoe and Plumas National Forests. Postfire analysis of the burn on the national forests determined that 70 percent of the area burned at high severity, prompting a need for restoration actions (USDA Forest Service 1999).

Triggered by the Pendola fire and its uncharacteristic proportion of high-severity fire, Tahoe National Forest managers determined that to better guide restoration planning efforts within the fire perimeter, and more generally on the forest as a whole, it was prudent to gain a better understanding of the natural range of variability (NRV, also called range of natural variability, or RNV) in vegetation composition and configuration. More specifically, pursuant to the 2012 Forest Planning Rule (NFMA, 2012 Planning Rule 2015), managers on the Tahoe decided to develop a quantitative assessment of the NRV in landscape structure to serve as a reference against which to evaluate current landscape conditions and provide a framework for deriving potential desired future conditions and planning future management. They decided to use the historical (i.e., pre-Euro-American settlement) range of variability (HRV) as the measure of NRV because it offered the best reference for evaluating the current and future landscapes (Keane et al. 2009) and because the historical data were deemed sufficient to reliably characterize landscape conditions during the historical reference period. In addition, Tahoe managers sought to explore the potential of alternative land management scenarios to move the landscape toward HRV. To meet these needs of the Tahoe National Forest, this study was conducted with the following specific objectives:

1. Synthesize empirical and expert knowledge on disturbance and succession processes characteristic of the pre-Euro-American settlement period in the northern Sierra Nevada ecoregion, which contains the upper Yuba River watershed.
2. Quantify HRV in landscape structure (i.e., vegetation land cover composition and configuration) in the upper Yuba River watershed by using the RMLands landscape disturbance-succession model.
3. Quantify current departure of the upper Yuba River watershed landscape structure from its HRV.
4. Quantify range of variability in landscape structure in the upper Yuba River watershed under several alternative management scenarios and compare them to the current landscape and HRV.
5. Synthesize simulation modeling results and summarize the implications for land management.

Historical Reference Period

We defined the historical reference period as the 300 years prior to Euro-American settlement (ca. 1550–1850). This is because our understanding of past climate and vegetation patterns becomes less clear as we move back in time, but 300 years is sufficient to capture notable variability (Meyer 2013a; Safford and Stevens 2017; Van de Water and Safford 2011). Because this reference period captures landscape changes over hundreds of years, far longer than the typical forest planning cycle, the HRV results allow managers to develop near-term plans and expectations within a broader temporal context. Indeed, in restoration planning efforts, it is logical to look back to the last known period during which a dynamic but resilient landscape existed. The arrival of Euro-American settlers in the Sierra Nevada led to sweeping ecological changes that now have greatly altered many Sierran landscapes through fire exclusion, grazing, road-building, timber cutting, recreation, and other activities (Hessburg et al. 2005; Knapp et al. 2013; Stephens et al. 2015; Storer and Usinger 1963). The period before Euro-American settlement, then, is a suitable reference condition against which we can compare current landscape structure and dynamics. Moreover, it is frequently used in the western United States as the historical reference period for restoration planning (Meyer 2013a; Safford and Stevens 2017; Van de Water and Safford 2011). This reference period is also several times the length of fire rotation periods identified for well-understood cover types within the project area. Finally, it is a timeframe for which we have sufficient information to have some confidence in model results.

We are mindful that this reference period overlaps the "Little Ice Age," which may temper the utility of the results as specific management targets, but does not diminish their usefulness in other ways (Minnich 2007; Safford and Stevens 2017). The chosen reference period was not a time of stasis climatically, ecologically, or culturally. The oscillation of the Palmer Drought Severity Index, a measure of climate variability in terms of precipitation and temperature, over time illustrates this (see *Methods* section). Although the Late Holocene was characterized by general cooling and gradual increases in precipitation, multiyear droughts and El Niño and La Niña events also occurred over this timeframe (Minnich 2007). The Medieval Drought periods were extremely dry and warm and are postulated to be climatic analogs to a warmer, drier future (Safford and Stevens 2017). Even though fire frequencies moderated during the Little Ice Age, frequencies were still much higher than today, permitting fire- and drought-tolerant species to dominate much of the landscape (Safford and Stevens 2017). During the reference period, several Native American tribes lived in the project area. Debate continues among scientists and other researchers about the extent to which those peoples managed vegetation through setting fires (Anderson and Morrato 1996). Because we lack empirical evidence to distinguish between lightning-caused and human-caused fires during this period, we decided not to exclude any fire frequency or rotation data on the basis of not being reflective of "natural" conditions.

We emphasize that our choice of reference periods does not suggest that it should be our goal in management to recreate all of the ecological conditions and dynamics of this period. Such a goal may not be possible, nor potentially desirable, in light of current climate change, ecological shifts, and social realities. However, the chosen reference period allows us to compare current conditions to a baseline set of data on ecosystem conditions (composition, configuration, and disturbance processes) to develop an idea of the level of departure of altered ecosystems from their "natural" state (Safford and Stevens 2017). The results of this study complement the NRV assessments compiled by the Forest Service, U.S. Department of Agriculture, Pacific Southwest Region Ecology group for the Bioregional Assessment process necessary for forest planning (e.g., Estes 2013a,b; Gross and Coppoletta 2013; Merriam 2013; Meyer 2013a,b; Safford and Stevens 2017), and provides a basis for forest management policies and associated actions that seek to emulate natural disturbance patterns (Perera et al. 2004; Romme et al. 2000).

Why Range of Variability?

Since the late 1970s, ecologists have increasingly focused on community and ecosystem dynamics rather than static endpoints such as the climax. Disturbance and response to disturbance are now recognized as natural processes that lie at the core of ecosystem dynamics, a concept that plant ecologists have variously expressed as “patch dynamics” (Pickett and Thompson 1978), the “shifting mosaic” (Bormann and Likens 1979), and the “mosaic cycle” (Remmert 1991). This is more generally known as the “dynamic view,” reflecting the increasing recognition that disturbances and other factors mitigate against ecological communities attaining a lasting constancy in species composition. This dynamic view of ecosystems and landscapes has had a tremendous impact on land management. It is now universally accepted that ecosystems and landscapes are dynamic in space and time and that disturbance and successional processes interact to affect the range of variability in ecosystem structure, composition, and function.

Although the notion of “natural” in ecological systems has multiple interpretations (Sprugel 1991), many scientists and land managers believe that NRV can provide a useful framework for managing dynamic ecosystems and landscapes, especially as human activity is increasingly seen as the causal agent of large-scale environmental changes resulting in departure of the ecosystem or landscape from its “natural” range of variability. For our purposes, NRV can be defined as “[t]he ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal” (Landres et al. 1999: 1180). Management use of NRV concepts began in earnest out of a search for a legally defensible strategy for maintaining biological diversity and sustaining the viability of threatened and endangered species, pursuant to the requirements of laws such as the National Forest Management Act of 1976 (https://www.fs.fed.us/emc/nfma/includes/NFMA1976.pdf) and the Endangered Species Act of 1973 (https://www.fws.gov/endangered/esa-library/pdf/ESAall.pdf). Eventually, it was realized that incorporating ecological variability into management is key to maintaining ecosystem integrity because it: (1) ensures optimal biodiversity, (2) recognizes the roles of disturbance, (3) widens the options for management, and (4) maintains resilience. Consequently, the NRV concept gradually evolved and expanded into a general “coarse filter” strategy for sustaining ecological integrity and as a benchmark for evaluating the impacts of human activities on ecosystems and landscapes (Christensen et al. 1996).

By 2000, the Planning Rule explicitly called for the Forest Service to estimate and describe the range of variability under natural disturbance regimes, and manage for those characteristics (NFMA, 2000 Planning Rule 2000). Decisions were to be grounded in the context of “maintain[ing] or restor[ing] ecological conditions that are similar to the biological and physical range of expected variability” (NFMA, 2000 Planning Rule 2000: 36 CFR § 219.4(b)(2)(vi)). The need to consider the NRV was maintained through various amendments to the rule, and is prominent in the current 2012 Planning Rule (finalized in early 2015): “Plan decisions affecting ecosystem diversity must provide for maintenance or restoration of the characteristics of ecosystem composition and structure within the range of variability that would be expected to occur under natural disturbance regimes of the current climatic period,” (NFMA, 2012 Planning Rule 2015: 36 CFR § 219.2o(b)(1)). Consequently, NRV concepts guide most current land management activities on national forests and other public lands.

The NRV approach required a baseline or reference, and historical ecology appeared to provide the best reference, so historical range of variability (HRV) quickly became the standard for applying NRV concepts (Keane et al. 2009; Swetnam et al. 1999). A prerequisite to the use of HRV, however, is the ability to define a meaningful historical reference period during which human activities had relatively minor effects on overall landscape structure and function, and the ability to examine the range of variation in key landscape attributes during this period. This range of variation can then be used as a benchmark for comparison with contemporary or potential future conditions. Assuming the prerequisites can be met, HRV can be a useful tool for understanding and evaluating change and communicating the concept that landscapes are dynamic to the public. Moreover, a quantitative characterization of HRV can help determine whether the current landscape is "outside" its natural range of variability and provide detailed, specific, and quantitative criteria for establishing desired future conditions that are intended to emulate natural disturbance patterns. HRV can also help to develop hypotheses about the drivers and mechanisms of ecosystem change that can then be tested with spatial and temporal data. The understanding obtained from these analyses can aid in predicting how ecosystems might change in the future (i.e., future range of variability, FRV) in response to novel structures and processes (e.g., accelerated climate change) (Romme et al. 2012).

Despite the appeal of HRV, it is not without some major challenges that should be addressed up front.

1. Is HRV relevant today given the following?

- Native and contemporary people have so altered natural systems that there are no pristine natural areas left on our planet, making information derived from the past difficult to interpret or irrelevant.
- Each point in time and space is unique, and dominant climate patterns are continually changing. Therefore, a description of past patterns and processes is largely irrelevant today or in the future.
- Management goals based on HRV seek to recreate past environments and then maintain those environments in a static condition.

We submit that the use of HRV does not require pristine conditions during the reference period, nor does it suggest that it should be our goal in management to recreate all the ecological conditions and dynamics of the historical reference period. Complete achievement of such a goal would be impractical in many cases given the current and future ecological, sociocultural, economic, and political climate. In general, understanding past conditions and the natural processes that influenced those conditions, regardless of the level of human impact, yields insight into why and how current conditions developed, and what changes may be expected in the future. In addition, the use of HRV is not necessarily an attempt to simply mimic or recreate the processes that occurred on a site long ago, or to return managed landscapes to a single and unchanging past condition. Rather, it is an attempt to improve understanding about the ecological context of an area and the landscape-scale effects of disturbance in an effort to make existing and future conditions more ecologically sustainable.

2. Are there sufficient data for generating a reliable reconstruction of HRV given the following?

- Site-specific data are lacking for most areas, requiring extrapolation from other areas and a great deal of expert opinion to fill the knowledge gaps.
- There is insufficient temporal depth of data for most areas, precluding a reconstruction of historical conditions for a sufficiently long reference period, and the estimates derived from paleo-reconstructions become more uncertain further back in time for several reasons, making the analysis of long-term trends difficult.
- The spatial configuration and severity of disturbances are not usually identified with confidence from historical data, resulting in a general lack of information about the spatial variation of past conditions.

Our understanding of spatial and temporal dynamics in ecological systems will never be complete and will always be based on imperfect data. Consequently, in applying HRV concepts, multiple sources of information are needed, ranging from site-specific data and simulation models, to expert opinions and judgments. These disparate types of information allow for the forming and testing of hypotheses about how HRV concepts can best be applied to managing ecological systems. Of course, HRV results must be interpreted within the scope and limitations of the information sources, but the ultimate issue is whether we are able to make more informed decisions with or without an HRV based on the incomplete and imperfect data.

3. Is HRV practical for managing dynamic, especially nonequilibrium, systems in today's society given the following?

Management systems are not geared to managing moving targets or coping with the uncertainty and surprise that are inherent and fundamental aspects of dynamic ecological systems. Consequently, managing dynamic systems will always be difficult and fraught with surprises.

Even in those cases where there is sufficient ecological understanding of how to manage the processes that drive dynamic systems, there may be insufficient social or political will to maintain or restore these processes given people's unwillingness to accept high uncertainty in the protection of life and property.

Even if there is sufficient ecological understanding and sociopolitical will to manage for variability, HRV derived under dynamic equilibrium conditions may not help us manage future landscapes under nonequilibrium conditions being driven by rapidly changing climate and human land use.

HRV is not a panacea for dealing with uncertainty and surprises, but no other approach will eliminate the uncertainties and surprises that are inherent in all dynamic systems. HRV merely helps to understand and communicate these uncertainties as "normal" behavior of the system. Moreover, using the concept of HRV to discuss planned forest management with the public can put change into contex. The concept of HRV can help people to understand and expect the changes brought about by disturbance events and to view them as important and integral to the resiliency of the system. Last, despite the possibility of novel and nonequilibrium conditions in the future, characterizing HRV can nonetheless help to determine when those future conditions might be forcing the system to operate outside its natural range of variability. This knowledge can either aid in building expectations for different future outcomes or serve as a "call to arms" for proactive management to promote greater resiliency.

Why Simulation Modeling?

Range of variability analyses have been conducted by using literature searches exclusively, including within the Sierra Nevada (e.g., Safford and Stevens 2017). Results of such analyses depend on the assumption that an aggregation of many small studies is sufficient to address long-term, broad-scale questions, and require researchers to accept many unknowns about research methodologies. Moreover, in landscapes severely impacted by European settlement, such as those of the northern Sierra Nevada, we can never observe trajectories in which fire suppression is not part of the equation (Keane 2012). In the absence of consistent and complete data, simulations can be used to incorporate the data available and generate new datasets of otherwise unobservable landscape trajectories (Keane et al. 2009; Mladenoff and Baker 1999; Swetnam et al. 1999). From these new datasets, statistical analyses can be used to describe the landscape quantitatively and subsequently make inferences about the HRV of an area, as well as compare current conditions to the HRV. Within the western United States, the Rocky Mountains and Oregon Coast Range in particular have been the focus of several simulated HRV studies. To our knowledge only one has been conducted in the Sierra Nevada, and it took place in Sequoia National Park in the southern Sierra (Miller and Urban 1999).

Models for simulating HRV (and NRV in general), as well as FRV, have proliferated since the early 1990s. By 2004, some 45 landscape disturbance and succession models alone had been developed (Keane et al. 2004). Many of these, such as SAFE-FORESTS (Sessions et al. 1997), LANDIS (He and Mladeno 1999), ZELIG-L (Miller and Urban 1999), BFOLDS (Perera et al. 2003), SIMPPLLE (Chew et al. 2004), LANDSUM (Keane 2012), and RMLands (McGarigal and Romme 2005a,b, 2012) are still in use today. Such models are used to create spatially explicit simulations of both of these key forest processes, typically generating a set of GIS layers for each timestep of the model that can then be analyzed to quantify trajectories and patterns in the disturbance regime and vegetation over time (Gustafson et al. 2010; Keane et al. 2004).

Scope and Limitations

This study relied on computer models, so the scope and limitations of the modeling must be understood from the outset.

First, we used a "phenomenological" modeling approach that sought to emulate the statistical properties of disturbance and succession processes consistent with the historical data. This contrasts with a "mechanistic" modeling approach, which tries to simulate the actual physical, chemical, or biological mechanism of the process, such that the outcomes are emergent properties of the mechanism governing the process (Gustafson 2013). Of course, there are advantages and disadvantages to both approaches. The major advantage of the phenomenological approach is that it does not require a complete understanding of the mechanisms associated with the processes, requires far fewer model parameters, and can be more easily parameterized to reflect the limited observations of real-world behavior (which are more often statistical rather than mechanical). The major disadvantage is that the algorithms can be somewhat arbitrary, and thus may not have an intuitive ecological interpretation or may be viewed as somewhat of a "black box." The major advantage of the mechanistic approach is that if the mechanisms are well understood and parameterized correctly, it allows for the projection of landscape changes under novel environmental conditions (e.g., future climate) for which we have no observational data. Because we used a phenomenological modeling approach, we limited our simulations of wildfire disturbance to reflect the historical and modern fire record. In particular, we did not project wildfire disturbance under future climate conditions.

Second, the model results should be viewed as "fuzzy" estimates, not as exact answers. Models have many uses and advantages over strictly empirical studies, but they are fundamentally abstract and simplified representations of reality. This is especially true for landscape disturbance-succession models. The processes that drive real landscapes to change are far too many and complex to model comprehensively and accurately. Therefore, our goal in modeling these systems is to capture the most important drivers well enough that our results, in a very general sense, reflect our real-world expectations. Although it is tempting to view the results as exact, given their quantitative nature and apparent numerical precision, we should resist overinterpreting them.

Third, as long as the model gets it right most of the time, it still can have great utility. The results of our model, as with any model, are constrained by the quality of input data, which are not perfect. For example, the vegetation cover layer is subject to human interpretation errors and objective classification errors, and is further limited by the spatial resolution of the grid. Consequently, there will be places where the model gets it wrong, not necessarily because the model itself is wrong, but rather because the input data are wrong. Getting it wrong in some places, however, should not undermine the utility of the results as a whole. In the end, the results should be used and interpreted with the appropriate degree of caution and an appreciation for the limits of the available data.

Fourth, the model results are subject to change as new scientific understanding or better data become available. RMLands, like all landscape disturbance-succession models, requires substantial parameterization before it can be applied to a particular landscape. To the extent possible, we used local empirical data. However, we also drew on relevant scientific studies, often from other geographic locations, and relied heavily on expert opinion when scientific studies and local empirical data were not available. Despite our best efforts to incorporate the most relevant data and scientific findings, it is clear that we have a very limited understanding of the disturbance and succession processes being modeled. This does not undermine the utility of the results. The key question is whether the results lead to more informed and thus better decisions. Moreover, the model should lead to new insights that might at first seem counterintuitive or inconsistent with our limited observations, because the model is able to integrate a large amount of data over broad spatial scales and long timeframes in a consistent manner and thus provide a perspective not easily obtained via direct observation.

Fifth, the model results reflect landscape dynamics as driven by the selected succession and disturbance processes—in our case, wildfire and forest vegetation treatments (both mechanical and prescribed fire). The results do not reflect the influence of other disturbance processes or all of the complex interactions among them that characterize real landscapes and drive the full range of variability. Other kinds of natural disturbances also occur in the project area, including insects and disease, windthrow, wild ungulate and beaver herbivory, avalanches, and other forms of soil movement, but the impacts of these other natural disturbances tend to be localized in time or space and have far less impact on vegetation patterns over broad spatial and temporal scales than does fire. In addition, other kinds of anthropogenic disturbances also occur, including domestic livestock grazing and both rural and urban development. These also tend to be extremely limited within the project area, however; they thus also have limited impact on coarse vegetation patterns and dynamics, at least within the project area.

Sixth, the model results pertaining to individual cover types should be interpreted with caution for cover types having limited extent within the project area. The Sierra Nevada vegetation is extremely diverse and complex in its spatial arrangement of ecological settings and conditions; accordingly, the accuracy of maps of each unique ecological setting (i.e., cover type) and condition varies considerably. In general, because the model results are statistical in nature, confidence in the model results should decline as the extent of a cover type declines. Consequently, we limit our interpretation of the results to cover types that extend across 1,000 hectares (2,500 acres) or more of the project area.

Last, extrapolating the model results for the upper Yuba River watershed to other landscapes should be done with caution. Landscapes are idiosyncratic; in other words, they have a unique internal structure and history such that no two landscapes are the same. Our general findings pertain to other similar surrounding landscapes and can probably be safely extrapolated to some extent. However, to the extent that detailed quantitative results are desired for other geographies, a separate modeling exercise should be undertaken.

PROJECT AREA

Physical Geography

The Sierra Nevada is a major North American mountain range and ecological region, located east of California's Central Valley and extending from Fredonyer Pass in the north to southern Kern County in the south. Much of the Sierra Nevada is reserved as Federally held public land, managed by the Forest Service, Bureau of Land Management, and National Park Service. The Tahoe National Forest is located in the northern portion of the Sierra Nevada. The project area is located on the northern part of the Tahoe National Forest, on the Yuba River and Sierraville Ranger Districts, and encompasses 181,556 hectares (448,625 acres) (fig. 1). It is defined by a set of three Hydrologic Unit Code level-5 watersheds, the Upper North Yuba River, the Middle Yuba River, and the Lower North Yuba River, which are collectively referred to in this document as the "upper Yuba River watershed."

The topography of the project area consists of rugged mountains incised by two major and a few minor river drainages. Elevation ranges from about 350 to 2,500 meters (1,100–8,200 feet). The area receives 30–260 centimeters (12–102 inches) of precipitation annually, with snow exceeding rain above about 1,750 meters (5,740 feet) elevation (Storer and Usinger 1963). A summer drought typically persists from May to September, increasing the importance of developing a significant snowpack during the winter because snowmelt runoff is a key source of soil moisture during the late spring and summer (Minnich 2007). In the Sierra Nevada, the heaviest precipitation occurs to the east and north of the San Francisco Bay area; our project area is within this region (Van Wagtendonk and Fites-Kaufman 2006). Datasets of the 30-year normal (1981–2010) precipitation at 800-meter (2,600-foot) resolution for the northern Sierra illustrate that particularly high amounts of precipitation fall across the middle elevations of the project area compared to the larger region (Oregon State University 2014). This increased moisture contributes to the occurrence of exceptionally productive patches of forest (Alan Doerr, Tahoe National Forest, Camptonville, California, personal communication, May 2013; Littell et al. 2012).

Land Use

The arrival of Euro-Americans in the 1850s sparked a transformation of this landscape as people harvested timber, extracted gold using hydraulic mining techniques, and suppressed wildfires (Storer and Usinger 1963). Forestry, mining, grazing, and dozens of recreational activities, including hunting, mountain biking, and hiking, are all important uses in the project area. Fifteen cattle and sheep grazing allotments exist within the project area. In addition, 57,117 hectares (141,136 acres) inside of the project area have non-Forest Service ownership. Many of these lands were privately held, often by timber companies, before the Tahoe was created. In addition, many public lands were given to the Central Pacific Railroad in the late 19th century and subsequently returned to the public land system under the Bureau of Land Management, resulting in a "checkerboard" ownership pattern persisting today (fig. 2). Mining of gold and other minerals also continues. These activities affect and interact with ongoing vegetation succession and disturbance processes in the area (USDA Forest Service 2014).

Although many uses of the forest led to changes in vegetation structure and composition, logging and wildfire suppression since the early 19th century in combination have altered the historical fire regime and vegetation patterns the most (Hessburg et al. 2005; Knapp et al. 2013; McKelvey et al. 1996; Safford and Stevens 2017; Stephens et al. 2015). The Tahoe National Forest has active timber and fire management programs. Clearcutting, shelterwood,

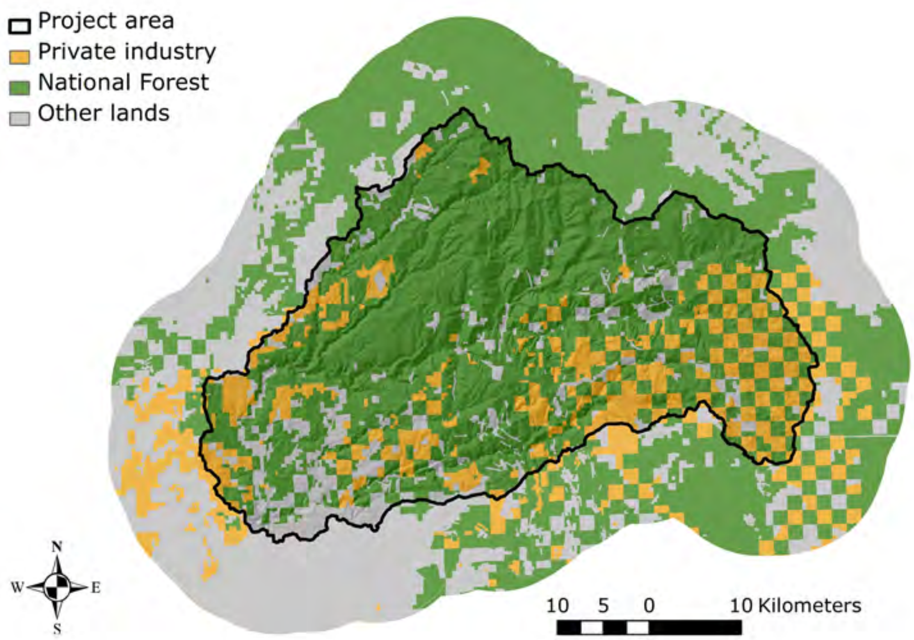


Figure 2—Map of land ownership within the upper Yuba River watershed located on the Tahoe National Forest. This image also depicts the 10-km (6-mi) buffer around the project area that was included in the simulations.

salvage cutting, and plantation management have been major components of timber management on the forest in the past. Between 1988 and 2002, timber sales in the Sierra Nevada dropped drastically, but on the Tahoe National Forest timber sale levels have fluctuated both up and down (although annual sawtimber sold has decreased similarly to other Sierran national forests) (USDA Forest Service 2004). Although the area burned in the Sierra Nevada has been increasing over the past several decades (Miller et al. 2009b), relatively few large fires have impacted the upper Yuba River watershed in the last 100 years (USDA Forest Service 1990). Total burned area is low despite fairly high fire starts (both human and lightning caused), indicating that suppression efforts have been very successful (USDA Forest Service 1990).

Vegetation

Vegetation in the project area is tremendously diverse and changes slowly along an elevation gradient and in response to local changes in microclimate and soils, and includes the following major ecological zone groupings (Van Wagtendonk and Fites-Kaufman 2006) (see also Appendices A and B; capitalized cover types and variants are defined and described in the latter):

- Foothill shrubland and woodland—This zone lies directly adjacent to and west of the project area. A small part of the buffer that we used around the project area (see *HRV Model Execution*) includes this zone, which is represented by the Oak Woodland cover type. This type is characterized by savannas, woodlands, or forests of either monospecific or mixed stands of various broadleaf species, including: blue oak (*Quercus douglasii*), valley oak (*Q. lobata*), interior live oak (*Q. wislizenii*), canyon live oak (*Q. chrysolepis*), madrone (*Arbutus menziesii*), California buckeye (*Aesculus californica*), and bigleaf maple (*Acer macrophyllum*). Foothill pine (*Pinus sabiniana*) is also an important tree in this zone, and chaparral shrubland stands are common as well.

- *Lower montane forest*—This zone includes Oak-Conifer Forests and Woodlands and Mixed Evergreen Forests at lower elevations, developing into Sierran Mixed Conifer Forests with increasing elevation. All three of these cover types are typified by a combination of both coniferous and broadleaved trees.

Mixed Evergreen Forest is characterized on very moist sites by dense stands of tanoak (*Notholithocarpus densiflorus*) and madrone with a variable component of Douglas-fir. In mesic sites, Douglas-fir will often dominate, and broadleaf species are dominated by canyon live oak and California black oak (*Q. kelloggii*). In dry sites Douglas-fir is less common, and is replaced by patchy stands of foothill pine and (mostly evergreen) oaks (canyon live oak and interior live oak), interspersed with chaparral and occasional stands of knobcone pine (*P. attenuata*). Historically, low- and mixed-severity fires were fairly common in this cover type (mean fire return interval, FRI = ~30 years), and vegetation would quickly recover even from severe fires because the hardwood dominants resprout after fire.

Oak-Conifer Forests and Woodlands are characterized by ponderosa pine and one or more oaks, such as California black oak, interior live oak, or canyon live oak. Lower amounts of incense cedar, Douglas-fir, and sugar pine are also found in these forests. Historically, low-severity fires were extremely common. Fire is integral to the ecology of yellow pines, and this cover type is one of the most altered by fire suppression and urban development.

Sierran Mixed Conifer Forests are characterized by multiple conifer and hardwood species, including: ponderosa pine, Jeffrey pine (*Pinus jeffreyi*) (in higher, colder, or drier sites and on the east side of the Sierra crest), sugar pine, white fir, Douglas-fir, incense cedar, California black oak, canyon live oak, and other broadleaf species. At least three conifers are typically present in any given stand. Today white fir and Douglas-fir tend to be the most ubiquitous species, especially on moister aspects and drainages. Pines were historically the dominant species under the previous frequent low-severity fire regime and are still common on south slopes. Pines (primarily ponderosa pine) are present continuously from the Oak-Conifer Forest and Woodland zone below it in elevation. Historically, low- to moderate-severity fires were very frequent in this forest type (mean FRI = ~11–16 years), and fire suppression and widespread logging have greatly altered forest structure and composition (Safford and Stevens 2017).

- *Upper montane forest*—This zone is defined by the presence of Red Fir Forests, which occur within and above the level of maximum precipitation and maximum snowfall on the Sierra Nevada westslope (Potter 1998; Safford and Van de Water 2014). The Red Fir cover type is dominated by red fir (*A. magnifica*), but other species do co-occur, for example western white pine (*P. monticola*) and lodgepole pine (*P. contorta* ssp. *murrayana*). On xeric sites, Jeffrey pine can occur. Historically, wildfires were less common in these forests than those of the lower montane zone (mean FRI = ~40 years), and stands were characterized by complex patches of even-aged trees within a single stand arising from localized disturbance events. The boundaries between Sierran Mixed Conifer and Red Fir Forests are fuzzy, and the types tend to co-occur, particularly in the ecotones. Similarly, Red Fir Forests of the upper montane zone blend into the lodgepole pines and subalpine conifers of the subalpine forest zone.
- *Subalpine forest*—This extremely heterogeneous zone is composed of patches of dense trees, rock outcrops, meadows and lakes, and open forest. This zone includes two major cover types: Lodgepole Pine and Western White Pine. Lodgepole pine is found throughout the subalpine zone in a variety of habitats, including in wetter soils, such as along meadow edges, or in very rocky soils. Unlike the subspecies of lodgepole pine found in the Rocky Mountains, the lodgepole pine subspecies found here does not have serotinous cones.

Wildfires in lodgepole pine occur in a mixture of severities, from low-severity underburning in drier subalpine stands, to high severity in dense stands in drainages. Mountain hemlock (*Tsuga mertensiana*) is common on north slopes where heavy snows accumulate. Red fir is often an associate. Drier slopes support western white pine at lower elevations and whitebark pine (*P. albicaulis*) at higher elevations. Trees often grow as krummholz forms at the highest elevations. Wildfire is relatively rare in this cover type (mean FRI > ~100 years).

Western white pine sometimes occurs in sufficiently continuous patches to be classified as its own type, separate from the Subalpine Conifer group. Typified by western white pine, species from the Subalpine Conifer and Red Fir cover types sometimes co-occur as well. This cover type tends to occur on drier soils. Most fires are low severity, which promotes the development of late-successional forests.

- <u>*Eastside forest and woodland*</u>—Although the project area does not include any lands east of the Sierra crest, the buffer around the project area created for purposes of the simulation (see *HRV Model Execution*) does, and we classified and described the Eastside Yellow Pine cover type to capture most of this vegetation community. It is characterized by Jeffrey pine (with some ponderosa pine), but other conifers and oaks, as well as western juniper (*Juniperus occidentalis*) may occur. Under historical conditions, wildfires were extremely common and were almost always low severity; fire is integral to the ecology of yellow pines. Oak-Conifer Forests and Woodlands, as described previously, are also present in this zone. Also east of the crest are two shrub community types typified by either big sagebrush (*Artemisia tridentata*) or a mixture of black sagebrush (*A. arbuscula*) and low sagebrush (*A. nova*).
- <u>*Other cover types and variants*</u>—Some cover types not already listed can be found in any zone. Montane riparian vegetation occurs throughout the project area and is usually dominated by willow (*Salix* spp.), alder (*Alnus* spp.), and cottonwood (*Populus* spp.). Curl-leaf Mountain Mahogany (*Cercocarpus ledifolius*), a shrubland cover type, is most common in the upper montane zone and above, but may occur in the lower montane zone as well. Several of the major forest cover types described earlier include variants growing on ultramafic ("serpentine") soils, which are characterized by low levels of macronutrients and high levels of toxic heavy metals (Alexander et al. 2006). Vegetation on ultramafic soils is almost always more open than on neighboring, more fertile substrates and therefore supports a more diverse understory. Chaparral stands are common on ultramafic sites, but open forests are also found, dominated by Jeffrey pine, incense cedar, and other conifers usually at low density. Many endemic species grow on ultramafic soils (Safford et al. 2005), and biomass and fuels accumulation is lower than on other soil types (DeSiervo et al. 2015). Several of the major forest cover types include an aspen (*Populus tremuloides*) variant that is seral to the corresponding conifer forest type in the absence of fire, thereby maintaining the aspen component.

METHODS

Historical Range of Variability and Departure

RMLands Overview

To simulate fine-grained disturbance and succession processes representative of the historical reference period within the project area, we used the RMLands (Rocky Mountain Landscape Simulator) landscape disturbance-succession model. RMLands was originally developed to simulate HRV of forests in southwestern Colorado (McGarigal and Romme 2005a,b, 2012), but it has been similarly applied to forests in the northern Rocky Mountains in Montana (Cushman et al. 2011). Here, we adapted the software for use in the Sierra Nevada. It is beyond the scope of this document to fully describe RMLands (a detailed technical document is forthcoming). Here, we provide only a brief overview of the model structure and a brief description of the major components pertaining to the simulation of natural disturbance and succession processes:

- *Grid-based*—The data format is a grid or raster. Each cell or pixel has a suite of attributes that record its biophysical condition and disturbance history over time. Disturbance and succession act to change these attributes over time. The grain (cell size) and extent of the grid is limited only by computer memory.
- *Spatially explicit*—Location matters, particularly in the disturbance model, in which disturbance events are modeled as a contagious process—that is, one that spreads from cell to cell. For example, the location of a cell will affect whether it gets disturbed during an event because the disturbance may spread faster uphill, in the direction of the prevailing wind, or through more susceptible vegetation.
- *Stochastic*—Each step of the disturbance and succession processes has a stochastic component that adds uncertainty to the outcome. Consequently, the model outcomes from replicate simulations will never be exactly the same. As a result, the specific outcomes are not intended to be predictive of what will actually happen in any particular place at any point in time. Rather, the outcomes are intended to be representative, in a statistical sense, of the kinds of outcomes that could happen.
- *Process-oriented*—The model simulates disturbance and succession as processes. Specifically, the model treats each process as having a series of steps that reflect our understanding of how these processes play out in the real world. For example, disturbance events are initiated, spread, terminate, and then affect the vegetation.
- *Phenomenological*—The model seeks to emulate the statistical properties of disturbance and succession processes, in other words produce simulated behavior that is consistent with the statistical properties of real-world observations (e.g., mean disturbance patch size, mean return interval). In this statistical or phenomenological modeling approach, the mechanics of the process are deemed unimportant so long as the observed statistical properties of the phenomenon are emulated well. For example, the actual mechanism by which a fire of a given intensity determines whether a tree (or stand) is killed (i.e., severity) is not represented explicitly in the algorithm. Instead, the algorithm is designed to produce the desired result of, say, a 20-percent chance of high severity.

Given this overall modeling structure, succession occurs at the beginning of each timestep in the simulation and represents the gradual growth or development, or both, of vegetation communities over time. Succession is implemented with a stochastic state-and-transition approach in which vegetation cover types transition probabilistically between discrete states (seral stages). Transition pathways and rates of transition between states are defined uniquely for each cover type and can be conditional on any number of biophysical and disturbance history attributes of a cell tracked by the model. We forced succession to occur in patches, defined as spatially contiguous cells having the same cell attributes (e.g., identical disturbance history and age). Succession patches represent something akin to forest stands. Most cover types progress through a series of seral stages (states) over time as a result of successional processes (albeit at different rates due to the stochastic nature of succession). In some cases, these transitions are affected by the occurrence of certain disturbances (e.g., low-severity fire) or are regulated by management (e.g., silviculture). Other cover types (e.g., Meadow, Barren, Water) are treated as nonseral and remain in the same state over time (i.e., they are static).

Disturbance follows succession in each timestep in the simulation. RMLands uses a generic disturbance algorithm that can be meaningfully parameterized to represent a variety of natural disturbances, including fire, insects and pathogens, and wind, although only fire was simulated in this project. Each disturbance process is implemented separately, but affects and is affected by other disturbance processes operating concurrently to produce changes in landscape conditions. The common disturbance algorithm consists of the following key components:

- *Climate*—Climate can play a significant role in determining the temporal and spatial characteristics of the disturbance regime. Climate is specified as an optional global parameter that can affect initiation, spread, and mortality for all disturbance events within a timestep. Climate can be specified as constant with a user-specified level of temporal variability, a trend over time (with variability), or a user-defined trajectory reflecting the climate conditions during a specific reference period.
- *Initiation*—Disturbance events are initiated at the cell level. Each cell has a relative probability of initiation in each timestep that is a function of its susceptibility to the disturbance, which can be specified as a function of any of the spatial attributes of the cell (e.g., cover type, seral stage, time since last disturbance, and topographic position). However, the overall initiation rate is governed by a single global parameter that determines the number of disturbance attempts per unit area.
- *Spread*—Once initiated, disturbance spreads to adjacent cells (or nearby cells via "spotting") in a probabilistic fashion. Each cell has a probability of spread during each iteration of the spread process that is a function of its susceptibility to disturbance (as defined in the preceding paragraph), which can be further modified in a variety of ways including, for example, its relative position (e.g., relative elevation or wind direction), the influence of potential barriers (e.g., roads and streams), and the maximum size of the event.
- *Termination*—An event terminates either due to the probabilistic spread (i.e., fails to spread further by chance due to the low spread probabilities in adjacent cells) or because of a limit placed on spread to reflect variable weather conditions at the time of the event. This event modifier limits the final size of the disturbance and is specified as a user-defined size distribution.
- *Mortality*—Following spread, each cell is evaluated to determine the magnitude of ecological effect of the disturbance. Each cell can exhibit either high mortality (>75 percent of the dominant overstory plants are killed) or low mortality.
- *Seral stage transition*—Following mortality, each cell is evaluated for potential immediate transition to a new seral stage (state). Transition pathways and rates of transition between states are defined uniquely for each cover type and can be conditional on any attribute of the cell. Note: These immediate disturbance-induced transitions are differentiated from the successional transitions that occur at the beginning of each timestep in response to gradual growth and development of vegetation over time.

HRV Spatial Input Data

We compiled several spatial input data layers needed for the HRV simulation. All layers were represented as 30-meter (100-foot) rasters. See Appendix A for a detailed description of these layers. We provide a brief description of three important layers here.

- *Cover type*—We developed a system of land cover classification based on LandFire (2007) biophysical settings and the presettlement fire regimes of Van de Water and Safford (2011), crosswalked to the Forest Service corporate spatial data based on the North Sierran CALVEG classification using the Forest Service Region 5 existing vegetation layer (EVeg). We also considered information from the updated A Guide to Wildlife Habitats of California (Mayer and Laudenslayer 1988), popularly known as the "Wildlife Habitat Relationship" cover types. Our classification included 31 cover types, although many of these were variants of the major types based on microclimate (mesic versus xeric) and soils (ultramafic) (table 1). Cover types included both potential natural vegetation types (i.e., the expected vegetation community

Table 1—Cover types in the upper Yuba River watershed project area, including the formal project area and the simulation area (project area plus 10-km [6-mi] buffer), given in rank order of extent within the core project area.

Cover type	Abbreviation	Project area (ha)	Project area (ac)	Simulation area (ha)	Simulation area (ac)
Sierran Mixed Conifer – Mesic	SMC_M	57,853	142,955	133,920	330,916
Sierran Mixed Conifer – Xeric	SMC_X	52,198	128,981	91,443	225,956
Oak-Conifer Forest and Woodland	OCFW	23,279	57,522	56,987	140,815
Red Fir – Mesic	RFR_M	8,563	21,159	19,626	48,496
Red Fir – Xeric	RFR_X	7,493	18,515	9,989	24,683
Mixed Evergreen – Mesic	MEG_M	7,273	17,972	13,548	33,477
Mixed Evergreen – Xeric	MEG_X	6,768	16,724	13,774	33,036
Sierran Mixed Conifer – Ultramafic	SMC_U	4,124	10,190	9,774	24,152
Water[a]	WAT	4,058	10,027	8,157	20,156
Barren[a]	BAR	2,665	6,585	8,751	21,624
Grassland[a]	GRASS	1,379	3,408	4,617	11,409
Meadow[a]	MED	1,201	2,968	3,435	8,488
Oak-Conifer Forest and Woodland – Ultramafic	OCFW_U	1,060	2,619	2,185	5,399
Lodgepole Pine	LPN	837	2,068	2,816	6,958
Montane Riparian	MRIP	732	1,809	2,216	5,476
Subalpine Conifer	SCN	638	1,576	2,044	5,051
Mixed Evergreen – Ultramafic	MEG_U	604	1,492	1,655	4,090
Red Fir – Ultramafic	RFR_U	294	726	321	793
Western White Pine	WWP	273	675	510	1,260
Urban[a]	URB	114	282	782	1,932
Sierran Mixed Conifer with Aspen	SMC_ASP	58	143	121	299
Red Fir with Aspen	RFR_ASP	31	77	34	84
Oak Woodland	OAK	19	47	4,192	10,358
Curl-Leaf Mountain Mahogany	CMM	18	45	41	101
Agriculture[a]	AGR	16	40	5,416	13,383
Lodgepole Pine with Aspen	LPN_ASP	8	20	31	77
Yellow Pine	YPN	0	0	10,499	25,943
Big Sagebrush	SAGE	0	0	1,600	3,954
Subalpine Conifer with Aspen	SCN_ASP	0	0	6	15
Black and Low Sagebrush	LSG	0	0	5	12
Yellow Pine with Aspen	YPN_ASP	0	0	3	7
Total		181,556	448,625	408,498	1,009,399

[a] Cover types treated as nonseral.

in the presence of natural disturbance regimes, such as Sierran Mixed Conifer) and current anthropogenic cover types (e.g., Agriculture). The anthropogenic cover types were retained for the HRV simulation because we had no way to predict the potential natural vegetation type for these areas with any certainty. We assigned each cell to a single cover type, which we treated as static (i.e., constant over time) during the simulation; cover type served as a fixed spatial template upon which disturbance and succession processes played out over time.

- <u>Seral stage</u>—We classified each cover type, except those treated as nonseral such as Barren and Meadow (table 1), into seral stages based on a combination of developmental stage (early, mid-, late development based on expected tree size of the dominant and codominant individuals), and canopy cover class (open, moderate, and closed canopy based on percent canopy cover from above) derived primarily from the EVeg layer (table 2). The specific tree sizes and percent canopy cover for each seral stage varied among cover types as given in Appendix B. Our classification was similar to LandFire except that we added a moderate canopy cover stage to the mid- and late-development stages. In addition, we created a unique classification scheme for the Mixed Conifer-Aspen cover types. We initially assigned each cell to a single seral stage, but unlike with cover type, we treated seral stages as dynamic (i.e., changing over time) in response to simulated succession and disturbance. Because RMLands does not model individual trees, we used age in the model as a proxy for tree size to determine transitions from one developmental stage to the next. The combination of cover type and seral stage formed the primary basis for characterizing vegetation patterns and dynamics.
- <u>Topographic position index</u>—We created a topographic position index (TPI) that combined heat load, which was based on aspect and slope, with slope position. We scaled the index to the project area (including the buffer; see *HRV Model Execution*) such that the values were relative to topography of the project area. We assigned a TPI value to each cell, which was of course treated as static during the simulation. High values of TPI were associated with locations on steep, south- and west-facing, upper slopes. Low values were associated with locations on gentle, north- and east-facing, lower slopes, and valley bottoms. Values in between occurred along a gradient of these characteristics. We used TPI to affect wildfire susceptibility and mortality as described next.

Table 2—Seral stages defined for cover types in the upper Yuba River watershed. Seral stages represent a combination of vegetation development stage (based on size of the dominant and codominant individuals) and canopy cover class. The tree sizes and percent canopy cover for each seral stage varied among cover types as given in Appendix B.

Seral stage	Abbreviation
Nonseral	NS
Early - all structures	ED
Mid-open	MDO
Mid-moderate	MDM
Mid-closed	MDC
Late-open	LDO
Late-moderate	LDM
Late-closed	LDC
Early - Aspen	ED-A
Mid - Aspen	MD-A
Mid - Aspen and Conifer	MD-AC
Late - Conifer and Aspen	LD-CA

HRV Model Parameterization

RMLands has many model parameters that govern the disturbance and succession processes, and these must be specified by the user to represent a particular scenario. For the HRV scenario, we parameterized the model to reflect our best understanding of the succession and disturbance processes characteristic of the historical reference period in the project area. Most of the model parameters were associated with state-and-transition models defined for each of the cover types, although some parameters were global and applied to all cover types. Here, we describe the global parameters and the general parameterization of the state-and-transition models; see Appendix B for the detailed parameterization of each cover type model.

Each state-and-transition model defined the alternative states (i.e., seral stages) of the cover type and the rules for transitioning among states due to both succession and disturbance processes. Not all cover types had the seven-state model depicted in figure 3. The Mixed Conifer-Aspen cover types had either a three-state model (Subalpine Conifer with Aspen, Yellow Pine with Aspen) or five-state model (Lodgepole Pine with Aspen, Red Fir with Aspen, and Sierran Mixed Conifer with Aspen). The shrubland cover types (Black and Low Sagebrush, Curl-leaf Mountain Mahogany, and Big Sagebrush) all had a three-state model. In general, however, our state-and-transition models followed those defined by the corresponding LandFire models, except for the additional moderate-canopy cover state.

The state-and-transition model for each cover type included a set of rules that governed the succession process. In general, these rules specified how long a cell remained in a seral stage, subject to certain contingencies, before probabilistically transitioning to the next seral stage. We used LandFire models to determine the initial transition probabilities, but we subsequently evaluated and refined these probabilities with input from local experts and current literature to capture subtle changes in succession at the project scale. Four important characteristics of the final succession rules are worth noting:

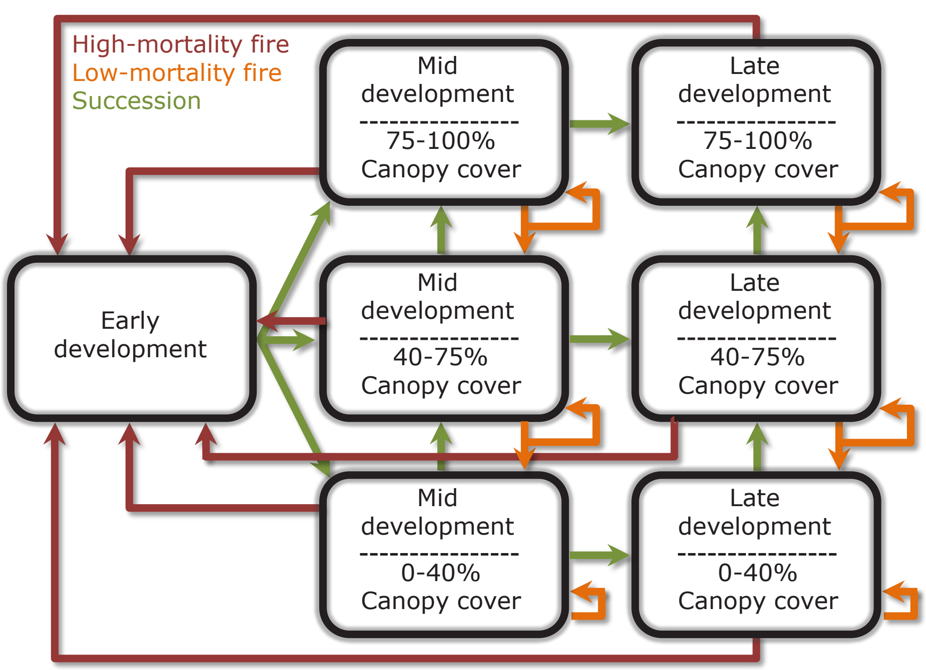


Figure 3—Generic state-and-transition model for forested cover types. Each box represents one of the seven standard seral stages (or states) for a forested cover type. Each column of boxes represents a stage of vegetation development. Each row of boxes represents a different level of canopy cover. Transitions between seral stages may occur as a result of high-mortality fire, low-mortality fire, or succession, each of which is indicated by a colored arrow between boxes.

1. Succession transitions between developmental stages (from early to mid- to late development) were governed by development age (i.e., how long the cell was in the current developmental stage) because, as noted previously, RMLands uses age as a proxy for tree size. For example, if a cell was in the early-development stage for, say, 20 years, it was given some probability of transitioning to the mid-development stage.
2. Succession transitions between canopy cover states (from open to moderate to closed canopy) were governed by a combination of seral stage age (i.e., how long the cell was in the current seral stage) and the time since the last low-mortality fire. For example, if a cell was in the mid-development, open-canopy cover seral stage for, say, 20 years without the occurrence of low-mortality fire, it was given a probability of transitioning to the mid-development, moderate-canopy cover seral stage.
3. All transitions were probabilistic once minimum required conditions were met (e.g., seral stage age and time since low-mortality fire). For probabilities less than 1, it was therefore possible for a cell to remain in a state for many timesteps. As a whole, cells eligible for transition did so gradually. This allowed us to capture the range of postfire behaviors, from rapid tree growth to the presence of a multidecade chaparral stage.
4. Succession pathways were sometimes branching; that is, one seral stage transitioned with some probability to two or more different seral stages. For example, in some models if a cell was in the early-development seral stage for some years it was given some probability of transitioning to either the mid-development open-canopy, moderate-canopy, or closed-canopy seral stage. As a result, some percentage of the cells would transition into each of the mid-development canopy cover seral stages, perhaps reflecting the relative likelihood of successful establishment of trees following disturbance.

The state-and-transition model for each cover type included several parameters that governed the occurrence of wildfire in that cover type as well as a set of rules that governed the disturbance-induced seral stage transitions (i.e., immediate transitions between seral stages caused by the disturbance).

- *Climate*—The climate modifier was governed by a global parameter (*C*) that operated across all cover types within a timestep (*t*); thus, a single climate value was assigned to each timestep and it affected the rate of wildfire initiation, spread, and mortality. The climate parameter was based on a rescaling of the Palmer Drought Severity Index (PDSI). PDSI is a long-term measure of drought, on the scale of months to years. It is based on precipitation and temperature and incorporates soil moisture. Reconstructed PDSI values for the summer months during the historical reference period (1550–1850) are available from the National Oceanic and Atmospheric Administration (www.ncdc.noaa.gov/paleo/pdsi.html). We used datasets from Zhang et al. (2004) and Cook et al. (2004). These data are summarized at broad scales; for example, the Cook et al. (2004) data are calculated for a grid with points spaced at 2.5°. We selected the five points closest to the center of the project area from these two datasets and calculated the inverse distance-weighted mean of the values. We then converted the yearly data into 5-year averages to align with the 5-year timesteps in our model, centered the mean value on 1, rescaled the values to range between about 0.5 and 1.5, and took the inverse so that values less than 1 represented wetter-than-normal timesteps, and values greater than 1 represented drier-than-normal timesteps (fig. 4).
- *Susceptibility*—Susceptibility (*S*), which affected both wildfire initiation and spread, was determined by two major factors: (1) topographic position (*T*), and (2) fuel characteristics (*F*). Specifically, the *S* of the i^{th} cell in the current timestep (*t*) was determined by the product of these two factors, each represented as probabilities (0–1):

  $$S^{it} = T_i \times F_{it}$$

  Topographic position was computed as a logistic transformation of TPI and was treated as having a constant (over time) and universal effect on all cells of certain cover types (table 3) regardless of seral stage or disturbance history. We allowed topographic position to affect

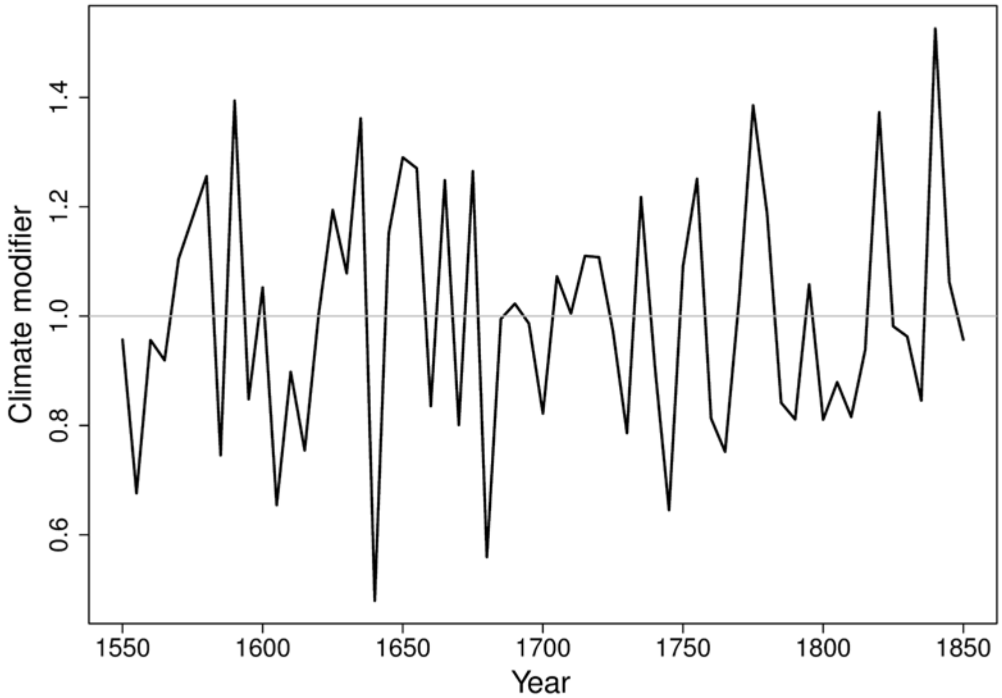


Figure 4—Climate modifier parameter derived from the Palmer Drought Severity Index, rescaled, inverted, and represented as a 5-year average for the historical reference period (ca. 1550–1850).

Table 3—Cover types whose susceptibility to fire and mortality following fire was modified by topographic position (based on the topographic position index).

Lodgepole Pine	Red Fir – Mesic
Mixed Evergreen – Mesic	Red Fir – Xeric
Mixed Evergreen – Xeric	Red Fir – Ultramafic
Mixed Evergreen – Ultramafic	Sierran Mixed Conifer – Mesic
Oak Woodland	Sierran Mixed Conifer – Xeric
Oak-Conifer Forest and Woodland	Sierran Mixed Conifer – Ultramafic
Oak-Conifer Forest and Woodland – Ultramafic	Western White Pine
	Yellow Pine

susceptibility for cover types that occurred across a broad range of topographic positions. For unaffected cover types, *T* was set to 1 and thus had no effect on *S*. For affected cover types, all other things being equal, susceptibility decreased by 30 percent as the TPI decreased over its full range (+3 to -3) according to the four-parameter logistic function depicted in figure 5. However, because the bulk of the landscape varied over a much smaller range of TPI values, the effect on susceptibility was typically much less than 30 percent. Thus, topographic position had no effect on susceptibility when TPI was maximum (i.e., on steeper, south- and west-facing, upper slopes), but acted to reduce susceptibility by up to 30 percent when TPI was minimum (i.e., on gentle, north- and east-facing, lower slopes, and valley bottoms). There was no empirical basis or published scientific studies that could be used directly to parameterize this function; thus, it was based on expert opinion and general support in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels were represented by vegetation cover type, seral stage, and recent disturbance history, and were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Fuels varied among cover types and seral stages in relation to the number of years since the last fire according to the function shown in figure 6.

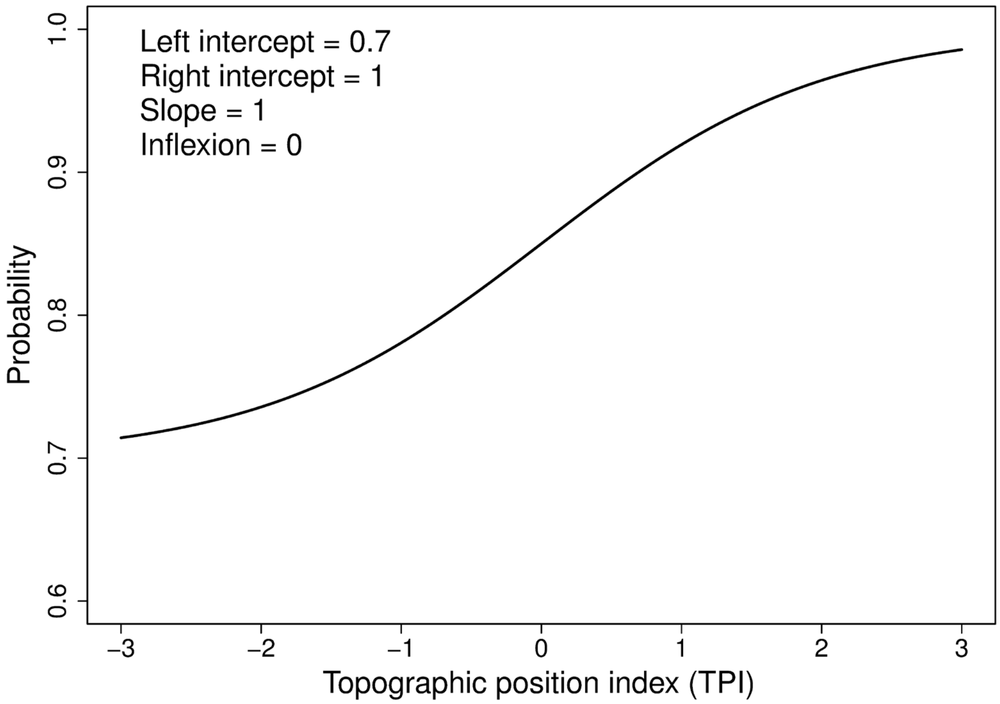


Figure 5—Susceptibility (relative probability) of a cell to wildfire as a logistic function of topographic position (as measured by the topographic position index; see text for description).

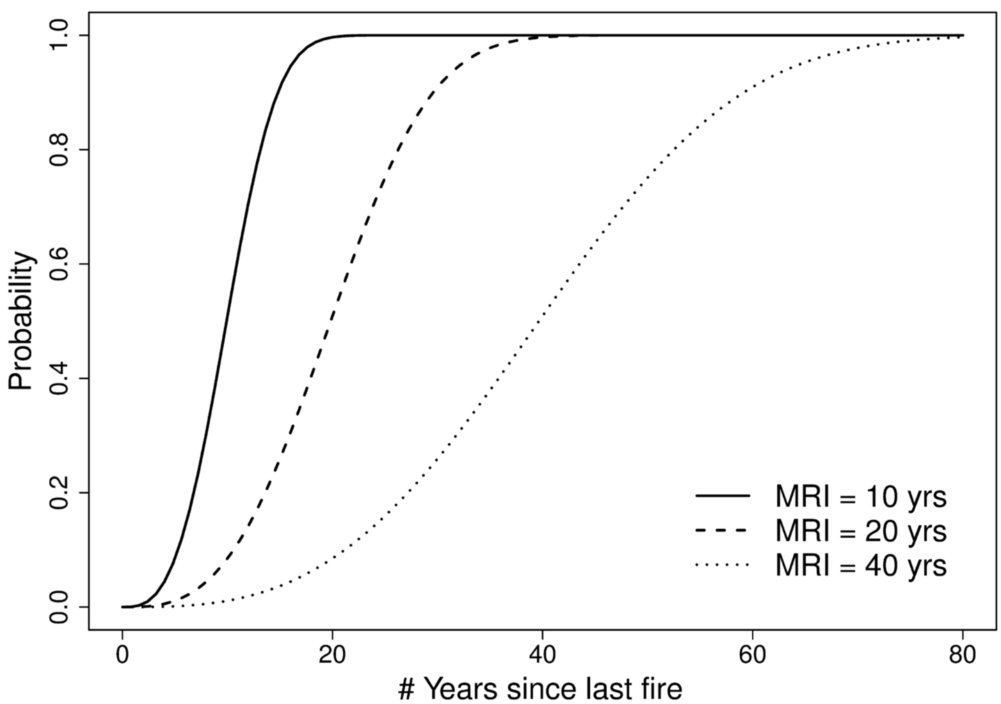


Figure 6—Susceptibility of a cell to wildfire given as a cumulative Weibull function of the number of years since the last wildfire, shown here for different mean return intervals and a shape parameter of 3.

Here, we used the cumulative form of the Weibull distribution, which gave the cumulative probability of a fire for any number of years since the last fire. Thus, the probability increased from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last fire. The shape parameter controls whether the probability of fire decreases (Shape <1), stays constant (Shape = 1), or increases (Shape >1) with the time since the last fire. We specified a Shape of 3 for all cover types, which represents a moderately strong feedback between the time since the last fire (as a proxy for fuel accumulation) and susceptibility (Collins and Stephens 2010).

We specified an MRI for each cover type and seral stage based on the corresponding LandFire models using the Vegetation Dynamics Development Tool (VDDT) models (LandFire 2007), as modified by H. Safford and B. Estes (Appendix B). We obtained single probabilities of wildfire for each cover type and each seral stage by summing the probabilities of a replacement, mixed, and surface fire (given by the corresponding VDDT model) and took the inverse (i.e., 1/ probability of fire) (e.g., table 4). Because we held the shape parameter of the Weibull function constant across all cover types and topographic position was a constant, susceptibility of the various seral stages was determined by MRI. However, these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS descriptions and modified VDDT models. Taken collectively, these values do not necessarily agree with the target fire rotation periods for the cover types (see *HRV Model Calibration and Verification*), which were based on values reported by Van de Water and Safford (2011) and Mallek et al. (2013) and expert input from Safford and Estes. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affected the relative susceptibility of the various vegetation states.

- *Initiation*—The relative probability of wildfire initiation (I) for the i^{th} cell in the current timestep (t) was determined by the product of susceptibility (S) and climate (C), as follows:

$$I_{it} = max\{S_{it} \times C_t, 1\}$$

Thus, the relative probability of initiating a wildfire within a timestep increased across all cells when the climate modifier was greater than 1 (to a ceiling of 1) and decreased across all cells when the climate modifier was less than 1, and otherwise varied among cells based on their relative susceptibility as determined by cover type, seral stage, and

Table 4—Weibull function parameters (mean return interval, and Shape) associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and the number of years since the last fire) and the probability of a high-mortality wildfire by seral stage for the Sierran mixed conifer – Mesic cover type (original values from Vegetation Development Dynamic Tool models in parentheses).

	Weibull parameters		
Seral stage	**Mean return interval (years)**	**Shape**	**Probability of high-mortality fire**
Early - all structures	44	3	0.67 (1.00)
Mid-open	10	3	0.06 (0.14)
Mid-moderate	13	3	0.09 (0.17)
Mid-closed	19	3	0.16 (0.23)
Late-open	8	3	0.03 (0.08)
Late-moderate	13	3	0.06 (0.14)
Late-closed	34	3	0.19 (0.37)

time since the last fire. The overall disturbance rate within each timestep was governed by a single parameter, which controlled the number of disturbance attempts per unit area. This parameter determined how many wildfire events were attempted, but the number that actually occurred was determined by the Iit of the selected cells. We treated this overall disturbance rate parameter as a calibration parameter, which we tuned to achieve the target overall fire rotation period of 30 years (see *HRV Model Calibration and Verification*).

- Spread—The relative probability of spread (*Z*) for the i^{th} cell during the j^{th} wildfire event in the current timestep (*t*) was determined by several factors: susceptibility (*S*) and climate (*C*), as described earlier, wind direction and strength (*W*), relative elevation (*E*), the presence of rivers and streams (R) as a potential impediment, and a calibration coefficient for each cover type (*G*). The relative weight (*w*) of susceptibility, wind, and relative elevation as well as the strength of the road or stream effect varied with the size of the event, as described later. These factors were combined as follows:

$$Z_{ijt} = max\left\{\left[\frac{max\{S_{it}, (w_j^v V_{it} + w_j^w W_{ij} + w_j^e E_{ij})\} \times R_{ij}}{distance}\right] \times C_t \times G_i, 1\right\},$$

where distance = 1 for the spread to an orthogonal neighboring cell (i.e., shares a full side) and distance = 1.4 for the spread to a diagonal neighboring cell.

Wind was incorporated in two parts. First, a prevailing wind direction for an individual wildfire event was selected probabilistically from the eight cardinal directions. To derive the wind distribution values, we summarized all available historical wind direction data from six local weather stations (Rice Canyon, Saddleback, Downieville, White Cloud, Emigrant Gap, and Blue Canyon) (fig. 7) for the fire season (May 15–October 15) and burning period times (1,000–1,800 hours) (fig. 8). Data from all weather stations were weighted equally. After the wind direction was selected for the particular event, the fire was able to grow in all directions, but was relatively more likely to spread with wind than against it (i.e., directional bias). We used expert opinion to parameterize the strength of this directional bias, which caused a reduction in the probability of spread as the angle increased from the direction the wind was blowing (fig. 8). Note that the realized effect of wind on the probability of spread depended on the weight assigned to wind and the maximum size of the fire (see *Termination*).

Relative elevation was defined as the percent slope uphill or downhill from the "burning" cell to the focal cell. A positive relative elevation meant that the focal cell was uphill of the burning cell. Conversely, a negative relative elevation meant that the focal cell was downhill of the burning cell. We used expert opinion to parameterize the strength of the relative elevation effect, which caused a reduction in the probability of spread from the maximum (1) when the focal cell was uphill at a slope of more than 50 percent from the burning cell (fig. 9). Probability of spread decreased for shallower slopes and cells downhill of the burning cell. Note that, as with wind, the realized effect of relative elevation on the probability of spread depended on the weight assigned to relative elevation and the maximum size of the fire.

Streams were treated as a potential impediment to spread, depending on stream size and maximum fire size. We used expert opinion to parameterize the magnitude of the effect, which caused a reduction in the probability of spread. Regardless of size, streams had no effect on spread for the largest fires, but their effect increased as the fire size decreased and stream size increased (fig. 10). Consequently, large streams were usually an effective barrier for the smallest fires, whereas small streams had only a minor effect even on the smallest fire.

Spread calibration coefficient is an arbitrary calibration parameter that we used to increase or decrease the probability of spread in each cover type. Here, we used it to decrease the probability of spread in some cover types to achieve the target overall fire rotation periods (see *HRV Model Calibration and Verification*).

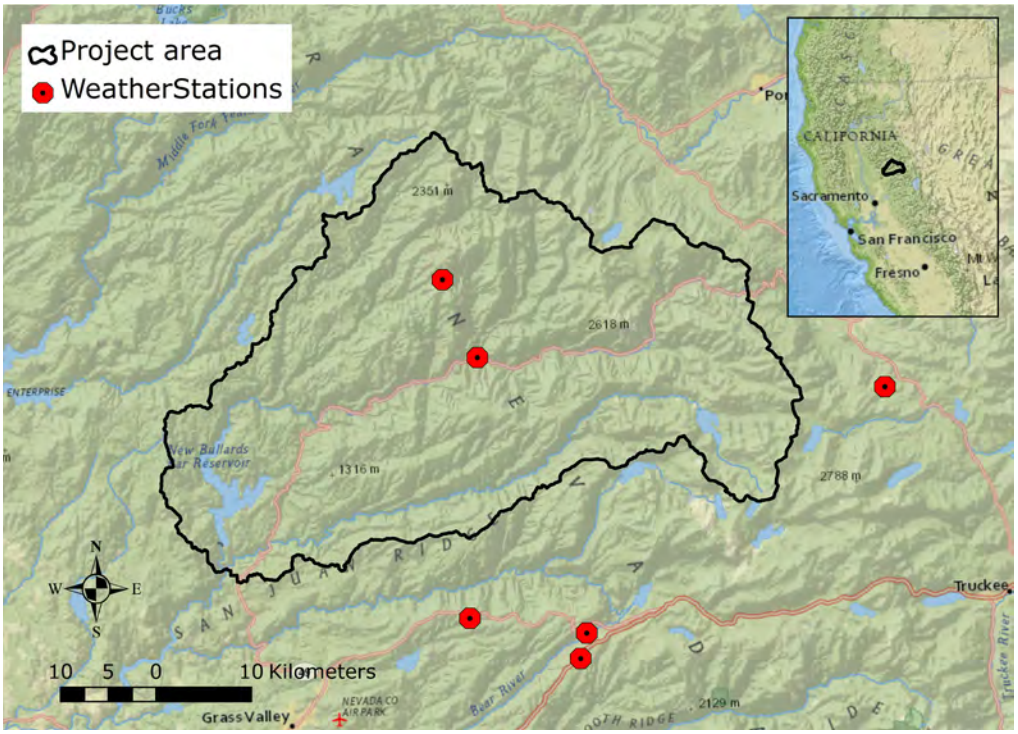


Figure 7—Weather stations in or near the upper Yuba River watershed. Data from these stations were used to inform wind direction parameters for modeling wildfires.

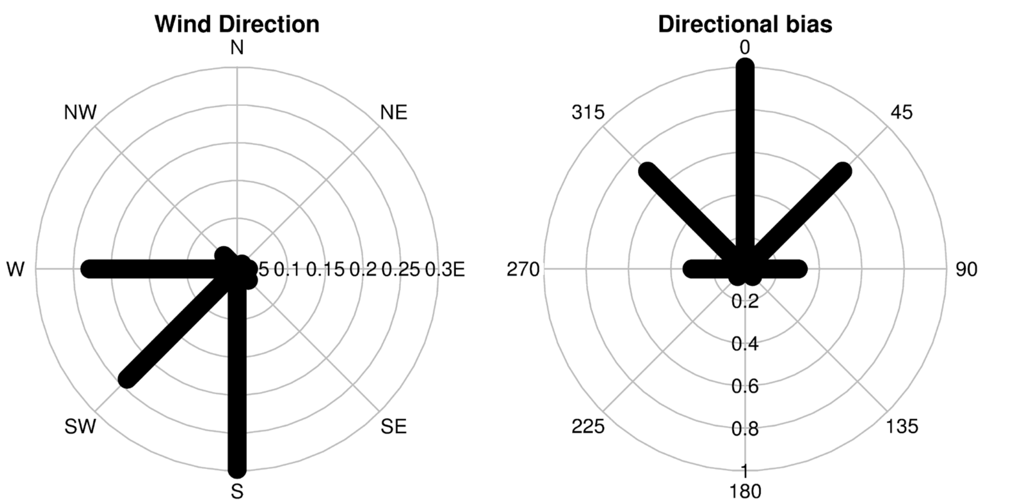


Figure 8—Distribution of wind directions (i.e., direction the wind is coming from) during the fire season (May 15–October 15) and burning period times (1,000–1,800 hours) derived from weather stations in or near the project area (fig. 7) and the strength of directional bias in spread (0o represents the direction the wind is blowing, which is opposite of the wind direction).

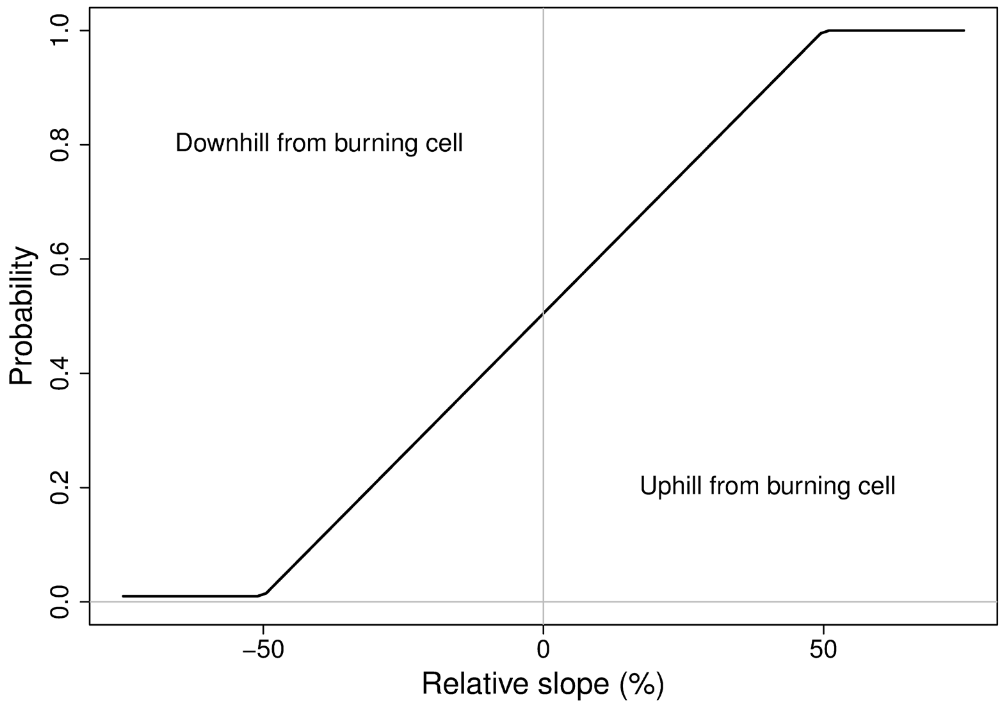


Figure 9—Effect of relative elevation (i.e., percent slope uphill or downhill from a burning cell) on the probability of wildfire spread.

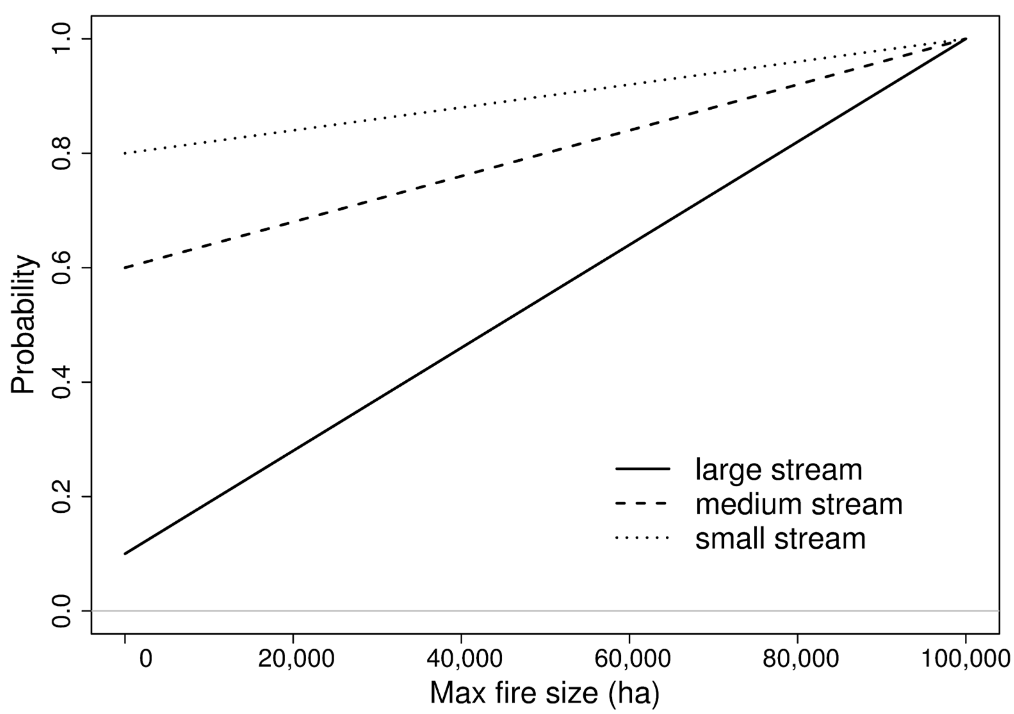


Figure 10—Effect of streams by size class on the probability of wildfire spread as a function of fire size.

We also allowed for "spotting" during spread, that is, the fire leaping ahead and initiating in cells ahead of the advancing front. Specifically, during each iteration of the fire spread there was a Bernoulli probability of spotting (i.e., yes or no) that varied with fire size (fig. 11). If the Bernoulli trial was successful, a cell on the fire front was selected at random to serve as the source of the spotting. Then a spotting distance was selected at random from a Uniform distribution between 1 and a maximum spotting distance that also varied with fire size (fig. 11). Next, the cell at the randomly selected distance from the source cell and in the direction the wind was blowing for this particular event was subjected to a Bernoulli trial based on its probability of initiation. If initiation was successful, the cell became part of the active fire front for the next spread iteration. We used expert opinion to parameterize spotting so that as fires became larger, their probability of spotting and spotting distance increased as depicted in figure 11. Thus, spotting was important only for the largest fires, where its main effect was to facilitate fire spread past potential barriers such as large rivers, barren areas, and water bodies.

A complete description of the spread algorithm is beyond the scope of this document. Briefly, based on the parameterization just described, after a successful initiation, fire spread contagiously to adjacent cells based on their probability of spread (Z_{ijt}) and occasionally spotted ahead of the burning front. Fire continued to spread in an iterative manner outward from all "burning" cells until either it stopped by chance due to low spread probabilities or it reached the randomly selected maximum fire size (see *Termination*). As given in the spread equation, the probability of spreading from a "burning" cell to an adjacent cell was largely determined by the maximum of the cell's current susceptibility (S_{it}) (which was a function of topographic position and fuels as determined by cover type, seral stage, and time since last fire) and a weighted combination of current susceptibility, wind, and relative elevation ($w_j^v Sit + w_j^w W_{ij} + wj^e E_{ij}$), where the weights varied as a function of the randomly selected maximum fire size for the current event. We parameterized these spread weights such that the larger the selected maximum fire size (see *Termination*), the more weight that was given to wind and relative elevation (fig. 12). For the largest fires (~100,000 hectares; 250,000 acres), wind was the dominant factor determining the local probability of spread. Rivers and streams (R_{ij}) were incorporated as a multiplier such that they acted to suppress the probability of spread across a stream, but with the strength of the effect decreasing with increasing fire size (fig. 10). Next, the climate modifier (C_t) was incorporated as a multiplier such that it acted to increase (to a ceiling of 1) or decrease the probability of spread for all cells within the current timestep (t). Last, the spread calibration coefficient for each cover type (G_i) was incorporated as a multiplier so as to variably decrease the probability of spread through some cover types in order to achieve the target overall fire rotation periods for each cover type.

Termination—The spread of an individual wildfire event was terminated when either it stopped by chance due to low spread probabilities or it reached a randomly selected maximum fire size. In this context, maximum fire size functioned as a surrogate for weather conditions (e.g., rain event) that limit the spread of a fire regardless of the underlying fuel conditions. We determined the maximum fire size distribution by analyzing the size distribution of all mapped fires in the North Sierran CALVEG mapping zone and west of the Sierran crest, available from the Forest Service and the California Department of Forestry and Fire Protection, Fire and Resource Assessment Program for 1908–2010 (fig. 13). Although these data do not stem from the historical reference period, local experts agreed that they were an acceptable representation of the expected fire size distribution for the reference period with the exception that they do not contain the very large fires that probably occurred during the historical reference period.

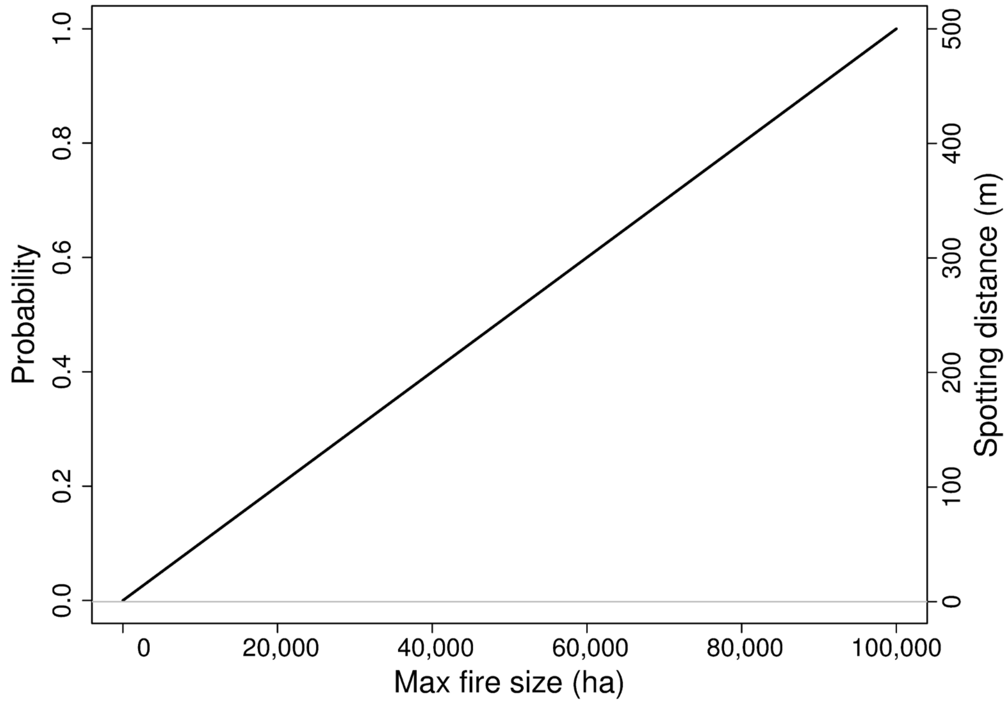


Figure 11—Probability of wildfire “spotting” ahead of the burning front and the spotting distance as a function of maximum fire size.

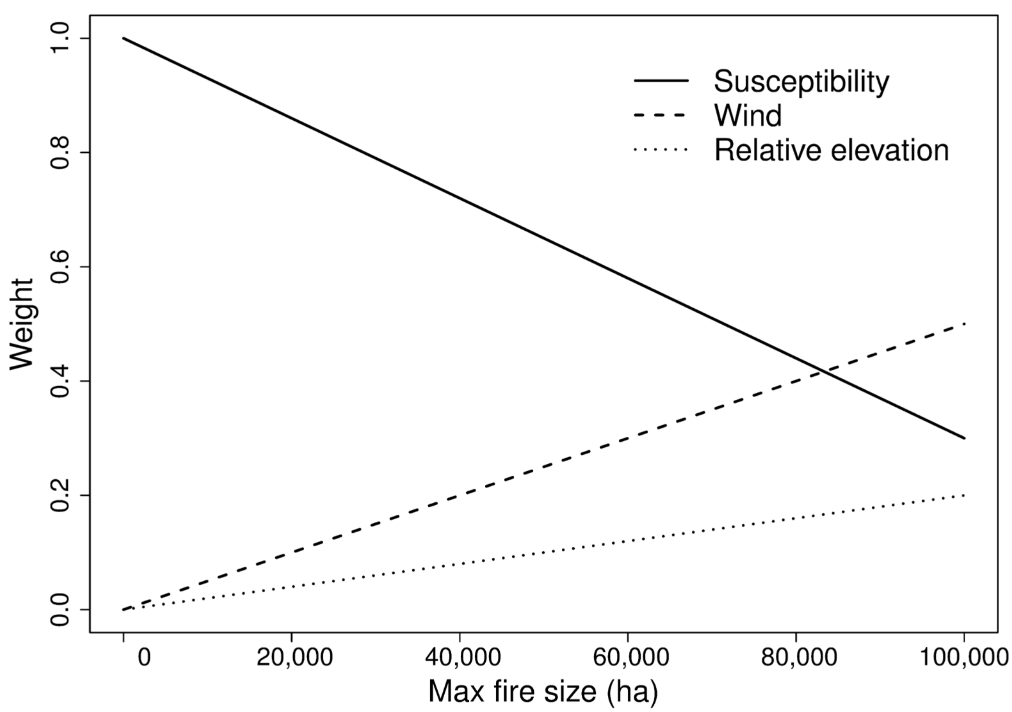


Figure 12—Spread weights assigned to susceptibility, wind, and relative elevation factors as a function of maximum fire size. Spread weights sum to 1 across factors for a given maximum fire size.

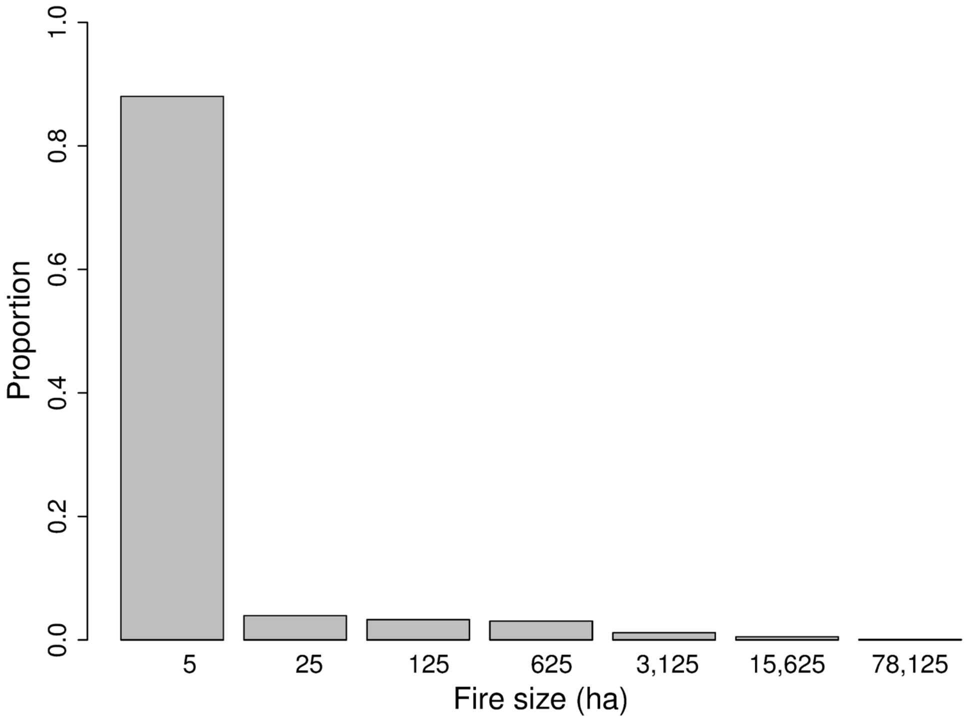


Figure 13—Estimated historical fire size distribution of wildfires occurring between 1900 and 2010 in the northern Sierra Nevada west of the Sierran crest (from USDA Forest Service and California Department of Forestry and Fire Protection, http://frap.fire.ca.gov/projects/fire_data/fire_perimeters_index).

Mortality—Mortality was defined as the level of mortality of the dominant overstory vegetation caused by the disturbance (i.e., fire severity), and it was classified as either high (>75 percent mortality) or low (≤75 percent mortality) at the cell level. Although researchers have differed on whether 75 percent or 95 percent overstory tree mortality is a more appropriate cutoff point for defining a "stand-replacing" event (Fulé et al. 2014; Mallek et al. 2013), we used 75 percent as our cutoff as it is widely accepted in the literature (Agee 1993, 2007; Baker 2014; Miller et al. 2009a). Importantly, RMLands does not classify individual fires as a whole by "low," "mixed," or "high" severity status. Some fire ecologists combine fire attributes such as flame length and fire size into their interpretation of the relative "severity" of a particular fire (e.g., Agee [1993]). Ecologists working at other scales and not working with models often describe "mixed severity" regimes (e.g., Kane et al. [2013]), which Collins and Stephens (2010) define as "stand-replacing patches within a matrix of low to moderate fire induced effects." At the 30-meter cell size of our application, nearly all fires would be classified as "mixed severity" by the prior definition. Instead, we focused on defining conditions under which transitions among potential states within a given cover type occurred or not. All burned cells were evaluated probabilistically and assigned to a high-mortality outcome or not. All nonhigh-mortality outcomes were considered low mortality. If a cell burned at high mortality, then it transitioned to the early-seral stage; otherwise, it either remained in the same seral stage or transitioned to another seral stage based on a set of disturbance transition rules.

The probability of a high- versus low-mortality response to fire was determined by four major factors: (1) topographic position (T), (2) disturbance history (D), (3) vegetation (V), and (4) climate (C). Specifically, the probability of a high-mortality response following wildfire for the i^{th} cell in the current timestep (t) was determined by the product of these four factors (the first three factors were each represented as probabilities, 0–1), but with a ceiling of 1 because *C* was not a probability and thus the product could exceed 1:

$$P_{it} = max\{T_{it} \times D_i \times V_{it} \times C_t, 1\}$$

Vegetation was represented by vegetation cover type and seral stage. We specified an overall probability of high-mortality response to fire for each cover type and seral stage. To derive these probabilities, we used the LandFire VDDT models, as modified by Safford and Estes (Appendix B). Specifically, from the VDDT models, we used the probabilities of a transition to the early-seral stage. We ignored the classified type of fire (given as replacement, mixed, or surface), focusing instead on the outcome of fire in terms of the seral stage, if any, to which a cell transitioned after fire. High-mortality fires were those that resulted in conversion to early-seral stage (regardless of whether they were called replacement or mixed-severity fire). All other fires were considered low mortality. The probability of a high-mortality outcome from fire was calculated by dividing the summed probabilities of high-mortality fires as defined earlier by the summed probabilities of all fires (e.g., table 4).

Topographic position was computed as a logistic transformation of TPI as described previously (fig. 5) and applied only to certain cover types (table 3). As before, topographic position had no effect on mortality when TPI was maximum (i.e., on steeper, south- and west-facing, upper slopes), but acted to reduce high mortality by up to 30 percent when TPI was minimum (i.e., on gentle, north- and east-facing, lower slopes, and valley bottoms). Note that because *T* was incorporated as a multiplier, it acted to depress the probability of high mortality from the nominal value set by the vegetation factor (*V*) described in the preceding paragraph.

Disturbance history was computed as a logistic transformation of the age (years) since the last fire. We applied disturbance history only in forested cover types; for nonforested cover types this parameter was set to 1 and thus had no effect. We varied the effect between low-elevation forest cover types and high-elevation forest cover types according to the three-parameter logistic function depicted in figure 14. Specifically, for low-elevation cover types the effect of burning on subsequent mortality was shorter lived, with the inflection occcurring at 15 years and a slope such that after 25 years there was no residual effect. For high-elevation cover types (e.g., Red Fir, Lodgepole Pine, and Subalpine Conifer), the effect was longer lived, with the inflection occurring at 20 years and a slope such that after 40 years there was essentially no residual effect. Note that because *D* was incorporated as a multiplier, it acted to depress the probability of high mortality from the nominal value set by the vegetation factor (*V*) described earlier. Thus, for a cell of low-elevation forest, the probability of high mortality was depressed to 0.1 times its nominal value immediately following a fire; at 15 years after the fire the probability was depressed by 0.5, and after about 25 years the probability of high mortality was back to its nominal value.

Climate (*C*) acted globally to modify the probability of high mortality within each timestep. Thus, the probability of a high-mortality outcome within a timestep increased across all cells when the climate modifier was greater than 1 (to a ceiling of 1), decreased across all cells when the climate modifier was less than 1, and varied among cells based on their relative probabilities of high-mortality fire as determined by topographic position and vegetation.

- *Seral stage transitions*—Following the mortality determination, each cell was evaluated for potential immediate transition to a new seral stage (state). Transition pathways and rates of transition between states were defined uniquely for each cover type and coded in a set of disturbance transition rules analogous to the succession transition rules described previously. In general, these rules specified the probability of transitioning to a new seral stage following high- and low-mortality fire. A high-mortality fire always caused a transition to the early-seral stage (probability = 1). The outcome of a low-mortality fire varied among

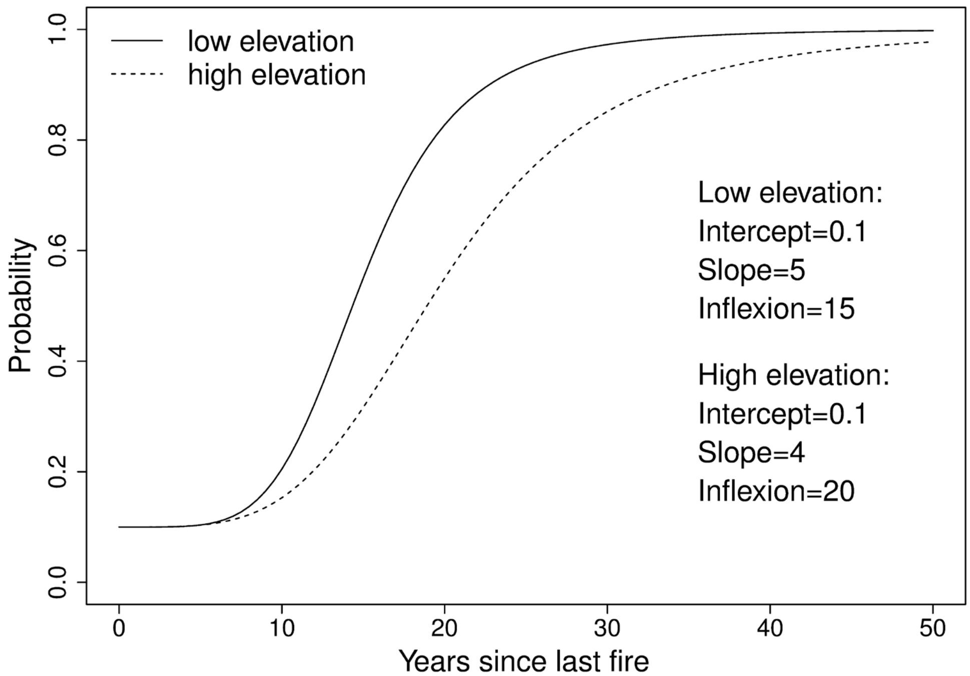


Figure 14—Modifier to the probability of high mortality for a cell burned in a wildfire as a logistic function of the number of years since the last fire (either wildfire or prescribed fire) for low-elevation and high-elevation forests.

cover types and seral stages, but generally resulted either in no change or in a transition to a more open-canopy seral stage (within the same developmental stage). We used the LandFire models, as modified by Safford and Estes (Appendix B), to determine the transition probabilities following low-mortality fire. Specifically, we used the probabilities of a transition to a more open-canopy seral stage or of no transition. We ignored the classified type of fire (given as replacement, mixed, or surface), focusing instead on the outcome from fire in terms of the seral stage, if any, to which a cell transitioned after fire. The probability of transitioning to a more open-canopy seral stage was calculated by dividing the summed probabilities of transitioning to a more open-canopy seral stage by the summed probabilities of all possible low-mortality outcomes. Thus, given a low-mortality fire, the probability of transitioning to a more open-canopy seral stage and the probability of no transition always summed to 1. We further modified the probabilities to accommodate our state-and-transition models, which have three canopy-cover stages instead of LandFire's two. We did this by evenly allocating the original probability of a single transition from a closed canopy to open canopy between the two possible transitions in our model: closed to moderate canopy and closed to open canopy.

HRV Model Calibration and Verification

Although RMLands is a process-oriented model with individual parameters sourced from either data, the literature, or expert opinion, the model outcomes reflect the complex spatiotemporal interactions of the stochastic processes. Consequently, it is necessary to calibrate the model by tuning (i.e., adjusting up or down) one or more of the model parameters to produce outcomes that are consistent with the data, the literature, and expert opinion. In this context, we considered the parameters associated with the disturbance process to be the "independent" variables and the vegetation conditions (e.g., seral stage distribution) to be the "dependent" outcomes. Thus, we calibrated the disturbance parameters to achieve the targeted disturbance regime, but without attention to the vegetation response, which we treated as the dependent outcome of the disturbance regime.

We focused model calibration on one major disturbance regime attribute: fire rotation period (FRP), which is the number of years required to burn a cumulative area equal to the extent of the landscape or of a single cover type. FRP combines fire frequency and fire size into a single integrated measure of how much fire occurred. Regardless of whether there are more smaller fires or fewer larger fires, FRP provides an effective measure of how much fire is actually applied to a unit of ground. FRP is equivalent to the "point-specific" or "population" mean fire return interval (FRI)—the average number of years between fires to a single point on the ground (or pixel)—and is roughly equivalent to the oft-reported "grand mean" FRI computed from a large sample of point-specific intervals (e.g., from a set of fire-scarred trees). Importantly, FRP is not equivalent to the "composite" FRI, which is computed based on the average interval between fires to an area of some specified size larger than a single point or pixel (e.g., a forest stand). The FRP or point-specific FRI is generally much longer than the composite FRI, because the interval between fires to a single point is generally much greater than the interval between fires to anywhere within an arbitrarily defined larger site. A major limitation with composite FRIs is that the unit area is arbitrary and varies considerably from one study to the next, making comparisons of published composite FRIs very difficult. In this report, we use FRP to describe the amount of fire applied to the landscape, in part because it is unambiguous in meaning and well understood by managers, but also because the simulation modeling gives us a complete census of simulated wildfires, which lends itself well to the calculation of FRP.

We tuned the overall disturbance rate parameter (see *Initiation*), which controlled the number of disturbance attempts per unit area within each timestep, and the spread calibration coefficients (Gi) for each cover type, which affected the probability of fire spread in each cover type, and measured calibration success based on conformity to prespecified target FRPs at the cover type level. We set our calibration goal as within 10 percent of the target FRPs for the 11 cover types with 1,000 hectares or more in the project area (excluding Barren and Water). Target values were based on empirical published values (Mallek et al. 2013; Van de Water and Safford 2011) and expert input from Safford and Estes. With one exception, we achieved this calibration goal (table 5).

Table 5—Simulated and target historical fire rotation periods (FRPs) for dynamic cover types with 1,000 ha (2,500 ac) or more in the upper Yuba River watershed, and the delta (percent difference) between simulated and target FRPs. The row for Total includes all cover types. Note that a positive delta indicates that the target FRP was greater than the simulated FRP, and a negative delta indicates that the target FRP was less than the simulated FRP.

			Fire rotation period		
Cover type	**Area (ha)**	**Area (ac)**	**Simulated**	**Target**	**Delta**
Sierran Mixed Conifer – Mesic	57,853	142,955	27	29	6.9%
Sierran Mixed Conifer – Xeric	52,198	128,981	24	22	-9.1%
Oak-Conifer Forest and Woodland	23,279	57,522	25	21	-19.0%
Red Fir – Mesic	8,563	21,159	63	60	-5.0%
Red Fir – Xeric	7,493	18,515	43	40	-7.5%
Mixed Evergreen – Mesic	7,273	17,972	48	50	4.0%
Mixed Evergreen – Xeric	6,768	16,717	37	40	7.5%
Sierran Mixed Conifer – Ultramafic	4,124	10,190	57	60	5.0%
Grassland	1,379	3,408	58	60	3.3%
Meadow	1,201	2,968	61	60	-1.7%
Oak-Conifer Forest and Woodland – Ultramafic	1,060	2,619	40	42	4.8%
Total	171,191	423,006	29	30	3.3%

In addition to model calibration, as confirmation of the correct model implementation, we also verified that the model generated the expected outcomes for three other disturbance regime attributes:

- *Simulated fire patterns*—We visually inspected output grids depicting wildfire events for both small and large fires and verified that their shapes and conformity to the topography and patterns of mortality were reasonably similar to actual wildfires (fig. 15).
- *Fire size distribution*—We compared the simulated fire size distribution (i.e., the resulting fire sizes) against the expected distribution (see *Termination*) and verified that they were similar (fig. 16). The simulated fire size distribution included a small proportion of very large fires that exceeded the largest fires in the historical dataset used to create the target distribution, but this was expected as noted previously.
- *Topographic position*—We examined our use of TPI to affect both susceptibility to wildfire and the probability of a high-mortality outcome. In the state-and-transition models, early-development and more open-canopy seral stages result from fire. We expected that an increase in the occurrence of fire and in the likelihood of high-mortality fire for cells with large TPI values would lead to a decrease in the average canopy cover for those cells (i.e., on steeper, south- and west-facing, upper slopes). We verified that this was in fact the case. Across all dynamic cover types for which we applied TPI (table 3), we observed an 18-percent absolute (or 28-percent relative) decrease in average canopy cover across the full TPI gradient (-3 to 3), although it varied somewhat among the dominant cover types (table 6). Although there was a clear negative relationship between TPI and average canopy cover, there was also considerable variability about this trend (fig. 17), reflecting the complex spatiotemporal interactions of the disturbance and succession processes.

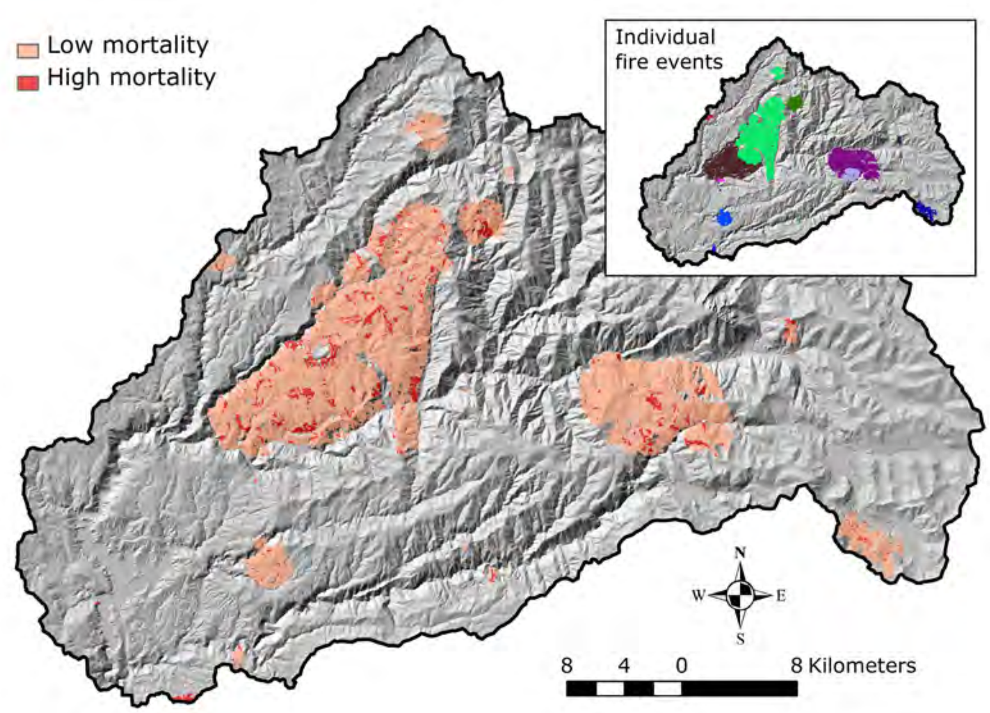


Figure 15—Typical simulated wildfires of average total extent during a single 5-year timestep depicting mortality level (low versus high) and the individual fire events (inset) in the upper Yuba River watershed.

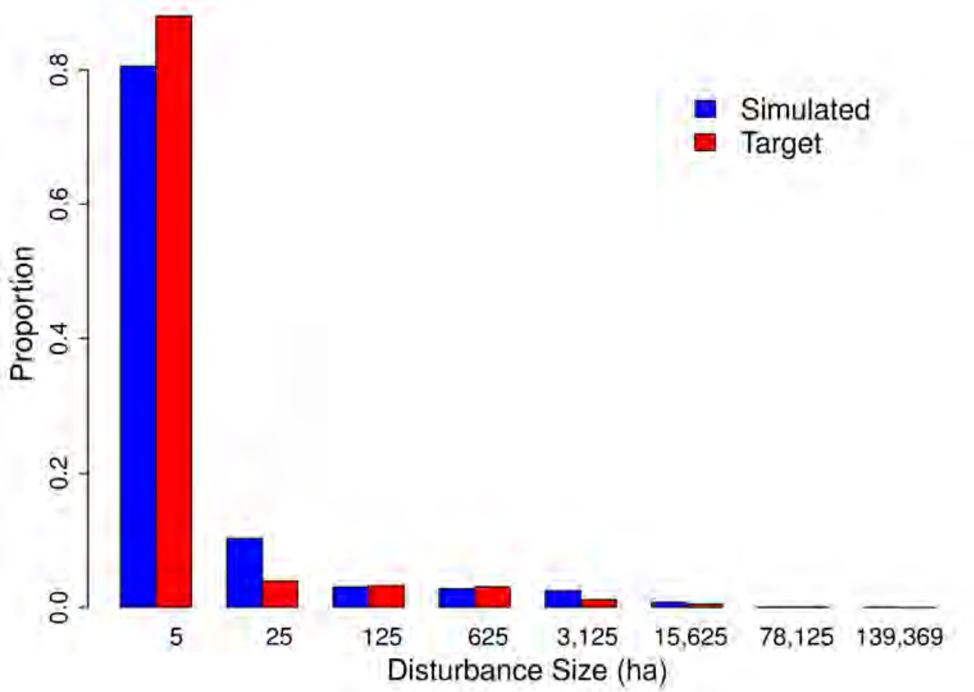


Figure 16—Distribution of simulated fire sizes within the upper Yuba River watershed and the target fire size distribution derived from fire size data in the North Sierran ecoregion (1900–2010). Note that the x-axis is geometrically scaled.

Table 6—Average percent canopy cover at the minimum and maximum values of the topographic position index (TPI) for dynamic cover types with 1,000 ha (2,500 ac) or more and whose susceptibility to fire and mortality following fire was modified by topographic position (see table 3) in the upper Yuba River watershed, the delta (difference) in percent canopy cover between minimum and maximum TPI values, and the percentage change in canopy cover (defined as delta/average canopy cover at min TPI, times 100). Note: The negative delta indicates canopy cover decreased as TPI increased.

Cover type	Min TPI	Max TPI	Average canopy cover at min TPI	Average canopy cover at max TPI	Delta	Percent change canopy cover
Mixed Evergreen – Mesic	-3.0	3.0	73.3	65.6	-7.7	-10.5
Mixed Evergreen – Xeric	-3.0	3.0	73.0	66.6	-6.4	-8.8
Oak-Conifer Forest and Woodland	-3.0	3.0	57.1	53.0	-4.1	-7.2
Oak-Conifer Forest and Woodland – Ultramafic	-3.0	3.0	31.1	28.9	-2.2	-7.1
Red Fir – Mesic	-3.0	3.0	76.4	70.2	-6.2	-8.1
Red Fir – Xeric	-2.1	3.0	56.3	42.3	-14.0	-24.9
Sierran Mixed Conifer – Mesic	-3.0	3.0	61.5	56.9	-4.6	-7.5
Sierran Mixed Conifer – Ultramafic	-3.0	3.0	48.2	36.4	-11.8	-24.5
Sierran Mixed Conifer – Xeric	-3.0	3.0	45.5	41.7	-3.8	-8.4
Total	-3.0	3.0	63.6	45.7	-17.9	-28.1

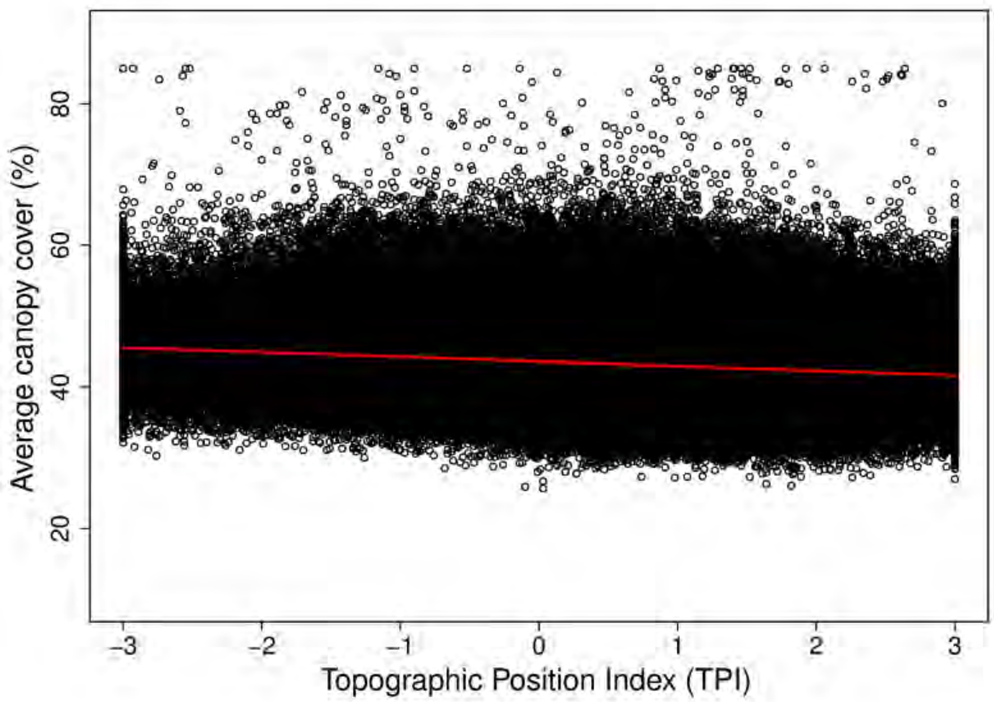


Figure 17—Relationship between topographic position index (TPI) and simulated average percent canopy cover for cells classified as Sierran Mixed Conifer – Xeric, showing an average decrease of 8.4 percent in percent canopy cover over the full range of TPI (red line).

HRV Model Execution

We used RMLands to simulate fire disturbance and succession representative of the historical reference period (ca. 1550–1850). We used a 5-year timestep in the model based on the short FRIs recorded in the literature. After calibrating the model, we ran a single simulation for 500 timesteps (i.e., 2,500 years) and generated several GIS data layers representing disturbance and vegetation state at each timestep. We treated the first 40 timesteps (200 years) as the model equilibration period based on preliminary simulations, which indicated that it took the landscape up to 200 years to reach dynamic equilibrium for all of the attributes of interest. Some attributes reached dynamic equilibrium much sooner, but for consistency we used a single equilibration period. Thus, we kept the last 460 timesteps (41–500) as snapshots of the landscape and used these samples to quantify HRV in various landscape attributes (see *Analysis of Landscape Structure*). Note that the use of a single 2,500-year simulation rather than several 300-year simulations was merely for processing efficiency to obtain a large sample of landscape snapshots representing multiple disturbance and succession cycles; it did not change the fact that the landscape shapshots were all stochastic realizations of the disturbance regime representative of the 300-year historical reference period.

Although our primary interest was simulating HRV for the 181,556-hectare project area, we included a 10-kilometer (6-mile) buffer around the project area for purposes of the simulation to avoid landscape boundary effects, resulting in a much larger landscape for the simulation (408,498 hectares; 1,009,399 acres). Thus, wildfires were allowed to spread across the project area boundary unimpeded. However, all of the results were calculated for the core project area (i.e., excluding the buffer).

Alternative Management Scenarios

To simulate the range of variability in landscape structure under alternative management scenarios, we used RMLands as described previously to simulate wildfire disturbance and succession processes. In several ways, the model parameterization for the management scenarios was similar to that of the HRV scenario described earlier. For instance, many of the parameters were given by the state-and-transition models defined for each cover type (Appendix B). In particular, the succession process was identical for both the HRV and management scenarios. What differed was the disturbance processes. For the management scenarios, we modified the wildfire disturbance regime to reflect modern conditions (reflecting aggressive fire suppression), and we added a variety of vegetation treatments to the disturbance process to reflect alternative vegetation management scenarios.

Management Scenarios

We created the following scenarios to examine how the range of variability in landscape structure may deviate from the current landscape and the HRV under alternative vegetation management strategies representing a wide range of treatment intensities and treatment types:

- *MS1: no treatment*—In this no treatment scenario, we simulated wildfire disturbance based on our best estimate of the modern fire regime reflecting aggressive fire suppression and no vegetation treatments.
- *MS2: current land management plan*—In this “business as usual” scenario, we simulated wildfire disturbance as in MS1 in combination with a suite of vegetation treatments modeled after the 1990 land management plan (LMP), as amended in 2004. We emphasized thinning; hand cut, pile, and burn; and mastication treatments. Realized overall treatment intensity was 3,458 hectares (8,545 acres) (2.8 percent of eligible area) per 5-year timestep.
- *MS3: prescribed fire only*—In this scenario, we simulated wildfire disturbance as in MS1 in combination with extensive prescribed fire treatments (10 times the amount in MS2) and no mechanical treatments. Realized overall treatment intensity was 34,191 hectares (84,486 acres) (27.6 percent of eligible area) per 5-year timestep. We simulated two versions of this scenario: MS3a included only “cool” burns typical of modern prescribed fire prescriptions (~2–5 percent canopy mortality); MS3b included “hotter” burns producing about three times the severity (i.e., probability of canopy mortality) as the cool burn scenario (~5–15 percent canopy mortality, as per Safford et al. 2012).
- *MS4: LMP moderate intensity*—In this scenario, we simulated wildfire disturbance as in MS1 in combination with the same distribution of vegetation treatments as MS2 (i.e., emphasizing thinning; hand cut, pile, and burn; and mastication treatments) but with about five times the realized overall treatment intensity at 15,572 hectares (38,478 acres) (12.6 percent of eligible area) per 5-year timestep.
- *MS5: Sierra Conservancy*—In this scenario, we simulated wildfire disturbance as in MS1 in combination with intensive vegetation treatment at the realized overall treatment intensity of 30,798 hectares (76,102 acres) (24.8 percent of eligible area) per 5-year timestep. Treatments consisted of both prescribed fire (based on the “cool” burns as in MS3a) and a variety of mechanical treatments, but with a strong emphasis on prescribed fire treatments. Note that this vegetation treatment scenario was developed by the staff of the Yuba River Ranger District in collaboration with the Sierra Nevada Conservancy (SNC). Briefly, in 2015 Tahoe National Forest managers took the lead for the region in helping the SNC display its vision of the environmental, social, and economic needs for restoration within the Sierra Nevada. District managers estimated a level of treatments that they felt should be implemented across the district to restore resiliency within the

landscape. They identified priority treatment areas focusing on the wildland-urban interface (WUI) and areas that contain larger proportions of forests with moderate to high canopy cover of mid- to late-successional forests, referred to as "old forest." Restoring resiliency to "old forests" first was selected because, once lost, these forests contain values that take the longest to replace. Treatments followed the existing LMP: excluding treatments in roadless areas, restricting mechanical treatments within California spotted owl (*Strix occidentalis occidentalis*) and northern goshawk (*Accipiter gentilis*) Protected Activity Centers (PACs), restricting mechanical treatments to primarily slopes of 30 percent or less, and maintaining canopy cover of more than 40 percent where it already exists above this level. Based on these priorities, district managers determined the total area to be treated each year and allocated the acreage among several different treatment types. The only modification we made here was to adjust upward the total treatment intensity from the original approximately 28,000 hectares (69,000 acres) per 5 years to about 31,000 hectares (77,000 acres) per 5 years.

- <u>MS6: balanced</u>—In this scenario, we simulated wildfire disturbance as in MS1 in combination with intensive vegetation treatment at the realized overall treatment intensity of 24,198 hectares (59,793 acres) (19.5 percent of eligible area) per 5-year timestep, consisting of an equal emphasis (i.e., "balanced") on prescribed fire (based on the "cool" burns as in MS3a) and mechanical treatments. This scenario was created after reviewing the results of the previous scenarios in an attempt to construct a scenario that would better emulate the HRV.
- <u>MS7: final</u>—In this, our final, scenario, we modified MS6 slightly to better emulate the HRV; specifically, we shifted the distribution between thinning treatments and matrix thin and group cut treatments in favor of thinning, switched to "hotter" burns for prescribed fire treatments (as in MS3b), and adjusted the dynamic priorities among cover types and seral stages somewhat (see *Constraints and Priorities*). We realized an overall treatment intensity of 22,174 hectares (54,792 acres) (17.9 percent of eligible area) per 5-year timestep allocated among treatment types as follows: 39.5 percent prescribed fire; 23.5 percent thinning; 17.3 percent matrix thin and group cut; 7.8 percent thin and burn; 3.9 percent matrix thin, group cut, and burn; 2.6 percent thin, masticate, and burn; 2.6 percent hand cut, pile, and burn; 1.5 percent mastication; and 1.2 percent thin, hand cut and pile, and burn.

Wildfire Disturbance Parameters

For all management scenarios, we kept the wildfire disturbance parameters the same as the HRV scenario except for the fire size distribution and the overall disturbance rate calibration parameter (which controls the number of disturbance attempts per timestep; see previous discussion). We adjusted these two parameters to produce a target overall FRP of 152 years for the no treatment scenario (MS1) instead of 30 years for the HRV scenario. Thus, we simulated many fewer fires, but the behavior of the fires was generally the same.

To determine the target overall FRP for the management scenarios, we used the Forest Service Fire Program Analysis-Fire Occurrence Data (FPA-FOD) records on fire occurrence between 1992 and 2013 in the North Sierran ecoregion (N = 13,336). Specifically, we summed the total area burned during this 21-year period, converted this to an average annual burned area, and computed FRP as the total area of the ecoregion divided by the average annual burned area. This resulted in a modern FRP of 152 years. We opted to use the overall landscape FRP as our model calibration target for the management scenarios rather than specifying a separate FRP target for each cover type for two reasons. First, the cover type classification does not include all the cover types or variants that we defined for this project. Thus, we do not have a one-to-one crosswalk between the empirically derived modern FRPs for the cover types and our larger set of cover types for our project area. Second, because landscape histories are idiosyncratic, the cover type FRPs computed from this one landscape trajectory may not be as reliable for forecasting purposes as the overall landscape FRP. For these reasons, we calibrated the disturbance rate parameter to achieve an overall FRP and kept the relative differences among cover types the same as for the HRV scenario.

In addition to tuning the overall disturbance rate parameter, we also adjusted the target fire size distribution to match the modern distribution derived from the FPA-FOD record. A comparison between the HRV fire size distribution derived from the longer record of 1908–2010 and the modern record of 1992–2013 reveals that the modern fire size distribution has a higher proportion of fires less than 1 hectare (2 acres), presumably reflecting successful fire suppression efforts as well as better detection and recording efforts (table 7). Accordingly, the average fire size in the modern record is considerably less than in the full record. However, the area-weighted mean fire size is substantially larger in the modern record, which suggests that the modern FRP, though much longer than historically (152 versus 30 years), is being driven by fewer but relatively larger fires.

RMLands Vegetation Treatments

It is beyond the scope of this document to fully describe the vegetation treatment module in RMLands (a detailed technical document is forthcoming). Here, we provide only a brief description of the vegetation treatment module as applied in this study. Like natural disturbances, vegetation treatments follow succession in each timestep in the simulation, and there are many parameters that control the treatment process.

- *Management zones*—We subdivided the project area into three management zones representing major ownerships (fig. 2) to reflect differences in goals and objectives:
    1. *National forest lands*—124,030 hectares (306,478 acres). In this zone, we varied treatment intensity and treatment types among management scenarios, as detailed in *Treatment Amount and Allocation.*
    2. *Private industrial forest lands*—32,768 hectares (80,970 acres). In this zone, we implemented a constant treatment regime across all scenarios, reflecting a goal of maximizing commercial timber production, as detailed in *Treatment Amount and Allocation.*
    3. *Other lands*—24,763 hectares (61,189 acres). In this zone, we implemented a constant treatment region across all scenarios, reflecting a variable but low intensity of treatments, as detailed in *Treatment Amount and Allocation.*

Table 7—Target fire size distribution specified for the historical range of variability scenario (ca. 1550–1850) and the management scenarios based on the modern fire record for the period 1992–2013 in the North Sierran ecoregion.

Size (ha)	Size (ac)	Historical	Modern
0–1	0–2	83.55%	92.80%
>1–10	>2–25	6.33%	4.96%
>10–100	>25–250	4.79%	1.27%
>100–1,000	>250–2,500	4.13%	0.65%
>1,000–10,000	>2,500–25,000	1.06%	0.27%
>10,000	>25,000	0.14%	0.05%
max		30,500 ha (75,400 ac)	30,523 ha (75,422 ac)
mean		72 ha (178 ac)	22 ha (54 ac)
area-weighted mean		8,356 ha (20,658 ac)	12,686 (31,347 ac)

- *Management types*—We divided all the forest and woodland cover types into two management types and specified a unique management regime for each type (detailed as follows):
    1. *Conifer forests and woodlands*—Conifer forests and woodlands of various types (excluding subalpine conifer forest) make up about 94 percent (170,636 hectares; 421,642 acres) of the project area.
    2. *Mixed conifer-aspen forests*—Mixed conifer-aspen forests of various types compose about 0.05 percent (97 hectares; 240 acres) of the project area and occurred only on national forest lands (at least as mapped).
- *Treatment amount and allocation*—Within each management zone and management type, we allocated a total treatment intensity (i.e., number of hectares treated per 5-year timestep) among the following treatment types, which varied among management scenarios as given in table 8:
    1. *Clearcut*—Removal of more than 90 percent of the overstory designed to regenerate the stand and create temporary early-seral stage conditions.
    2. *Thinning*—Single-tree selection designed to maintain an uneven-aged stand structure, promote continuous regeneration, and reduce canopy cover. Thinning involved partial overstory removal uniformly distributed throughout the treatment unit and always resulted in a transition to a more open-canopy class within the same developmental stage (e.g., late-development closed canopy to late-development moderate canopy) or maintained the stand in an open-canopy condition.
    3. *Mastication*—Mechanical mastication of understory vegetation designed to compact and distribute the understory fuels and reduce the likelihood of severe fire. This treatment had no effect on the overstory of forests and woodlands, and thus it did not result in a seral stage transition.
    4. *Prescribed fire*—Prescribed fire designed to be predominantly nonlethal surface fire to reduce fine fuels and reduce the likelihood of severe fire, but allowing for some lethal surface or crown fire in small patches aimed at opening up the stand. The probability of a prescribed fire causing cells and small patches to transition to a more open-canopy class within the same developmental stage varied among cover types and seral stages (Appendix B), but generally was about 2–5 percent under the "cool" burn scenarios. We increased the probabilities threefold for the "hotter" burn scenarios.
    5. *Matrix thin and group cut*—Small, randomly sized group cuts with complete overstory removal designed to create regeneration patches and increase spatial heterogeneity in canopy cover, embedded within a thinned matrix designed to reduce overall canopy cover. Group cuts encompassed 20 percent of the area and were distributed randomly throughout the treatment unit. The group cuts always resulted in a transition to the early-seral stage, and the matrix thinning always resulted in a transition to a more open-canopy class within the same developmental stage or maintained the matrix in an open-canopy condition.
    6. *Thin and burn*—Overstory thinning followed by prescribed fire over the entire unit, as previously described. This treatment always resulted in a transition to a more open-canopy class within the same developmental stage or maintained the stand in an open-canopy condition.
    7. *Hand cut, pile, and burn*—Hand cutting and piling of small diameter material followed by prescribed fire designed to reduce understory fuels and reduce the likelihood of severe fire. Hand cutting and piling was done within a randomly selected 75 percent of the treatment unit, followed by prescribed fire over the entire unit. Hand cutting and piling had no effect on the overstory, but it reduced the probability of canopy mortality (and subsequent seral stage transition) caused by the prescribed fire by 50–75 percent depending on the seral stage.

Table 8—Realized average treatment intensity (mean number of ha [ac] treated per 5-year timestep) across management scenarios involving vegetation treatments (MS2–MS7) (see *Management Scenarios* under *Methods*) by management zone (national forest, private industrial forest, and other), management type (aggregated cover types), and treatment type for the upper Yuba River watershed. Note that realized treatment intensity was based on the average across 20 replicated 100-year simulations, and in some cases it was less than the targeted treatment intensity due to dynamic landscape conditions and the specified constraints and priorities for treatment. The realized treatment rate (percentage of eligible forest) pooled across treatment types is also given for conifer-dominated forest on national forest lands.

		Scenario						
Management zone/type	Treatment type	MS2	MS3a	MS3b	MS4	MS5	MS6	MS7
National forest[a]								
Conifer-dominated forest	Thinning - thin	1,575 (3,892 ac)	-	-	7,328 (18,107 ac)	809 (1,999 ac)	3,954 (9,770 ac)	5,213 (12,881 ac)
	Matrix thin and group cut	-	-	-	-	1,206 (2,980 ac)	5,927 (14,646 ac)	3,839 (9,486 ac)
	Mastication	514 (1,270 ac)	-	-	2,275 (5,622 ac)	-	365 (902 ac)	336 (830 ac)
	Prescribed fire	118 (292 ac)	34,183 (84,466 ac)	34,178 (84,454 ac)[d]	335 (828 ac)	24,371 (60,221 ac)	9,566 (23,638 ac)	8,766 (21,661 ac)[d]
	Hand cut, pile, and burn	858 (2,120 ac)	-	-	3,930 (9,711 ac)	-	633 (1,564 ac)	579 (1,431 ac)
	Thin and burn	-	-	-	-	2,390 (5,906 ac)	1,880 (4,646 ac)	1,723 (4,258 ac)
	Thin, hand cut, pile, and burn	386 (954 ac)	-	-	1,697 (4,193 ac)	-	282 (697 ac)	259 (640 ac)
	Thin, masticate, and burn	-	-	-	-	808 (1,996 ac)	637 (1,574 ac)	583 (1,441 ac)
	Matrix thin, group cut, and burn	-	-	-	-	1,206 (2,980 ac)	947 (2,340 ac)	869 2,417 ac)
	subtotal	3,451 (8,527 ac) (2.78%)	34,183 (27.58%)	34,178 (27.58%)	15,565 (38,461 ac) (12.56%)	30,790 (76,082 ac) (24.84%)	24,191 (59,776 ac) (19.52%)	22,167 (54,775 ac) (17.89%)
Mixed conifer-aspen forest	Prescribed fire	-	13 (32 ac)	13	-	-	-	-
	Thinning	7 (17 ac)	-	-	7	8 (20 ac)	7	7
	subtotal	7	13	13	7	8	7	7
Private industry[b]	Clearcut	1,606 (3,968 ac)	1,612 (3,983 ac)	1,596 (3,944 ac)	1,600 (3,954 ac)	1,599 (3,951 ac)	1,609 (3,976 ac)	1,592 (3,934 ac)
	Mastication	357 882 ac)	358 (885 ac)	355 (877 ac)	355	355	357	352 (870 ac)
	Thinning	1,646 (4,067 ac)	1,653 (4,085 ac)	1,634 (4,038 ac)	1,641 (4,055 ac)	1,637 (4,045 ac)	1,648 (4,072 ac)	1,630 (4,028 ac)
	subtotal	3,609 (8,918 ac)	3,623 (8,952 ac)	3,585 (8,859 ac)	3,596 (8,886 ac)	3,591 (8,873 ac)	3,614 (8,930 ac)	3,574 (8,831 ac)
Other[c]	Clearcut	112 (278 ac)	111 (274 ac)	110 (272 ac)	111	111	111	112
	Mastication	277 (684 ha)	273 (675 ac)	271 (670 ac)	272 (672 ac)	276 (682 ac)	274 (677 ac)	273
	Thinning	274 (677 ac)	276 (682 ac)	276	275 (680 ac)	275	275	275
	subtotal	663 (1,638 ac)	660 (1,631 ac)	657 (1,623 ac)	658 (1,626 ac)	662 (1,636 ac)	660 (1,631 ac)	660

[a] Total area eligible: conifer-dominated forest = 123,933 ha (306,238 ac); mixed conifer-aspen forest = 97 ha (240 ac)

[b] Total area eligible: 32,768 ha (80,970 ac)

[c] Total area eligible: 24,763 ha (61,189 ac)

[d] These scenarios used "hotter" burns, resulting in about three times the level of canopy mortality as the "cool" burns.

8. *Matrix thin, group cut, and burn*—Matrix thinning and group cuts followed by prescribed fire, as previously described.
9. *Thin, masticate, and burn*—Mastication of small diameter material within a randomly selected 75 percent of the treatment unit combined with overstory thinning followed by prescribed fire over the entire unit. Because of the thinning, this treatment always resulted in a transition to a more open-canopy class within the same developmental stage or maintained the stand in an open-canopy condition.
10. *Thin, hand cut, pile, and burn*—Hand cutting and piling within a randomly selected 75 percent of the treatment unit combined with overstory thinning followed by prescribed fire over the entire unit. Because of the thinning, this treatment always resulted in a transition to a more open-canopy class within the same developmental stage or maintained the stand in an open-canopy condition.

- <u>Constraints and priorities</u>—We specified a number of constraints and priorities for treatments. First, we assigned "static" constraints and priorities for each treatment type, whereby each cell was assigned a value of 0–1 to indicate its eligibility and priority for treatment. These static constraints and priorities were constant over the duration of the simulation (i.e., they did not change over time) and were thus defined on the basis of relatively static landscape features (e.g., administrative areas such as roadless areas, designated areas for focal wildlife, edaphic and topographic features). We constructed four different static spatial constraints and priorities layers associated with four groupings of treatments:
  1. *Burn*—prescribed fire (used by itself without mechanical treatments). We created two versions of this layer: (1) priorities applied to scenarios MS2 and MS4–MS7 (fig. 18a), and (2) priorities applied to the burn-only scenarios (MS3a,b) that differed in also allowing prescribed fire to be used in the designated roadless areas (not shown).
  2. *Thin*—overstory thinning, applied to: (1) clearcut; (2) thinning; (3) thin and burn; (4) matrix thin and group cut; and 5) matrix thin, group cut, and burn (fig. 18b).
  3. *Mast*—understory fuel mastication, applied to: (1) mastication; and (2) thin, masticate, and burn (fig. 18c).
  4. *Hand*—understory fuel hand cut and pile, applied to: (1) hand cut, pile, and burn; and (2) thin, hand cut, pile, and burn (fig. 18d).

To construct each layer, we combined several spatial data layers, including: WUI zones, spotted owl and northern goshawk PACs, riparian conservation areas, topographic position, road proximity, roadless areas, and cover type. First, each of these layers was transformed to range from 0 to 1 based on the coefficients in table 9 for national forest lands; on private lands we considered only slope (fig. 19) and cover type (table 9). Next, we combined the transformed layers with a geometric mean. Consequently, at the cell level if any transformed layer was 0, the final result was 0 and the cell was deemed ineligible for treatment. If all the layers were greater than 0, the cell received an average value that was weighted toward the smallest value.

Second, we specified "dynamic" constraints and priorities, whereby each cell was assigned a value of 0–1 to indicate its eligibility and priority for treatment in the current timestep based on conditions that changed over the duration of the simulation. For conifer forests and woodlands on national forest lands, this was determined by the minimum of: (1) logistic function of the number of years since the last vegetation treatment of any kind (fig. 20), (2) logistic function of the number of years since the last fire (fig. 20), and (3) priority assigned to each seral stage by cover type as given in table 10. The seral stage priorities for scenarios MS2–MS6 were assigned a priori, whereas the adjustments to these priorities for our final scenario (MS7) were based on scrutiny of the previous results in an attempt to more closely emulate HRV. For conifer forests and woodlands on private industrial forest lands

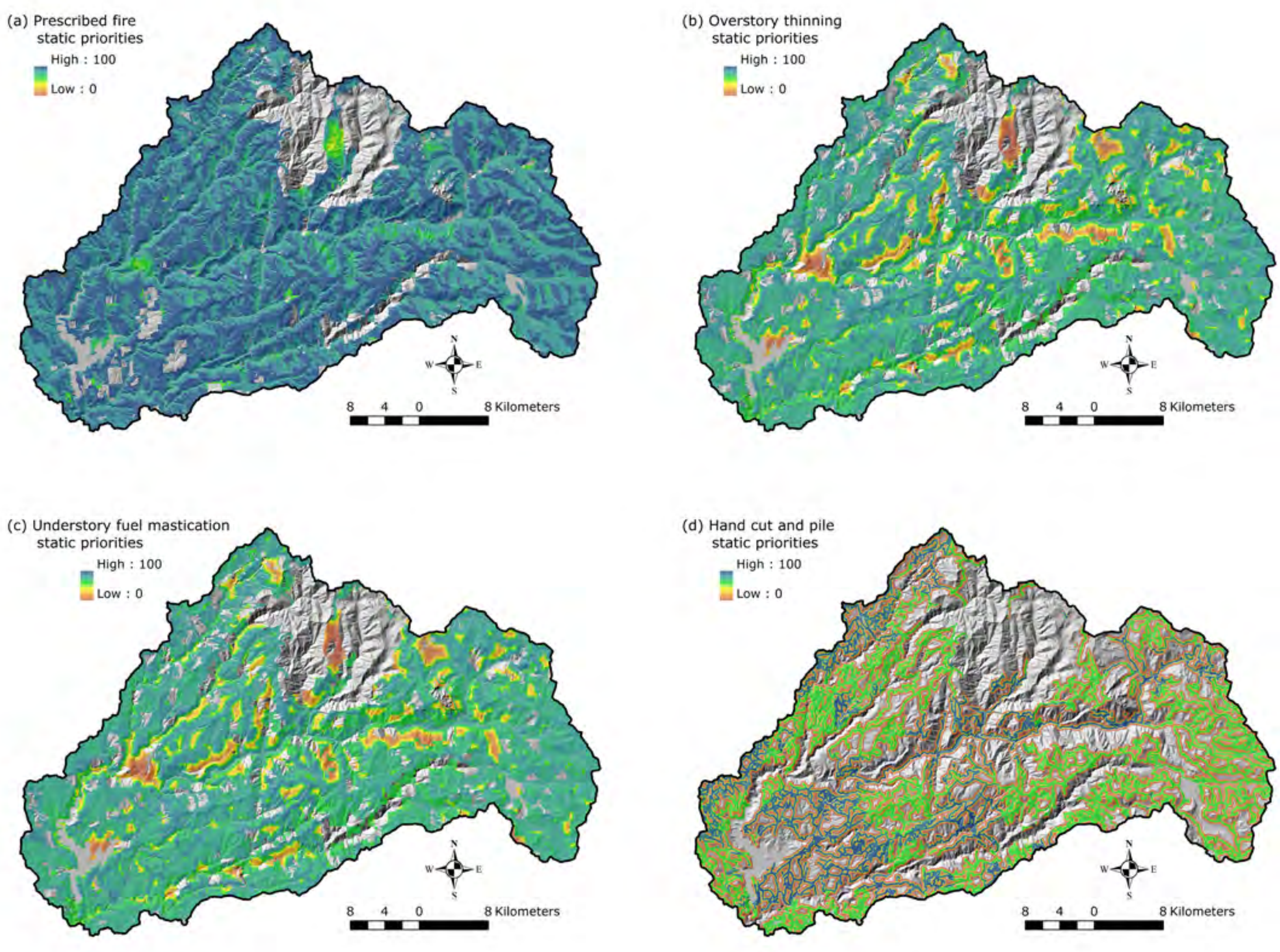
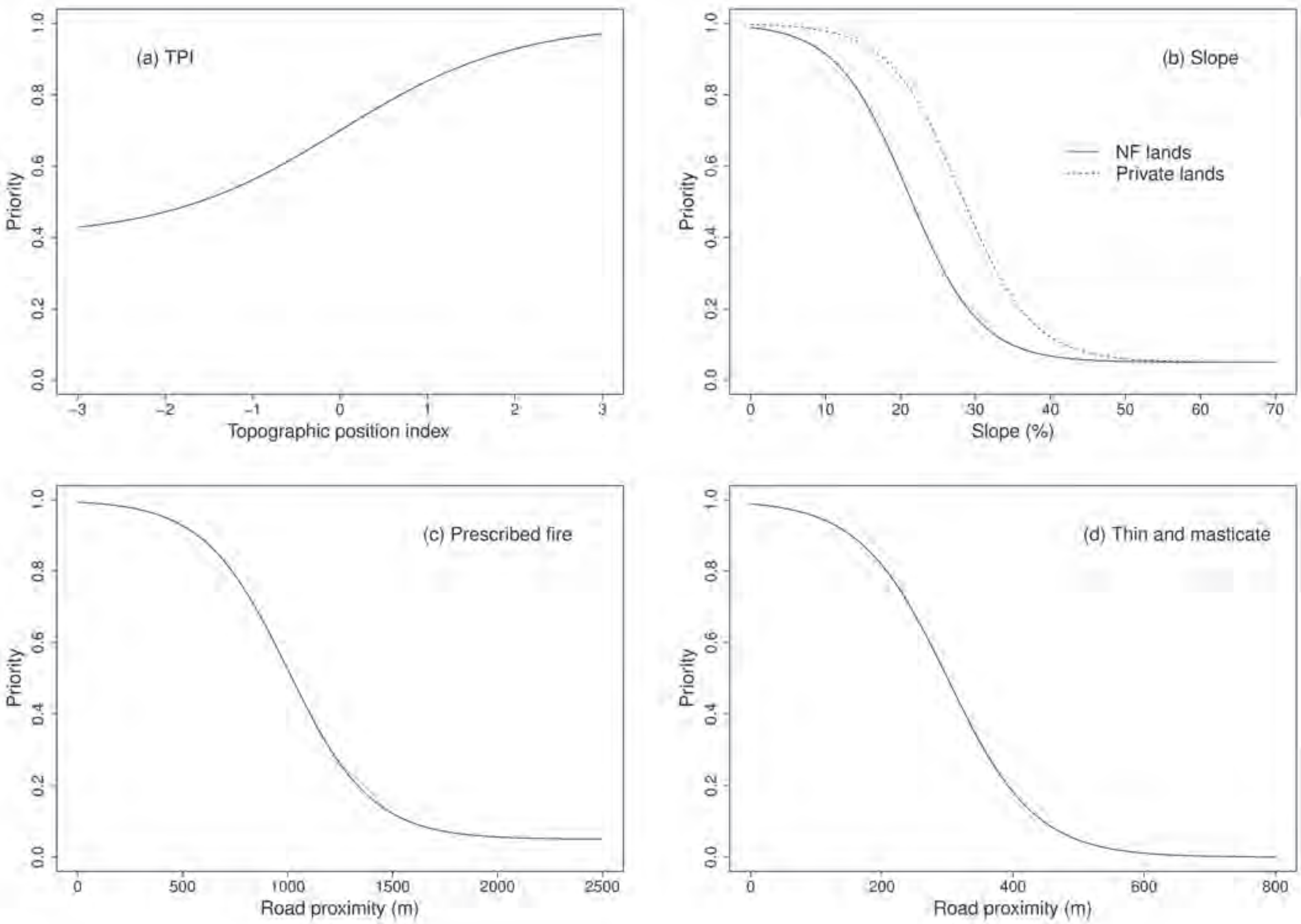


Figure 18—Static spatial constraints and priorities for: (a) prescribed fire treatments, (b) overstory thinning treatments, (c) understory fuel mastication treatments, and (d) hand cut and pile treatments in the upper Yuba River watershed. Transparent areas (showing gray hillshading) were excluded from treatment.

and other lands, this was determined by the minimum of: (1) logistic function of the number of years since the last vegetation treatment of any kind (fig. 20), and (2) priority assigned to each seral stage (across all cover types) as given in table 10. For mixed conifer-aspen forests (which occurred only on national forest lands, as mapped), this was based solely on seral stage, with treatments restricted to and assigned equal priority to the three most advanced seral stages (mid-aspen and conifer, late-aspen and conifer, and late-closed canopy).

Third, we computed the geometric mean of the static and dynamic constraints and priorities to determine the eligibility and priority of each cell for the corresponding treatment in each timestep. Consequently, at the cell level if either the static constraint or dynamic constraint was 0, the final result was 0 and the cell was deemed ineligible for treatment during the current timestep. If both layers were more than 0, the cell received an average value that was weighted toward the smallest value and prioritized for that treatment type accordingly.

Last, based on current Tahoe National Forest policy, we constructed a minimum canopy cover threshold layer to serve as a constraint on vegetation treatments. We set the threshold at 70 percent in PACs, 0 percent (i.e., no limit) in the WUI urban core and defense zones, and 40 percent for all other areas (fig. 21). Treatments were not allowed to occur if the average canopy cover within the potential treatment unit was below the average minimum canopy cover threshold as depicted in this layer.



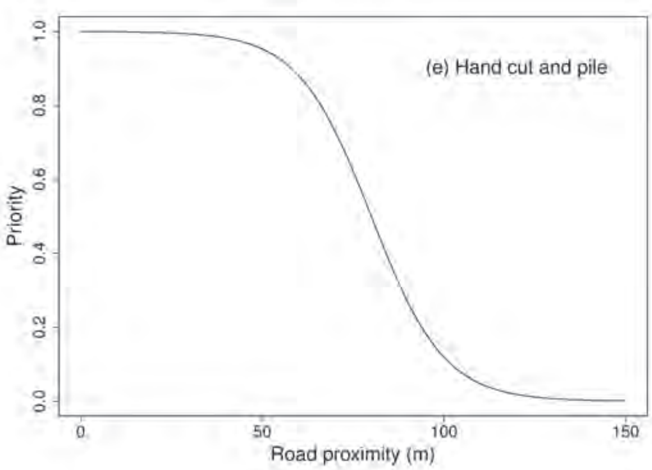


Figure 19—Transformation of (a) the topographic position index (TPI), (b) slope, and (c–e) road proximity for prescribed fire, thin and masticate, and hand cut and pile treatments, respectively, into a priority score (0–1) to be combined with other data listed in table 9 to create the static constraints and priorities layers for vegetation treatments (fig. 18). Note change in x-axis scale for road proximity figures.

Table 9—Static spatial constraints and priorities for vegetation treatments on national forest lands in the upper Yuba River watershed. Each spatial layer was transformed to range from 0 to 1, whereby 0 = exclude from treatment and >0 indicates relative priority. Transformed layers were combined with a geometric mean for each of the four groupings of treatments: Burn = prescribed fire; Thin = thinning (applied to clearcut; thinning; thin and burn; matrix thin and group cut; matrix thin, group cut, and burn); Mast = understory fuel mastication (applied to mastication; thin, masticate, and burn); Hand = understory fuel hand cut and pile (applied to hand cut, pile, and burn; thin, hand cut, pile, and burn).

		Treatment type (priority 0–1)			
Spatial layer	**Class**	**Burn**	**Thin**	**Mast**	**Hand**
WUI-PACs[a]	Urban core-PAC	0	0.1	0.1	0.8
	Defense zone-PAC	0.1	0.1	0.1	0.8
	Threat zone-PAC	0.6	0	0	0.6
	nonWUI-PAC	0.4	0	0	0.1
	Urban core-nonPAC	0	1	1	1
	Defense zone-nonPAC	1	1	1	1
	Threat zone-nonPAC	0.8	0.8	0.8	0.8
	nonWUI-nonPAC	0.8	0.8	0.6	0.1
Riparian conservation areas[b]	n/a	0.4	0	0	0
Topographic position	n/a	logistic function in figure 19			ignored
Slope	n/a	ignored	logistic function in figure 19		ignored
Road proximity	n/a	logistic function as shown in figure 19			
Roadless areas	n/a	0 (0.8)[c]	0	0	0
Cover types	n/a	Urban, Agriculture, Barren, and Water = 0			

[a] WUI-PACs = wildland-urban interface; Protected Activity Centers
[b] Perennial streams = 30-m (100-ft) buffer; intermittent streams = 23-m (75-ft) buffer
[c] Coefficient in parentheses was used for the burn-only scenarios (MS3a and MS3b)

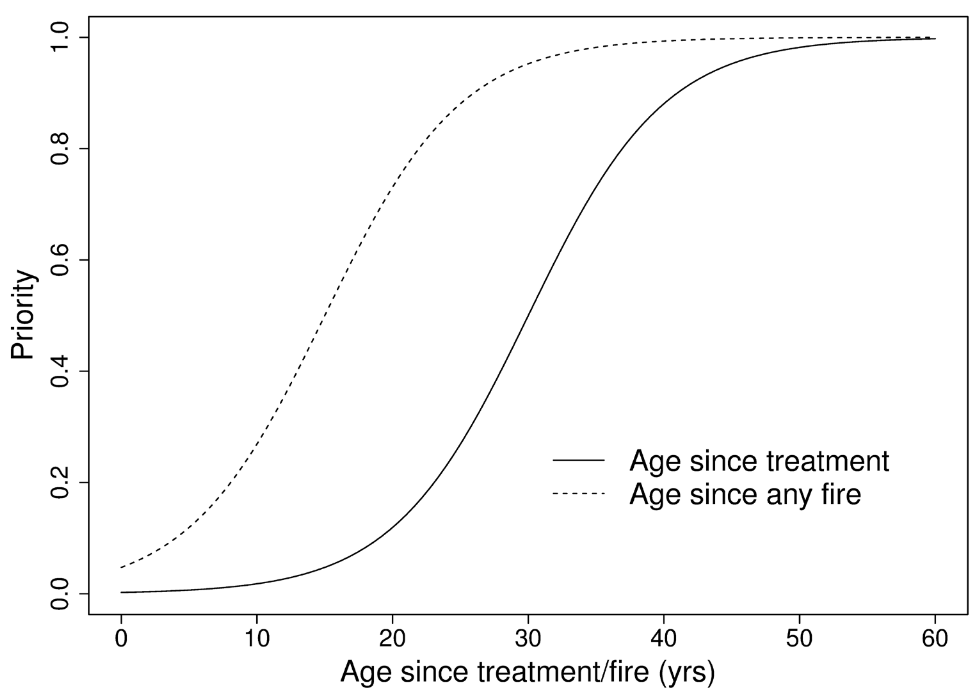


Figure 20—Logistic functions depicting the relationship between (1) age since any vegetation treatment and (2) age since any fire and the dynamic spatial constraints and priorities for vegetation treatments in conifer forests and woodlands.

Table 10—Dynamic spatial constraints and priorities assigned to vegetation seral stages for vegetation treatments in conifer-dominated forest and woodlands on national forest lands in the upper Yuba River watershed under the management scenarios (MS1–MS7) described in the text.

	National forest						Private industry and other private
	MS2–MS6		MS7				All scenarios
	Cover type[a]		Cover type[a]				Cover type
Seral stage	A	B	C	D	E	F	All
Early – all structures	0	0	0	0	0	0	0
Mid-open	0.05	0.1	0.1	0.1	0.05	0.05	0
Mid-moderate	0.3	0.4	0.6	0.7	0.5	0.4	0.1
Mid-closed	0.7	0.8	1	1	0.9	0.8	0.5
Late-open	0.1	0.2	0.1	0.1	0.05	0.05	0
Late-moderate	0.5	0.6	0.4	0.5	0.3	0.2	0.2
Late-closed	0.9	1	0.8	0.9	0.7	0.6	1

[a] A = Red Fir Forest (all variants); B = All other forest and woodlands; C = Sierra Mixed Conifer Forest (all variants), Western White Pine Forest, Lodgepole Pine Forest, and Oak Woodland; D = Oak-Conifer Forest and Woodland (all variants); E = Red Fir Forest – Xeric, Red Fir Forest – Ultramafic, and Mixed Evergreen Forest (all variants); F = Red Fir Forest – Mesic.

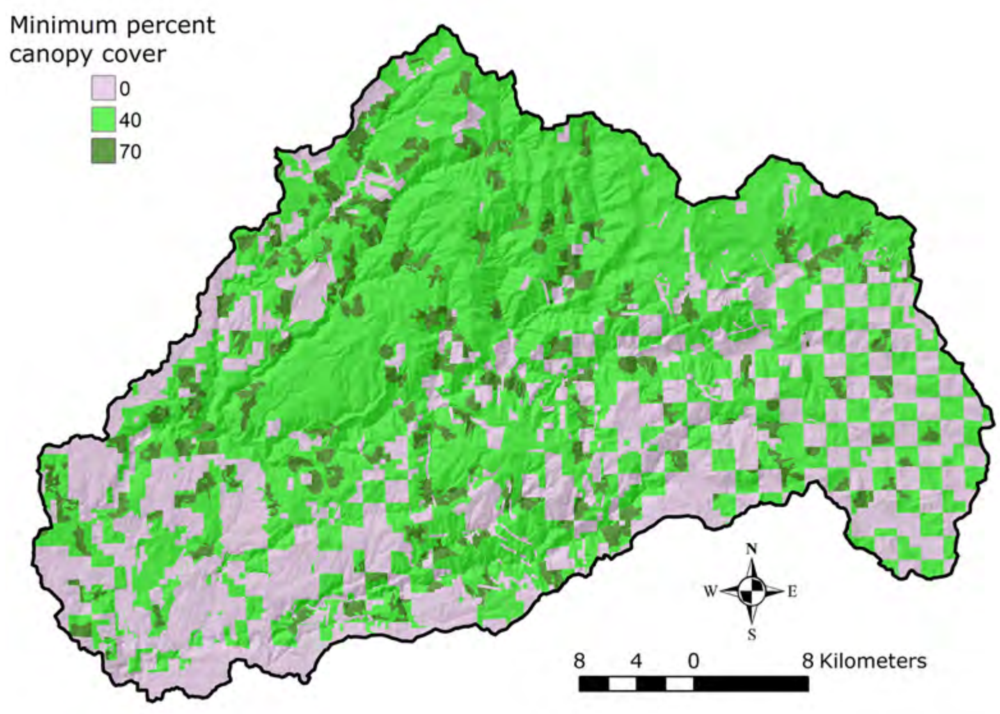


Figure 21—Minimum canopy cover threshold for vegetation treatments in the upper Yuba River watershed.

- *Treatment units*—We created individual treatment units by randomly selecting a treatment type and an initial cell and spreading outward based on the relative probabilities in the corresponding constraints and priorities layer until meeting either a barrier (i.e., constraint = 0) or a major topographic ridgeline, or achieving the maximum unit size. For conifer forests and woodlands, we constrained treatment units to be 20–120 hectares (50–300 acres) for mechanical treatments and 20–405 hectares (50–1,000 acres) for prescribed fires, whereas for mixed conifer-aspen forest we limited the units to 0.09–16 hectares (0.2–40 acres) to reflect the very small sizes of the existing patches. Subsequent treatment units within each management zone and management type were randomly assigned to treatment type according to the specified allocation and were implemented sequentially until the target overall treatment intensity was met or there were 100 failed attempts to create a viable unit.

Within a timestep, treatment units for conifer forests and woodlands were randomly dispersed within a compartment randomly selected from a pool of 20 compartments that ranged in size from 4,650 to 15,906 hectares (11,490–39,303 acres) (fig. 22). This resulted in an aggregation of treatment units within a geographic area generally corresponding to a project area. Multiple compartments were treated in a single timestep as necessary to achieve the target treatment area. For mixed conifer-aspen forests, treatments were randomly distributed across the entire project area to reflect the limited and scattered distribution of this forest type. Last, all treatments were implemented as single-entry treatments. A unit was created and treated once; then the cells were returned to the pool of cells and made available for another treatment (subject to their suitability) in a subsequent timestep.

Model Calibration and Verification

As described earlier, we adjusted the overall disturbance rate calibration parameter to achieve the target modern FRP of 152 years for the no treatment scenario (MS1) and modified the target fire size distribution to reflect the modern (1992–2013) fire record; all other succession and wildfire disturbance parameters were kept the same as the HRV scenario.

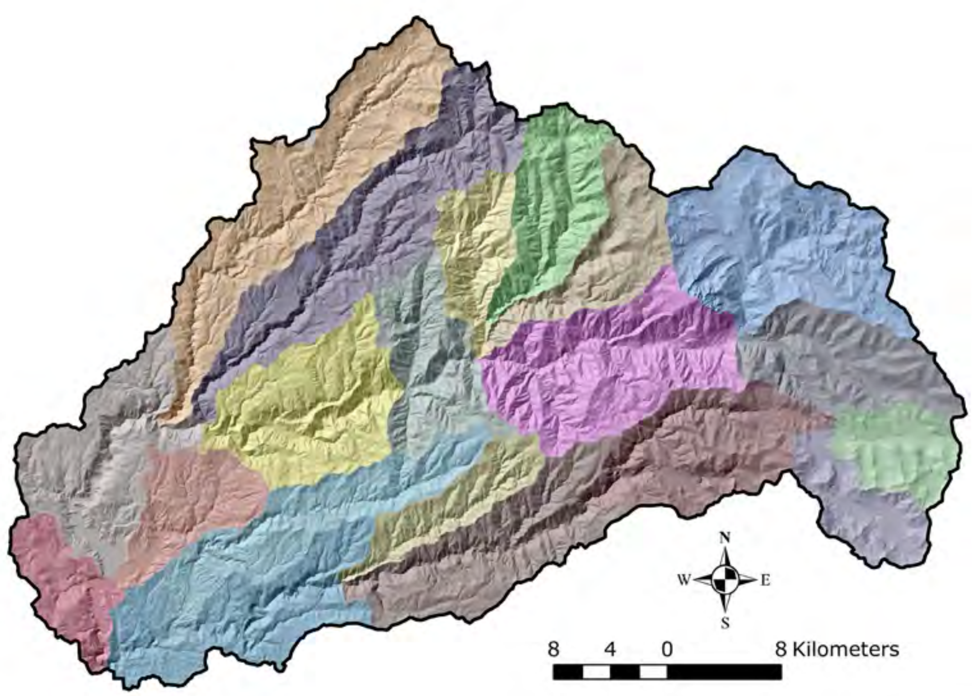


Figure 22—Vegetation treatment compartments in the upper Yuba River watershed.

Once the model was calibrated, we kept these parameters the same for all other management scenarios. As before, we set our calibration goal to be within 10 percent of the target overall FRP and limited our calibration to the overall FRP for all cover types combined rather than calibrating for each cover type separately. We realized an overall FRP for the no treatment scenario of 147 years (averaged across simulations), which was within 3 percent of the target. Last, as with the HRV simulation, we verified the model behavior with respect to the simulated fire patterns (not shown) and fire size distribution (fig. 23).

Model Execution

We used RMLands to simulate succession and fire disturbance under modern conditions (i.e., aggressive fire suppression) and vegetation treatments for a 100-year period (ca. 2010–2110). We used a 5-year timestep in the model for consistency with the HRV scenario. After calibrating the model, for each of the management scenarios we ran 20 replicate simulations for 20 timesteps (i.e., 100 years) and generated several GIS data layers representing disturbance and vegetation state at each timestep. For the analysis of landscape structure, we were most interested in comparing the landscape at the end of the 100-year simulation to the current landscape condition and the simulated HRV. Thus, for the landscape structure analysis we kept only the last timestep of each replicate simulation (N = 20 for each scenario) as snapshots of the landscape and used these samples to quantify the range of variability in various landscape attributes (see next section).

As with the HRV scenario, we included a 10-kilometer buffer around the project area for the simulation to avoid landscape boundary effects, resulting in a much larger landscape for the simulation (408,498 hectares; 1,009,399 acres). Wildfire disturbances were allowed to spread across the project area boundary unimpeded, but we restricted vegetation treatments to the core project area (i.e., excluding the buffer). All results were calculated for the core project area only.

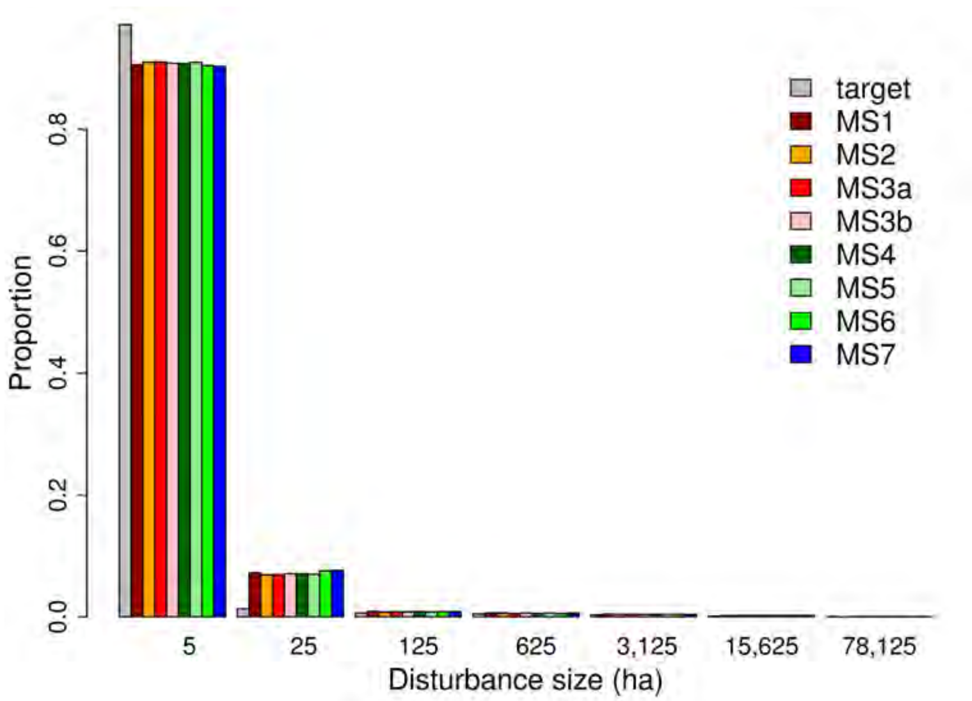


Figure 23—Distribution of simulated fire sizes for the management scenarios (MS1–MS7) within the upper Yuba River watershed and the target fire size distribution derived from the modern fire record in the North Sierran ecoregion (1992–2013). Note that the x-axis is geometrically scaled.

Analysis of Landscape Structure

To quantify landscape structure, we used FRAGSTATS (McGarigal et al. 2012), which is a software tool for quantifying the structure of patch mosaics based on hundreds of different landscape metrics. For the HRV scenario, we computed the variability in selected measures of landscape composition and configuration (see following) based on the 460 snapshots of the landscape. To evaluate current departure, we compared the initial landscape representing approximately the year 2010 (based on the source GIS data) to the corresponding HRV for each landscape metric. For each of the management scenarios, we computed the variability in the landscape metrics based on the 20 snapshots of the landscape derived from the replicate 100-year simulations, and compared the variability in each landscape metric to both the initial landscape (2010) and the HRV.

Landscape Composition

For our purposes, "landscape composition" refers to the total area of each vegetation class (or patch type). Landscape composition is nonspatial and ignores the spatial pattern of the patch mosaic. We quantified landscape composition based on four different classifications of the landscape:

- Developmental stage—Here, we classified the landscape into none or early-, mid-, or late-development classes pooled across cover types (table 11). Developmental stages represented stages of successional development and reflected the size of the dominant overstory trees (which varied among cover types; Appendix B). Nonvegetated (e.g., Water) and nonseral (e.g., Meadow) cover types were classified as "none."
- Canopy cover—Here, we classified the landscape into none or open-, moderate-, or closed-canopy classes by reclassifying seral stages and pooling across cover types (table 11). Here, we considered any seral stage with an average canopy cover from above of less than 40 percent as "open," between 40 and 75 percent as "moderate," and greater than 75 percent as "closed." Nonvegetated and nonseral cover types were classified as "none."
- Seral stage—Here, we classified the landscape into 12 seral stage classes pooled across cover types (table 11). Seral stages mostly represented a combination of developmental stage and canopy cover class, although they varied somewhat among cover types (Appendix B).

Table 11—Crosswalk between seral stage classes, developmental stages, and canopy cover classes for the simulated historical range of variability (ca. 1550–1850) and management scenarios in the upper Yuba River watershed.

Seral stage	Developmental stage	Canopy cover class
Nonseral	None	None
Early - all structures	Early	Open
Mid-open	Mid	Open
Mid-moderate	Mid	Moderate
Mid-closed	Mid	Closed
Late-open	Late	Open
Late-moderate	Late	Moderate
Late-closed	Late	Closed
Early - Aspen	Early	Open
Mid - Aspen	Mid	Moderate
Mid - Aspen and Conifer	Mid	Closed
Late - Conifer And Aspen	Late	Closed

- Cover-seral—Here, we classified the landscape into 151 unique combinations of cover type and seral stage. This was the most finely resolved thematic classification and represented the unique states that each cell could exist in during the simulation, as defined in the state-and-transition models (Appendix B).

For each of these landscape classifications, we generated the following statistical summaries (all of which excluded the class representing nonvegetated and nonseral cover types):

- Trajectory over time—Proportion of the eligible landscape in each vegetation class at each timestep, depicted as a stacked bar chart such that the proportions summed to 1 at each timestep. We used this graphical summary to visually display the model equilibration period, or the period of time required for the current landscape composition to return to within the historical dynamic equilibrium composition for the HRV scenario, and to display the dynamic nature of landscape composition under historical conditions.
- Range of variability and current departure table—Tabular summary of the range of variability in landscape composition and current landscape departure. Specifically, we computed the percentage of the eligible landscape in each vegetation class at the minimum value; 5th, 25th, 50th, 75th, and 95th percentiles; and maximum of the simulated range of variability (or a subset of these for the management scenario comparison). Each percentile represented the percentage of time the simulated landscape was at or below the corresponding percent composition of the landscape. Thus, the 5th–95th percentile range of variability, for example, represented the 90-percent range of variability in landscape composition, or the range of values the landscape exhibited 90 percent of the time under the particular scenario. We also computed the current landscape composition and the percentile of the simulated range of variability it represented.
- Range of variability and current departure figure—Graphical summary of the range of variability in landscape composition and current landscape departure. Specifically, we created a "box-and-whisker" plot in which the box represented the 25th–75th percentile range, the whiskers extended out to the minimum and maximum values, the solid horizontal line represented the median or 50th percentile, and the dashed horizontal line represented the current landscape condition. The box plot merely provided a graphical summary of the data in the previous table. For the management scenario comparison, the box plot was simplified to display only the 5th, 50th, and 95th percentiles along with the current condition.

Landscape Configuration

For our purposes, "landscape configuration" refers to the spatial pattern of the patch mosaic defined by either vegetation developmental stages, canopy cover classes, seral stages, or unique combinations of cover type and seral stage (table 11). Landscape configuration is the spatial component of landscape structure. For each of the four landscape definitions, we computed the following suite of landscape metrics for each snapshot of the landscape, including the current landscape. For pragmatic reasons, we report only the landscape-level metrics, which describe the configuration of the entire patch mosaic without regard to individual land cover classes:

- Largest patch index (LPI)—This metric measures the percentage of the landscape composed of the single largest patch and indicates the extent to which the landscape was dominated by a single matrix-forming patch. As such, this metric reflects the coarse patch structure of the landscape.
- Mean and area-weighted mean patch size (AREA_MN/AREA_AM)—These two metrics measure the size (hectares) of a patch selected at random (AREA_MN) and the size (hectares) of the patch for a point selected at random (AREA_AM), respectively. Mean patch size is a better measure of the "fine-grained" heterogeneity of the landscape, as it is heavily influenced by the vast number of very small patches. Area-weighted mean

patch size is a better measure of the coarse patch structure of the landscape, as it is predominantly influenced by the larger patches. Furthermore, because the latter metric is not affected by the many small patches that can be created as an artifact of the pixelation associated with a raster-based disturbance and succession model, it is a more reliable measure of landscape configuration than the mean for evaluating current departure.

- *Correlation length (GYRATE_AM)*—This metric measured the physical continuity of the landscape based on a measure of the extensiveness of each patch (meters), as measured by the radius of gyration (GYRATE), weighted by patch area. It can be interpreted as the average distance an organism might traverse the map from a random starting point and moving in a random direction without having to leave a patch. Because this is an area-weighted metric, like area-weighted mean patch size, it is a measure of the coarse patch structure of the landscape. Whereas area-weighted mean patch size measures the coarse patch structure in terms of area (hectares), correlation length measures the coarse patch structure in terms of distance (meters).
- *Mean and area-weighted mean shape index (SHAPE_MN/SHAPE_AM)*—These two unitless measures reflect the shape of a patch selected at random (SHAPE_MN) and the shape of the patch for a point selected at random (SHAPE_AM), respectively. The shape index is a normalized perimeter-to-area ratio that equals 1 for a square and increases as the patch becomes increasingly non-Euclidean (i.e., geometrically more complex). The greater the shape index value, the greater the ratio of edge to area, and thus potentially the greater the magnitude of edge effects (both positive and negative) on ecosystems and species. Like area-weighted mean patch size, the area-weighted mean shape index is a measure of the coarse patch structure of the landscape.
- *Mean and area-weighted mean disjunct core area (DCORE_MN/DCORE_AM)*—These two metrics measure the core area (hectares) of a disjunct patch of core area selected at random (DCORE_MN) and the core area (hectares) of the patch for a core area point selected at random (DCORE_AM), respectively. Core area is defined as the area that is greater than a specified distance (see Appendix C for our edge effect distances) from the nearest patch edge, that is, the patch interior. It is affected jointly by the size, shape, and specified edge depth. A single patch can have multiple disjunct core areas depending on its spatial character and the specified edge depths. This metric is based on the logic that the greater the core area, the greater the absolute amount of patch interior environment, and thus potentially the smaller the edge effects (both positive and negative) on ecosystems and species. Like area-weighted mean patch size, the area-weighted mean disjunct core area is a measure of the coarse patch structure of the landscape.
- *Mean and area-weighted mean core area index (CAI_MN/CAI_AM)*—These two metrics measure the percentage of a patch that is core area for a patch selected at random (CAI_MN) and of the patch for a point selected at random (CAI_AM), respectively. In contrast to the core area metric that measures the absolute core area (hectares), the core area index is a relative measure of core area that measures the percentage of the total area that is in core. This metric is useful because the greater the core area index, the greater the relative amount of patch interior environment, and thus potentially the smaller the edge effects (both positive and negative) on ecosystems and species. Like area-weighted mean patch size, the area-weighted mean core area index is a measure of the coarse patch structure of the landscape.
- *Total edge contrast index (TECI)*—This metric measures the relative magnitude of ecological differences between adjacent patches along an edge, that is, the abruptness of the edge. Specifically, it measures the average percentage of the maximum possible contrast along a randomly selected edge, where contrast weights for each pair of adjacent patch types are user defined (see Appendix C for our edge contrast weights). It gives the average contrast regardless of the total length of edge. The greater the edge contrast index, the greater the abruptness of the edges, and thus potentially the greater the edge effects

(both positive and negative) on ecosystems and species. In addition, edge contrast can affect the movement of organisms across the landscape (both positively and negatively). Thus, all other things being equal, the edge contrast index can loosely be interpreted as a measure of landscape connectivity.

- Interspersion and juxtaposition index (IJI)—This metric measures the interspersion (spatial intermixing) of patch types as a percentage of the maximum possible interspersion given the number of classes. This metric is interpreted as a general measure of spatial diversity. All other things being equal, the greater the interspersion and juxtaposition index, the greater the spatial diversity.
- Edge density (ED)—This metric measures the density of edges (meters per hectare) in the landscape, where an edge is defined as the boundary between adjacent patches. The greater the edge density, the greater the quantity of edge, and thus potentially the greater the magnitude of edge effects (both positive and negative) on ecosystems and species. This metric is also interpreted as a general measure of spatial heterogeneity. All other things being equal, the greater the edge density, the greater the spatial heterogeneity. In addition, edges can affect the movement of organisms across the landscape (both positively and negatively). Thus, all other things being equal, edge density can loosely be interpreted as a measure of landscape connectivity.
- Contrast-weighted edge density (CWED)—This metric measures the density of edges (meters per hectare) in the landscape weighted by the degree of contrast between adjacent patch types, where contrast weights are defined as before. It represents the equivalent maximum-contrast edge density (meters of maximum contrast edge per unit area). This metric essentially combines the total edge contrast index and edge density metric into a single measure that reflects both the quantity of edge and its average contrast. Similar to edge density, the greater the contrast-weighted edge density, the more higher-contrast edges, and thus potentially the greater the magnitude of edge effects (both positive and negative) on ecosystems and species. This metric is also interpreted as a general measure of spatial heterogeneity. All other things being equal, the greater the contrast-weighted edge density, the greater the spatial heterogeneity. In addition, edges and their contrast can affect the movement of organisms across the landscape (both positively and negatively). Thus, all other things being equal, contrast-weighted edge density can loosely be interpreted as a measure of landscape connectivity.
- Aggregation index (AI)—This metric measures the degree (percent) to which patch types are aggregated at the cell level relative to the maximum aggregation possible given the amount of each patch type. The aggregation index is maximum when each patch type is maximally aggregated into a single compact patch such that the cells are maximally adjacent to cells of the same patch type. As such, this metric reflects the spatial heterogeneity and physical continuity of the landscape and can loosely be interpreted as a measure of fragmentation, with higher values indicating less fragmentation and greater continuity.
- Contagion (CONTAG)—This metric measures the clumpiness of the landscape as a percentage of the maximum. Contagion is affected by both the aggregation and interspersion of patch types; it essentially combines the aggregation index and interspersion and juxtaposition index into a single measure. High contagion equates to highly aggregated patch types that are poorly interspersed (spatially intermixed).

For each of these landscape configuration metrics, we generated the following statistical summaries:

- Trajectory over time—Line plot depicting the change in the metric over timesteps. As with the landscape composition metrics, we used this graphical summary to visually display the model equilibration period for the HRV scenario and to display the dynamic nature of landscape configuration under historical conditions.

- *Range of variability and current departure table*—Tabular summary of the range of variability in landscape configuration and current landscape departure, similar to the table for the landscape composition metrics. However, to simplify the table given the number of scenarios, here we reported only the values of the landscape metric corresponding to the 5th, 50th, and 95th percentiles of the simulated range of variability.
- *Range of variability and current departure figure*—Graphical summary of the range of variability in landscape configuration and current landscape departure, similar to the box plots for the landscape composition metrics. However, to simplify the plots given the number of scenarios, here we displayed the range of the 5th to 95th percentiles as the box and the median or 50th percentile as a horizontal line.

RESULTS

Historical Range of Variability and Departure

For organizational purposes, we divided the HRV results into three major sections. In the first section, we describe the results of the simulated disturbance regime with respect to fire frequency, area burned, rotation period, and severity, recognizing that the disturbance regime was largely determined by the model parameterization and was calibrated to achieve certain targeted outcomes. In the second section, we describe the HRV in landscape composition with respect to the variability in vegetation developmental stage, canopy cover, and seral stage, and the degree of departure of the current landscape with respect to each of these landscape definitions. In the last section, we describe the HRV and current departure in landscape configuration (i.e., spatial pattern) with respect to each of the landscape definitions.

Disturbance Regime

Fire Frequency

The simulated number of individual fires per 5-year timestep varied from 61 to 331 (mean = 194), which translated to about 12 to 66 fires per year initiating within the 181,556-hectare project area. Recall that fire frequency was treated as a calibration parameter tuned to achieve the target overall fire rotation period of 30 years. Therefore, the absolute fire frequency is somewhat revealing because it indicates the number of fires that were required to achieve the scientifically supported overall fire rotation period. As expected given the model structure, fire frequency increased with the climate modifier, such that the warmer, drier timesteps realized on average about two to three times as many fires as the cooler, wetter timesteps (fig. 24).

Area Burned

Approximately 96 percent of the landscape, equating to 174,830 hectares (432,005 acres), was eligible for wildfire disturbance (all cover types except Barren and Water). The percentage of the eligible landscape that burned each 5-year timestep (across multiple fires) averaged about 18 percent (~30,000 hectares; 74,000 acres), but varied dramatically over time, ranging from less than 1 percent (~100 hectares; 250 acres) to almost 74 percent (~129,000 hectares; 319,000 acres) (figs. 25, 26). As with fire frequency, the total area burned increased with the climate modifier, such that, on average, much greater area burned during the warmer, drier timesteps, and the “bigfire” years (actually 5-year timesteps) in which more than 50 percent of the eligible landscape burned always occurred during these warmer and drier periods (fig. 27).

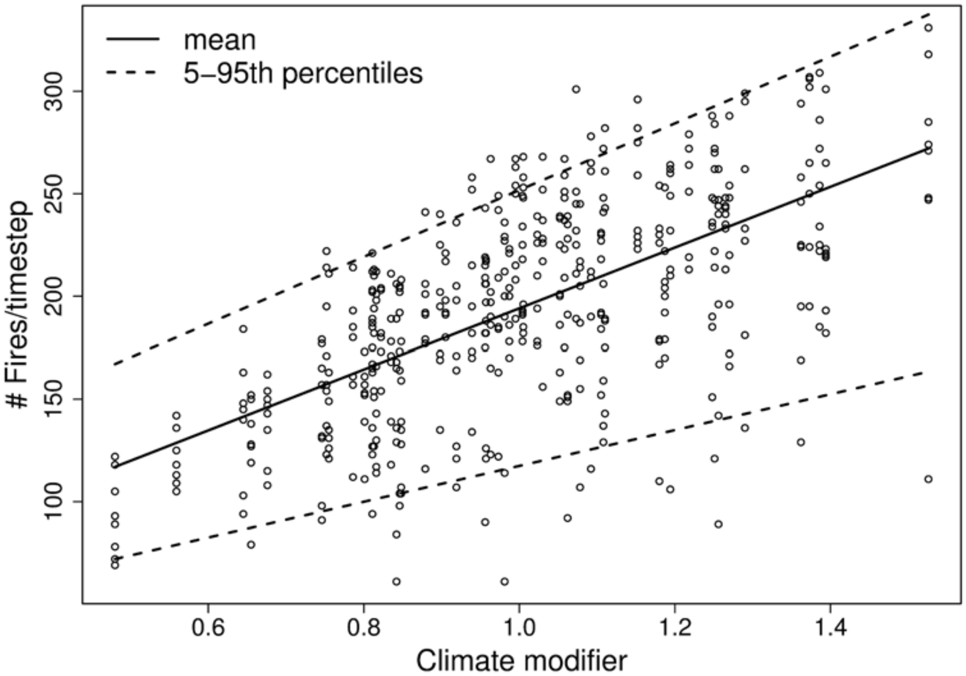


Figure 24—Simulated number of fires per 5-year timestep in relation to the climate modifier for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Solid line represents the average trend (R2 = 40 percent, *P* < 0.001) and the dotted lines represent the trends corresponding to the 5th and 95th percentiles of the data.

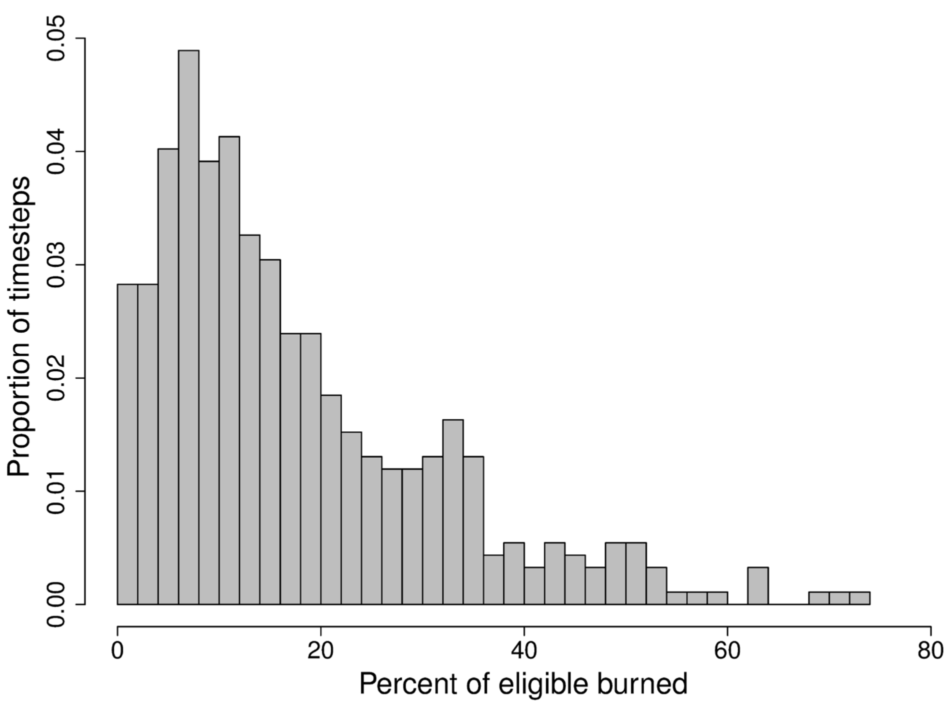


Figure 25—Simulated proportion of 5-year timesteps in which a given percentage of the eligible area burned for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed.

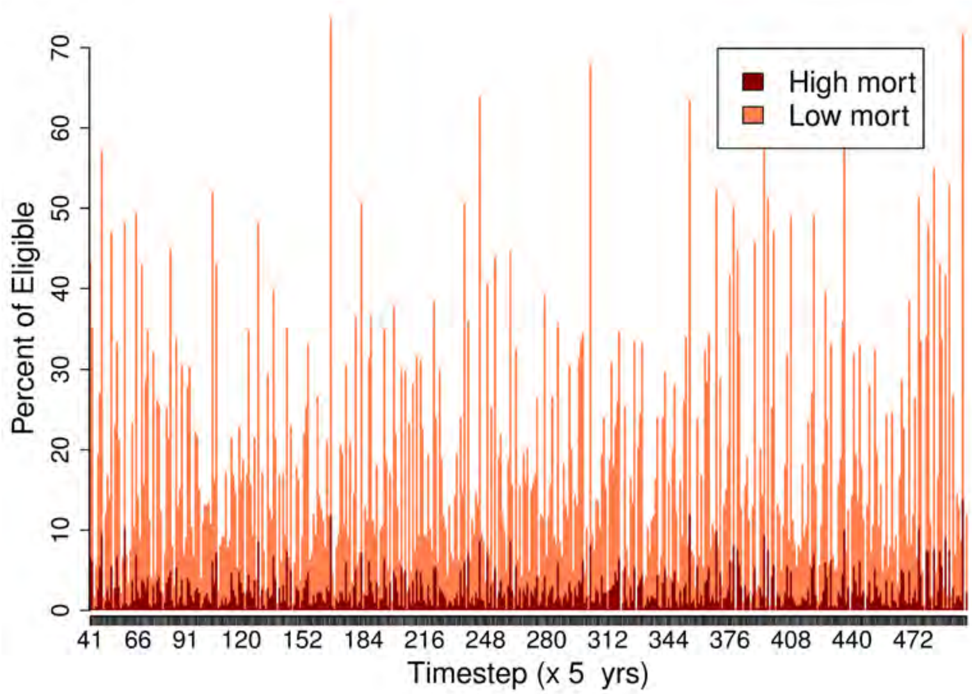


Figure 26—Simulated percentage of the eligible area burned per 5-year timestep and the proportion of high- versus low-mortality vegetation response (i.e., severity) for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed.

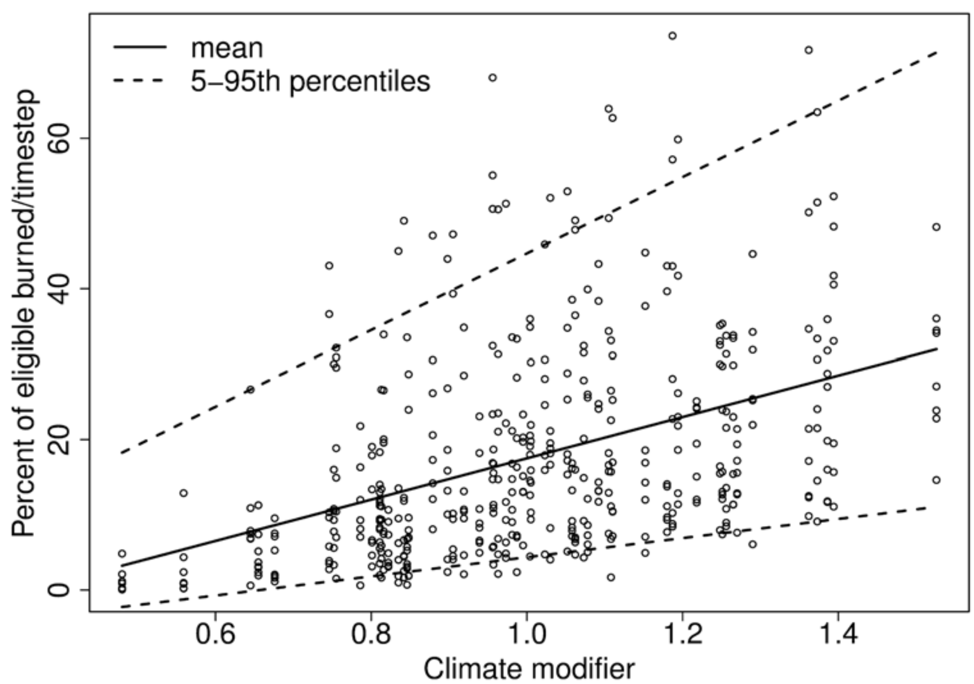


Figure 27—Simulated percentage of eligible area burned per 5-year timestep in relation to the climate modifier for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Solid line represents the average trend (R2 = 19 percent, $P < 0.001$) and the dotted lines represent the trends corresponding to the 5th and 95th percentiles of the data.

Another useful way of describing area burned is with exceedance probabilities and intervals. Exceedance probability (*P*) refers to the probability in any one timestep of the total area burned exceeding a certain percentage of the landscape, and the exceedance interval (*I*) is the average number of years between timesteps in which a certain exceedance level is achieved:

$$I = (^1/_E) \times t,$$

where *t* = length of the timestep in years (= 5 in this case).

Figure 28 depicts both exceedance probability and exceedance interval for the observed range of percentages of the eligible landscape burned in a single 5-year timestep (~0–74 percent). Exceedance probability decreases monotonically from 1 to 0 as the exceedance increases from the minimum to the maximum observed percentage of the landscape burned. Similarly, exceedance interval increases monotonically over the same range, as it is inversely related to exceedance probability. For convenience, table 12 lists both exceedance probabilities and intervals for three exceedance thresholds. It indicates that, on average, every 20 years (four timesteps in the model) more than 25 percent of the eligible landscape burned.

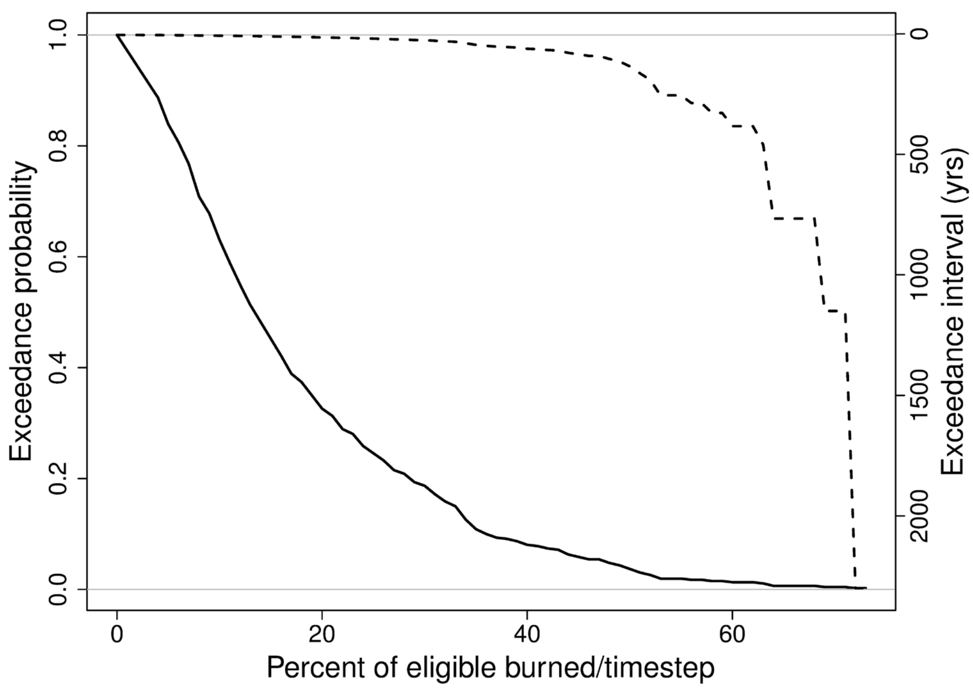


Figure 28—Simulated probability of wildfires exceeding (left y-axis and solid line) a given percentage of eligible area in a 5-year timestep, and the corresponding average interval between events of that magnitude (right y-axis and dashed line) for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed.

Table 12—Exceedance probabilities and intervals for burning greater than or equal to a certain percentage of the eligible landscape per 5-year timestep for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed.

Percentage of eligible burned per timestep	Exceedance probability	Exceedance interval (yrs)
10	0.63	8
25	0.25	20
50	0.04	135

Fire Rotation Period

As described previously, we calibrated the model to achieve a target overall FRP of 30 years for the eligible portion of the landscape (96 percent) and to achieve ±10 percent of the target FRPs for the dynamic cover types with 1,000 hectares or more in the project area. Consequently, the realized FRPs were not really a result of the model because they largely reflected the model parameterization. They were nonetheless useful to examine because they allow us to describe how much disturbance was ultimately applied to each cover type and the landscape as a whole.

FRPs varied as much as threefold among the dominant cover types from a low of 24 years in Sierran Mixed Conifer – Xeric to a high of 63 years in Red Fir – Mesic (table 13). We observed much longer FRPs for some of the less common cover types, but these should be interpreted with caution due to the small sample size as noted previously. We computed FRPs for low- and high-mortality fires, as well as for "any" fire (inclusive of both fire mortality levels). FRPs for high-mortality fires were anywhere from 2 to 10 times longer than FRPs for low-mortality fires, but this too was largely a reflection of the model parameterization.

Table 13—Fire rotation periods (FRPs) by mortality level (i.e., severity) for all of the dynamic cover types for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Note that cover types are sorted by extent within the project area and we considered FRPs for cover types with extent of less than 1,000 ha (2,500 ac) as unreliable, even though they are reported in this table for completeness.

			Fire rotation period (years)		
Cover type	**Area (ha)**	**Area (ac)**	**Low mortality**	**High mortality**	**Any mortality**
Sierran Mixed Conifer – Mesic	57,853	142,955	31	199	27
Sierran Mixed Conifer – Xeric	52,198	128,981	26	257	24
Oak-Conifer Forest and Woodland	23,279	57,522	32	122	25
Red Fir – Mesic	8,563	21,159	84	253	63
Red Fir – Xeric	7,493	18,515	65	126	43
Mixed Evergreen – Mesic	7,273	17,972	58	277	48
Mixed Evergreen – Xeric	6,768	16,724	43	269	37
Sierran Mixed Conifer – Ultramafic	4,124	10,190	65	450	57
Grassland	1,379	3,408	737	63	58
Meadow	1,201	2,968	1,843	63	61
Oak-Conifer Forest and Woodland – Ultramafic	1,060	2,619	42	982	40
Lodgepole Pine	837	2,068	62	275	51
Montane Riparian	732	1,809	102	106	52
Subalpine Conifer	638	1,576	1,245	357	277
Mixed evergreen – ultramafic	604	1,492	132	648	110
Red fir – ultramafic	294	726	167	467	123
Western white pine	273	675	109	506	90
Urban	114	282	3,882	162	156
Sierran mixed conifer with aspen	58	143	41	131	32
Red fir with aspen	31	77	85	207	60
Oak woodland	19	47	30	137	25
Curl-leaf mountain mahogany	18	44	280	109	78
Agriculture	16	40	3,209	162	154
Lodgepole pine with aspen	8	20	59	246	48
Total	174,830	432,004	33	195	29

It is extremely important to recognize that FRP reflects the average point-specific fire return interval, but says nothing about its spatial variability. The point-specific FRI is more appropriate for examining spatial variability in fire frequency. We noted substantial spatial variability in the point-specific FRI across the landscape (fig. 29), reflecting gradients in cover types with varying propensities to burn, but also reflecting complex interactions among fire, vegetation, and terrain that emerged from the simulation. The dramatic variability in point-specific FRI within each cover type was especially noteworthy. For example, although the point-specific FRI for the Red Fir – Mesic cover type averaged 63 years, it varied from about 25 to 125 years among cells within this cover type (fig. 30). This spatial variability within even a single cover type resulted from the complex interactions among the spatial processes in the model and almost certainly was strongly influenced by the local landscape context of the focal cell. For example, a cell of Red Fir – Mesic in a neighborhood dominated by subalpine conifer typically had a much longer FRI because of the considerably longer average FRI of subalpine conifer (277 years). Indeed, the variability in point-specific FRI within cover types was generally as great as the variability among cover types, reflecting the overriding importance of landscape context.

Fire Severity

Recall that at the cell level, fires caused either low or high mortality to the overstory vegetation, which we defined as less than or greater than 75 percent of the canopy, respectively. Furthermore, recall that one of the key model parameters was the probability of a high-mortality response, which we specified separately for each unique combination of cover type and seral stage, as modified by topographic position, as part of the state-and-transition models (Appendix B). The realized percentage of high-mortality fire, however, was at least partly an emergent property of the simulation because it reflected the unspecified proportion of time each cover type spent in each seral stage. Therefore, it was useful to examine because it allowed us to describe how often fire caused an immediate state transition to the early-development seral stage.

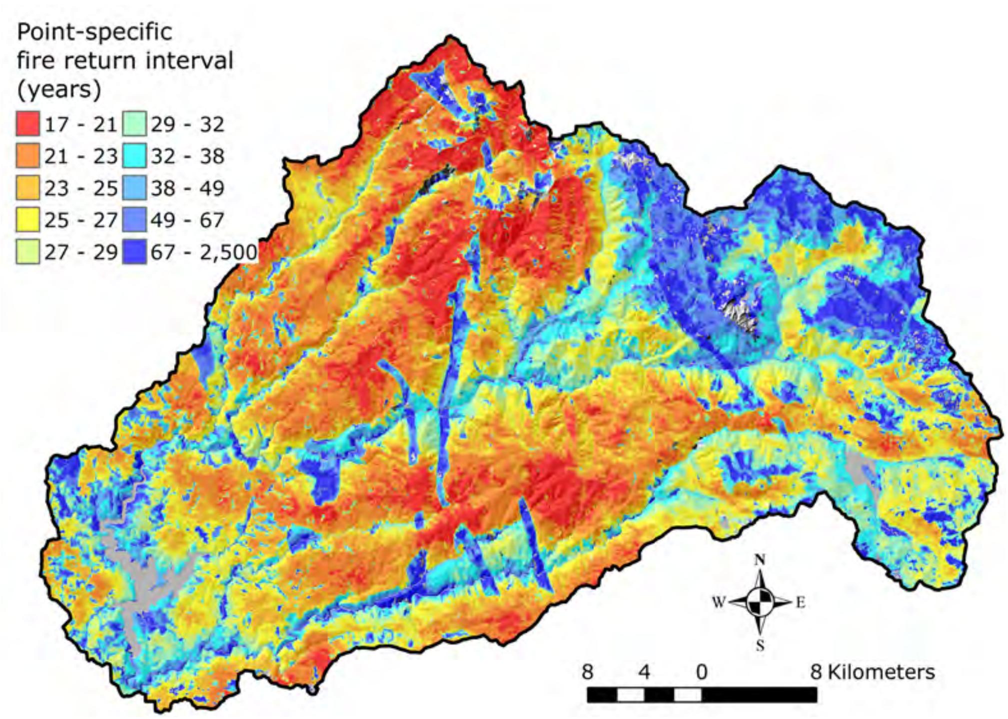


Figure 29—Simulated point-specific fire return interval for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed.

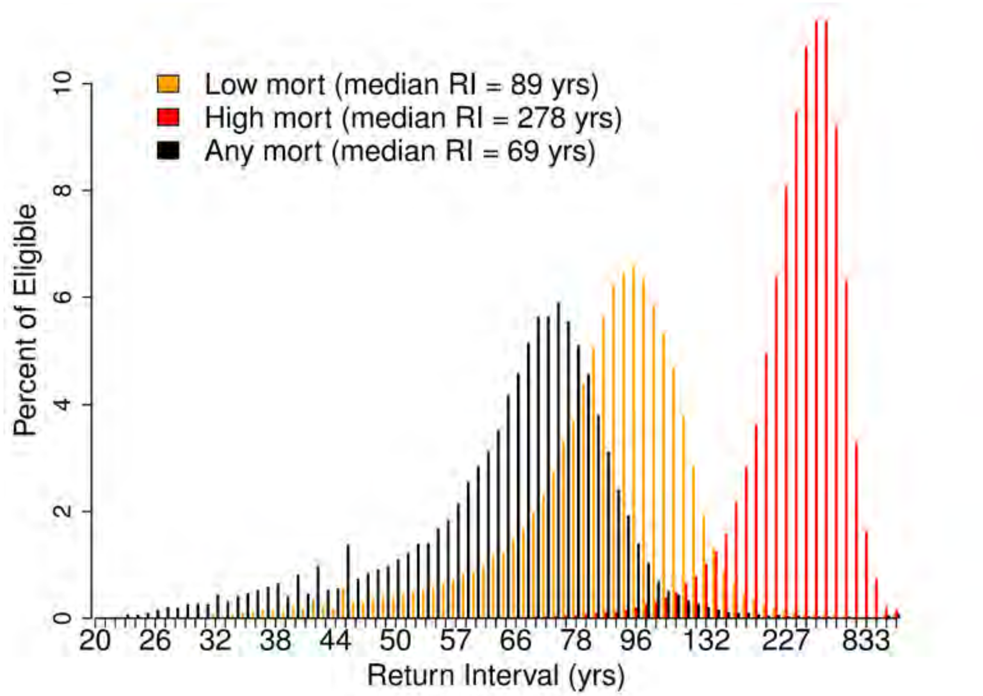


Figure 30—Simulated distribution of point-specific fire return intervals (or fire rotation periods) by fire mortality level for cells classified as Red Fir – Mesic for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed.

The percentage of high-mortality fire varied over time from a low of about 2 percent to a high of 24 percent, but averaged around 13 percent per timestep (fig. 31), or 15 percent when pooled across timesteps. The 95-percent range of variability was about 7–21 percent high mortality. This variability was driven primarily by the variation in climate over time (via variation in the climate modifier parameter), but it also reflected the interaction between climate and the changing seral stage composition over time. For example, a warmer, drier period generally increased the percentage of high mortality, but a warmer, drier period that coincided with a greater proportion of the forest in closed-canopy conditions increased the percentage even more.

Landscape Composition

We have defined "landscape composition" as the land cover composition of the project area, that is, the extent of each class (or patch type) without considering the spatial configuration of the patch mosaic. In this section, we describe the HRV in landscape composition with respect to: (1) vegetation developmental stage (none or early, mid-, or late development), (2) canopy cover class (none or open, moderate, or closed canopy), and (3) seral stage (largely a combination of developmental stage and canopy cover), and the degree of current landscape departure in each of these attributes (i.e., how much the current landscape, as it existed ca. 2010, deviates from the simulated HRV).

Importantly, although the simulated landscape composition was clearly affected by the model parameterization, we did not calibrate the model to achieve any prespecified vegetation conditions. Calibration was restricted to disturbance regime characteristics as described previously. Therefore, we considered the simulated landscape composition to be a result of the simulation from which we can make inferences about HRV and current departure.

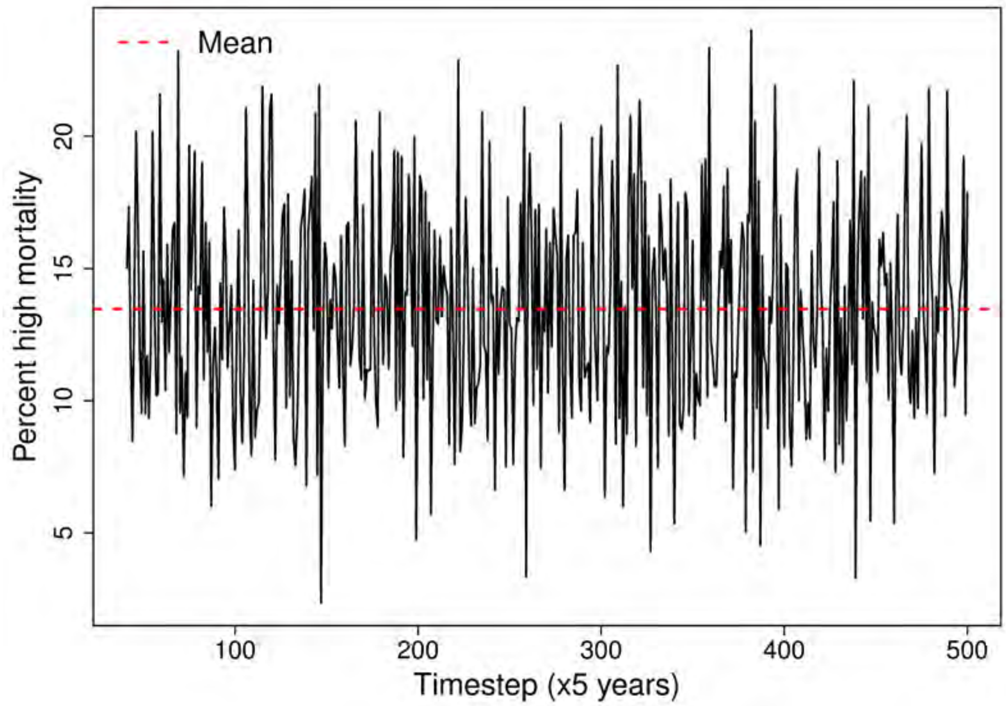


Figure 31—Simulated percentage of the area burned per 5-year timestep that resulted in high mortality (>75 percent canopy mortality) for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Red dotted line represents the average.

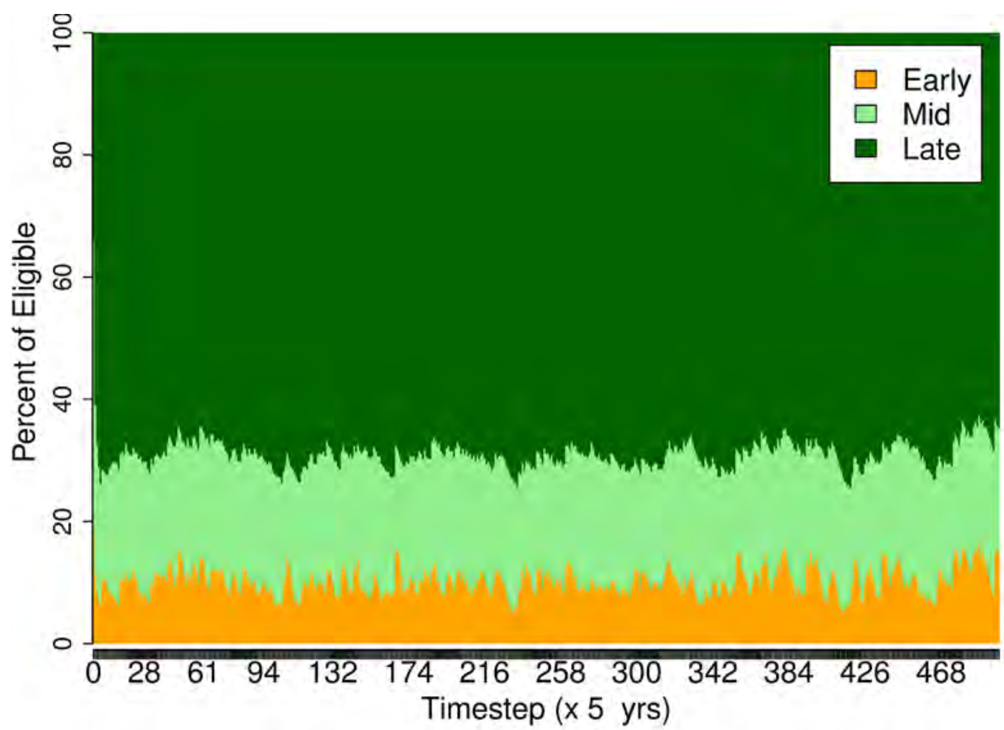


Figure 32—Simulated trajectory in the percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated land cover) in each vegetation developmental stage for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Note that the trajectory includes the current landscape (timestep = 0), the equilibration period (timesteps 1–40), and the period used to compute the historical range of variability (timesteps 41–500).

Developmental Stage Dynamics

Vegetation developmental stage rapidly achieved dynamic equilibrium in the simulation, after which the percentage of the landscape in each developmental stage remained relatively constant at approximately a 10:20:70 ratio of early- to mid- to late-development stages (fig. 32). The relatively minor variability of this ratio was indicative of the landscape achieving a nearly perfect shifting-mosaic equilibrium (sensu Bormann and Likens 1979), in other words, a constancy in landscape composition, despite the shifting spatial mosaic of stages.

The current landscape's overall developmental stage distribution (i.e., pooled across all cover types) deviates considerably from the HRV (table 14, fig. 33). Specifically, the current landscape has a 19:47:34 ratio of early- to mid- to late-development stages, and therefore has much more in the early- and mid-development stages and much less in the late-development stage. This finding is not surprising given the land use history of the past century. The current landscape also has a somewhat more even distribution of developmental stages, whereas in the HRV the distribution was heavily skewed toward the late-development stage.

Table 14—Historical range of variability (HRV) in vegetation developmental stages, represented as the percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated land cover) for ca. 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV.

	Percentile of HRV							Current	
Developmental stage	**0th**	**5th**	**25th**	**50th**	**75th**	**95th**	**100th**	**% eligible**	**% HRV**
Early	5.33	6.73	8.72	10.02	11.88	14.42	16.82	18.99	100
Mid	16.24	17.94	19.68	20.69	21.68	23.12	24.22	47.00	100
Late	62.53	65.52	67.67	69.10	70.52	72.47	74.54	34.01	0

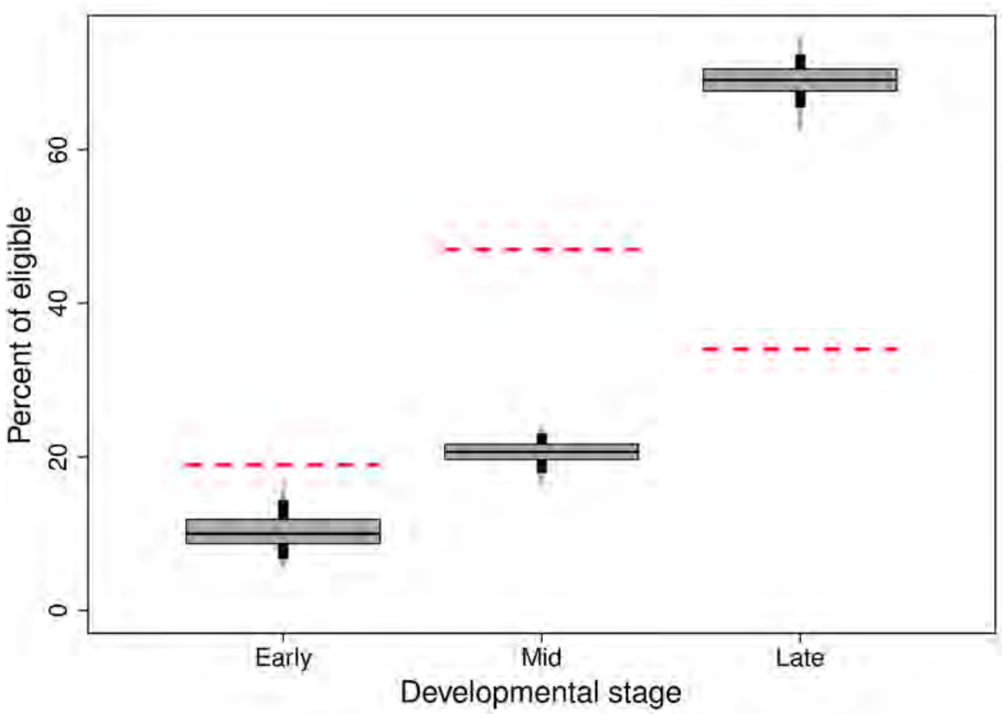


Figure 33—Graphical summary of the data in table 14 for percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated land cover) in each vegetation developmental stage for the simulated historical range of variability (HRV) (ca. 1550–1850) in the upper Yuba River watershed. Boxes represent the interquartile range (25th–75th percentiles) of the HRV; the median is the dark horizontal line in the middle of the box. Thick, solid vertical lines represent the 5th–95th percentiles of the HRV, and the thin, gray vertical extensions represent the full range of the simulated HRV. Dashed, red horizontal lines represent the current condition of the landscape.

These general patterns were relatively consistent across the major cover types, although the specific HRV distribution of developmental stages (i.e., the early:mid:late ratio) differed somewhat among cover types, as did the magnitude of current departure from HRV (fig. 34). For example, the HRV median percentage area in the early-development stage varied among cover types from about 4 to 26 percent, and the HRV median percentage area in the late-development stage varied from about 47 to 91 percent, largely reflecting differences among cover types in the prevalence of high-mortality (i.e., stand-replacing) fire and fire rotation periods. Similarly, the current departure in the late-development stage is extreme in Mixed Evergreen Forest and Oak-Conifer Forest and Woodland and somewhat less so in Sierran Mixed Conifer Forest and Red Fir Forest. Despite these differences, all major cover types showed a preponderance of area in the late-development stage under the HRV and a deficiency of late-development forest in the current landscape (see table D1 in Appendix D for detailed results).

Canopy Cover Dynamics

We considered canopy cover as both a continuous variable and categorical variable by reclassifying seral stage into average percent canopy cover (see Appendix B for crosswalks) or into discrete classes. The discrete classification is more straightforward for quantifying HRV. Like vegetation developmental stage, the distribution of canopy cover classes rapidly achieved dynamic equilibrium in the simulation, after which the percentage of the landscape in each canopy cover class remained variable but stable about a 38:24:37 ratio of open- to moderate- to

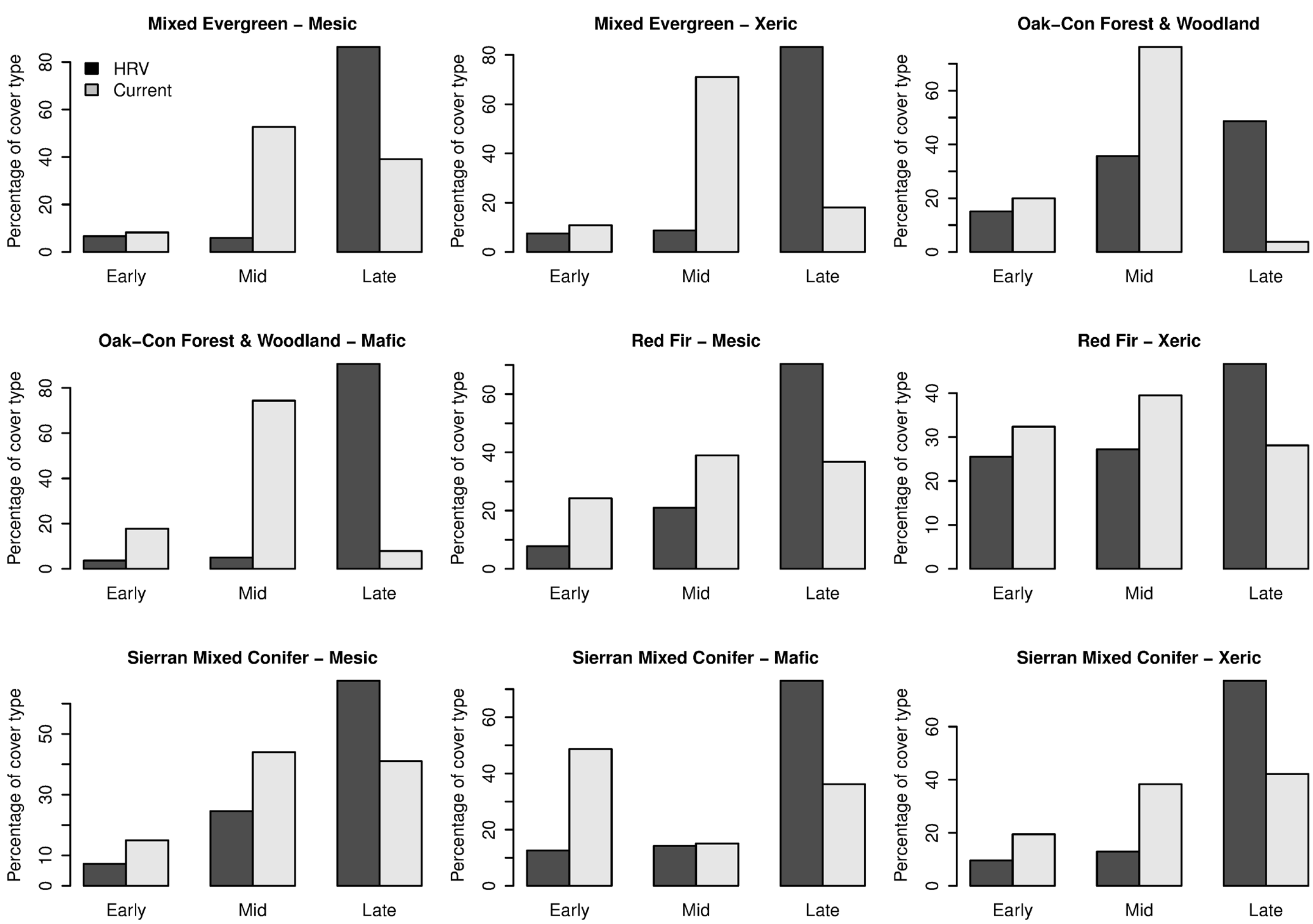


Figure 34—Median percentage area in early-, mid-, and late-development stages of succession for the major cover types (≥1,000 ha extent) for the simulated historical range of variability (ca. 1550–1850) in comparison to the distribution for the current landscape in the upper Yuba River watershed. Note differences in y-axis scales.

closed-canopy classes (fig. 35). In general, the landscape fluctuated over time between having an approximately equal mixture of open-, moderate-, and closed-canopy conditions and one that was either slightly dominated by open-canopy conditions or slightly dominated by closed-canopy conditions (e.g., fig. 36).

The current landscape's overall canopy cover composition (i.e., pooled across all cover types) does not differ much from the HRV, being within the 95-percent range of variability for all three canopy cover classes (table 15, fig. 37). At first, this result seems somewhat surprising given the popular belief that the current landscape has an uncharacteristic predominance of closed-canopy forest. However, it is important to recognize that this result is for the landscape as a whole, pooled across all cover types. It is being driven by the abundance of early-development stands (which are classified as open canopy) in the current landscape, which make up about 20 percent of the landscape (fig. 33). Thus, this result for the landscape as a whole masks important departures within individual cover types and developmental stages, as follows.

First, the HRV distribution of canopy cover classes varied substantially among cover types, with the xeric and ultramafic cover types typically maintaining a preponderance of open- and moderate-canopy conditions and the mesic cover types typically maintaining a preponderance of closed-canopy conditions (fig. 38). These patterns were partly due to lower productivity and slower vegetation growth on the xeric and, especially, ultramafic sites compared to the mesic sites, as governed by the state-and-transition models. The mixed evergreen forests maintained a preponderance of closed-canopy conditions in both xeric and mesic sites, presumably because of the relatively fast succession on both xeric and mesic sites supporting this productive forest type. Similarly, the magnitude of current departure varies considerably among cover types, with some cover types exhibiting very little departure (e.g., Mixed Evergreen Forest), others exhibiting moderate departure (e.g., Sierran Mixed Conifer Forest), and still others showing major departure (e.g., Oak-Conifer Forest and Woodland – Ultramafic and Red Fir – Mesic).

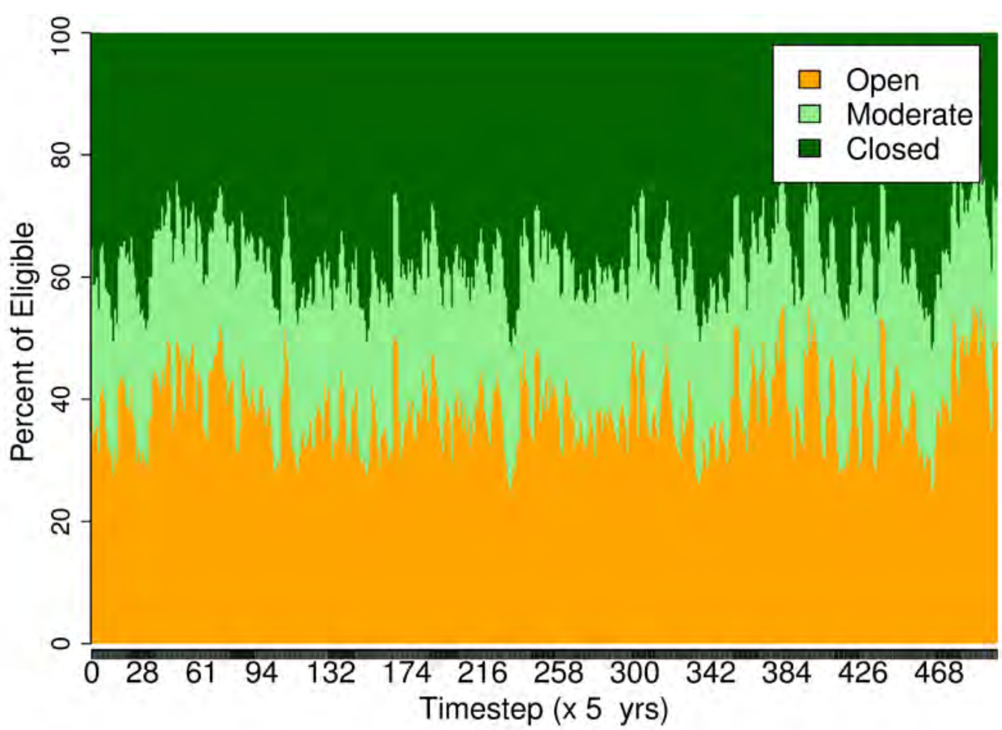


Figure 35—Simulated trajectory in the percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated land cover) in each canopy cover class (<40 percent = "Open," 40–75 percent = "Moderate," and >75 percent = "Closed"), for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Note that the trajectory includes the current landscape (timestep = 0) and the equilibration period (timesteps 1–40) and the period used to compute the historical range of variability (timesteps 41–500).

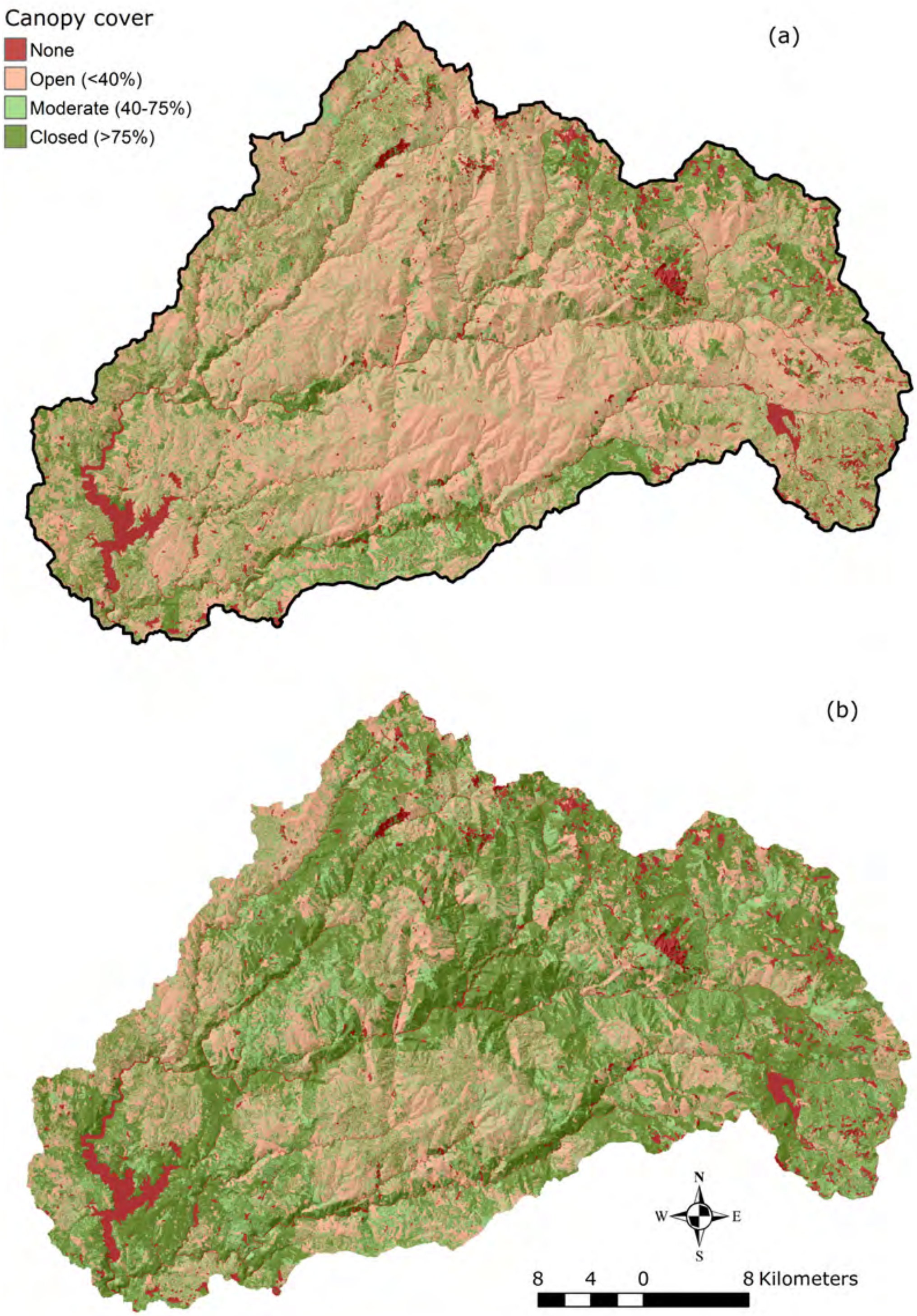


Figure 36—Snapshots of the canopy cover class mosaic for timesteps in which the landscape had a slight majority of (a) open-canopy versus (b) closed-canopy conditions during the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed.

Table 15—Historical range of variability (HRV) in vegetation canopy cover classes (<40% = "Open," 40–75% = "Moderate," and >75% = "Closed"), represented as the percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated land cover) for ca. 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV.

	Percentile of HRV							Current	
Canopy cover class	**0th**	**5th**	**25th**	**50th**	**75th**	**95th**	**100th**	**% eligible**	**% HRV**
Open	25.22	28.97	33.56	37.82	43.32	50.47	55.34	37.57	47
Moderate	20.96	22.25	23.45	24.20	25.25	27.69	30.06	27.02	93
Closed	21.19	25.62	32.42	37.35	41.63	45.98	51.77	35.40	40

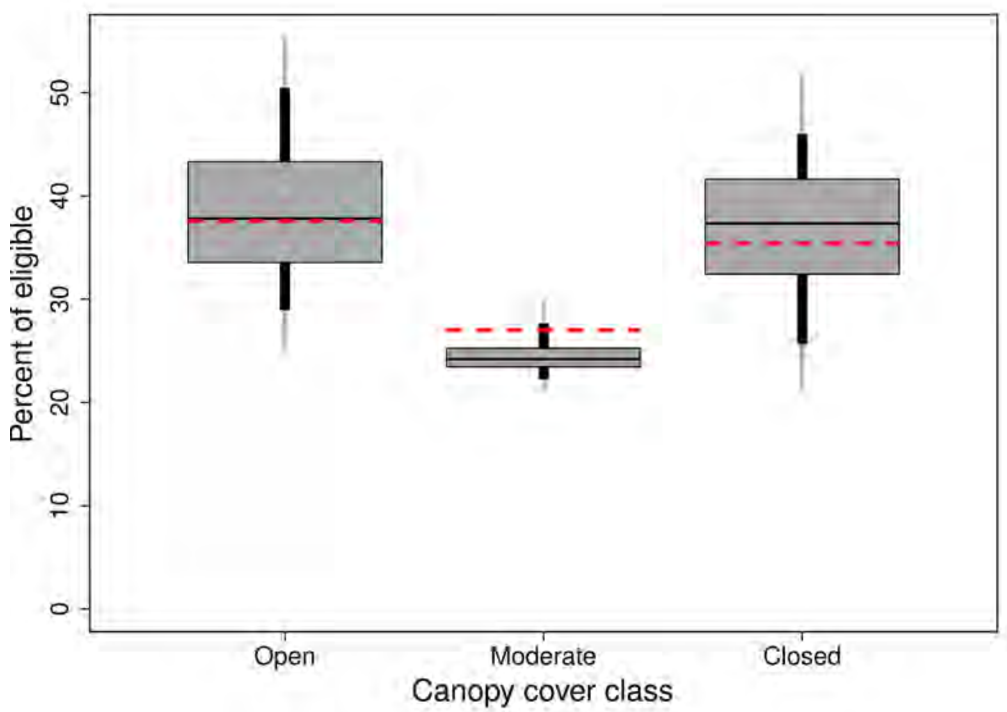


Figure 37—Graphical summary of the data in table 15 for percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated land cover) in each vegetation canopy cover class for the simulated historical range of variability (HRV) (ca. 1550–1850) in the upper Yuba River watershed. Boxes represent the interquartile range (25th–75th percentiles) of the HRV; the median is the dark horizontal line in the middle of the box. Thick, solid vertical lines represent the 5th–95th percentiles of the HRV, and the thin, gray vertical extensions represent the full range of the simulated HRV. Dashed, red horizontal lines represent the current condition of the landscape.

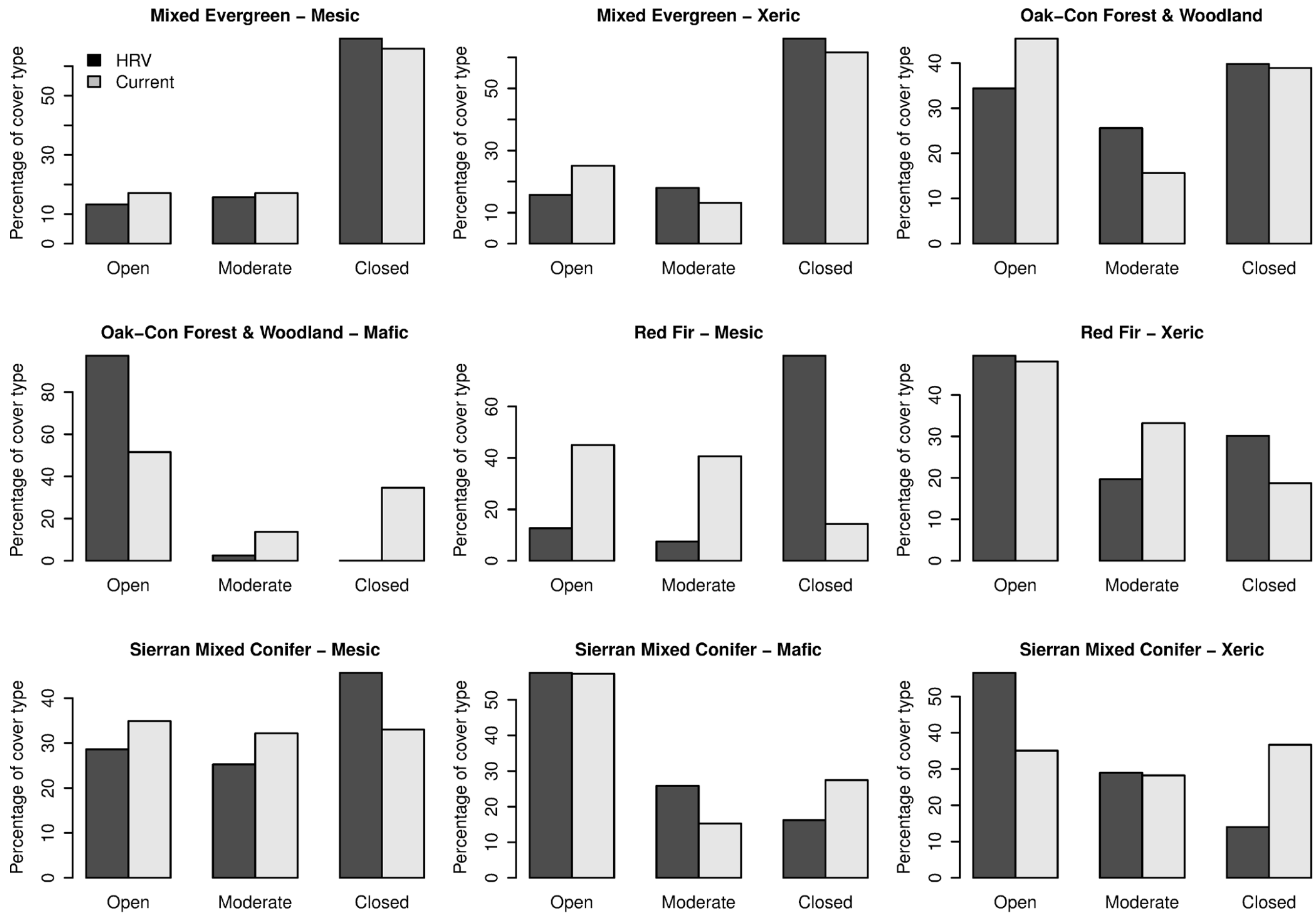


Figure 38—Median percentage area in open-, moderate-, and closed-canopy classes for the major cover types (≥1,000 ha extent) for the simulated historical range of variability (ca. 1550–1850) in comparison to the distribution for the current landscape in the upper Yuba River watershed. Note differences in y-axis scales.

Second, the result for the landscape as a whole masks important canopy cover departures occurring within individual developmental stages (fig. 39). There are two important things to note about figure 39. First, for simplicity the median HRV distribution is shown here as a benchmark for comparison to the current distribution, but it can be somewhat misleading because the full HRV distribution includes (often considerable) variability in the distribution among canopy cover classes (see table D2 in Appendix D for detailed results). Second, the percentage in each canopy cover class is within each developmental stage, so that the percentages sum to 100 percent within each developmental stage separately. Given these caveats, it is apparent that the proportional distribution of canopy cover classes within the late-development stage deviates considerably from the HRV. Specifically, the late-development stage in the current landscape contains far more area in the moderate- and closed-canopy conditions than in the open-canopy condition. The ratio of open to moderate to closed canopy in the late-development stage was roughly 1:1:1.5 in the HRV, whereas in the current landscape the ratio is about 1:4:6. In addition, canopy cover departure within individual developmental stages is more apparent in some cover types than others (fig. 40). Some of the notable results by cover type are as follows:

- *Mixed Evergreen (Mesic and Xeric)*—Current departure is prevalent only in the mid-development stage, with the current landscape containing much more closed-canopy and much less moderate-canopy cover.
- *Oak-Conifer Forest and Woodland*—Current departure is relatively minor in both developmental stages.
- *Oak-Conifer Forest and Woodland – Ultramafic*—Current departure is pronounced in both developmental stages, with the current landscape containing much more closed canopy and much less open canopy in both developmental stages.
- *Red Fir – Mesic*—Current departure is pronounced in both developmental stages, with the current landscape containing much more open canopy and much less closed canopy in both developmental stages. Note that this is opposite of the pattern observed in other cover types.
- *Red Fir – Xeric*—Current departure is pronounced in both developmental stages, with the current landscape containing much more closed or moderate canopy and much less open canopy in both developmental stages.
- *Sierran Mixed Conifer – Mesic*—Current departure is evident in both developmental stages, but the pattern differs. The current landscape contains much more closed canopy and much less open canopy in the late-development stage, and contains much more moderate canopy and much less closed canopy in the mid-development stage.
- *Sierran Mixed Conifer – Ultramafic and Xeric*—Current departure is pronounced in both developmental stages, with the current landscape containing much more closed canopy and much less open canopy in both developmental stages.

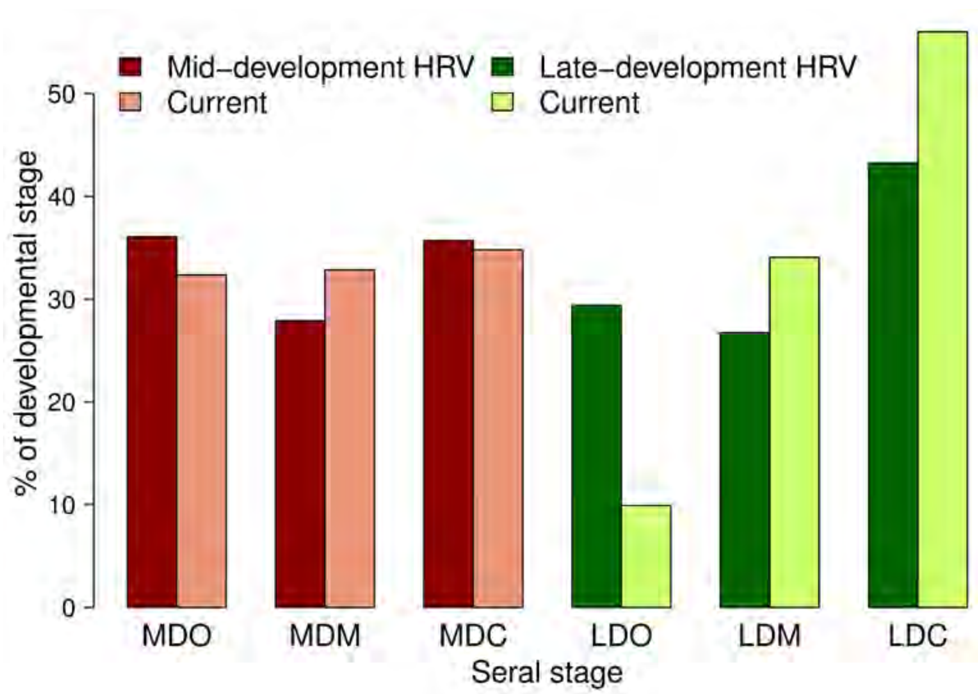


Figure 39—Median percentage area of mid-development forest in open- (MDO), moderate- (MDM), and closed-canopy (MDC) conditions and separately of late-development forest in open- (LDO), moderate- (LDM), and closed-canopy (LDC) conditions for the landscape as a whole for the simulated historical range of variability (ca. 1550–1850) and the current landscape in the upper Yuba River watershed. Note that the percentage distribution among canopy cover classes is within each developmental stage separately.

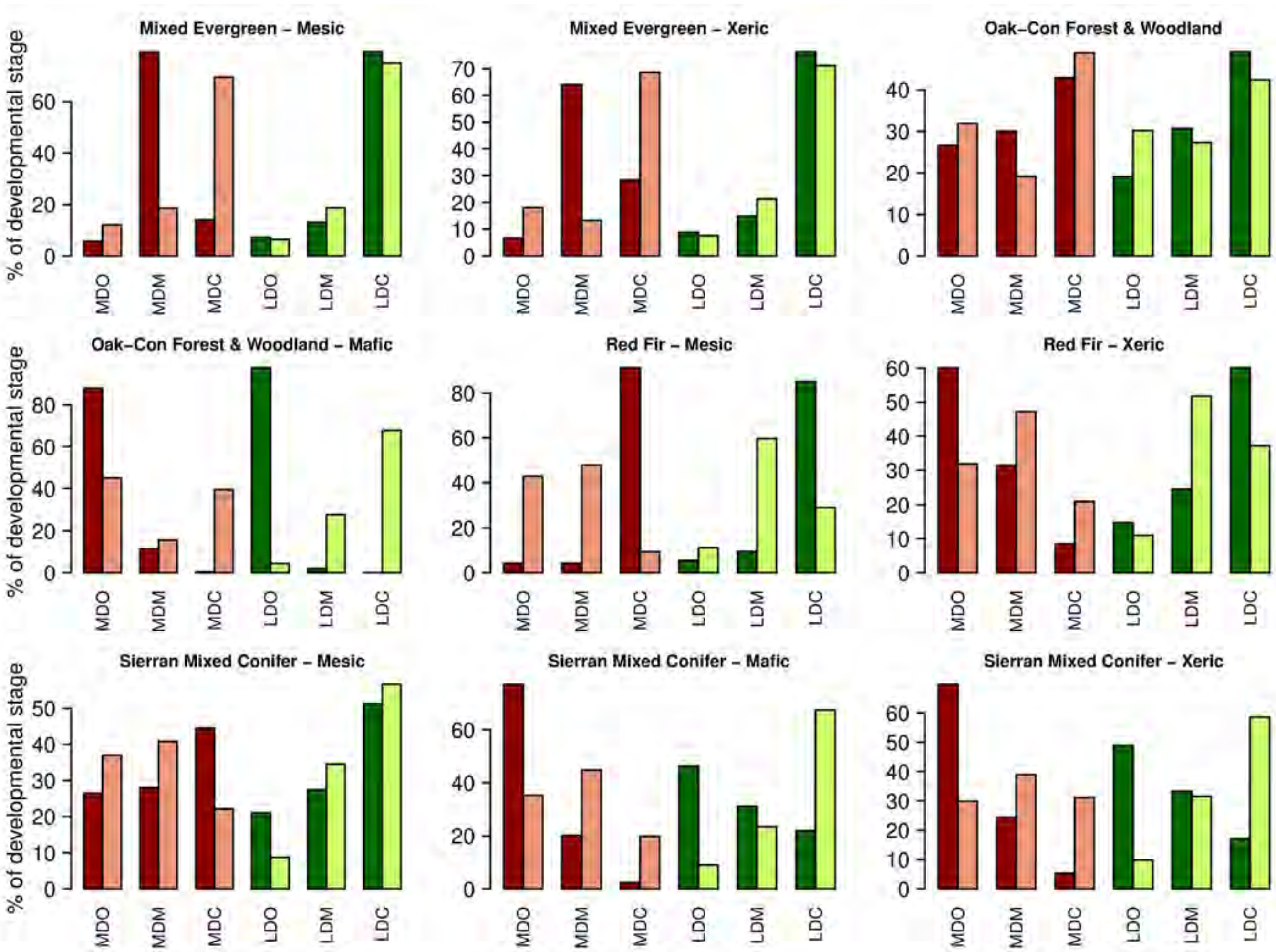


Figure 40—Median percentage area of mid-development forest in open- (MDO), moderate- (MDM), and closed-canopy (MDC) conditions and of late-development forest in open- (LDO), moderate- (LDM), and closed-canopy (LDC) conditions for the major cover types (≥1,000 ha extent) for the simulated historical range of variability (ca. 1550–1850) (darker bars) and the current landscape (lighter bars) in the upper Yuba River watershed. Note that the percentage distribution among canopy cover classes is within each developmental stage separately. Also note differences in y-axis scales.

Thus, despite the result for the landscape as a whole, the results by cover type and developmental stage suggest that for several of the major cover types the current landscape contains much more closed or moderate canopy and much less open canopy than was observed for HRV.

It is important to recognize that these results are ultimately driven by the model parameterization, specifically pertaining to several key parameters that determined the relative probability of fires causing a transition to a more open-canopy seral stage and the rate of succession in canopy closure in the absence of fire. For example, in the Sierran Mixed Conifer – Mesic forest type, the dominant cover type in the project area, wildfires in the closed-canopy seral stages had a 13- to 19-percent chance (depending on developmental stage) of being high mortality and causing the stand to transition to an early-development, open-canopy condition. The remaining 81 to 87 percent of wildfires were low-mortality fires with an 18- to 54-percent chance (depending on developmental stage) of causing a transition to a more open-canopy condition (see Appendix B for details). However, succession in canopy closure was relatively rapid, with an average of only 16 years to transition from open to moderate canopy or moderate to closed canopy. This, coupled with a 29-year FRP for low-mortality fires and a 199-year FRP for high-mortality fires, produced a strong tendency for the canopy to close before another fire could potentially maintain the open canopy.

Last, as described previously, we verified that the model, as parameterized for the HRV, simulated a greater preponderance of fire (and high-mortality fire) on steeper, south- and west-facing, upper slopes, resulting in a decrease in average canopy cover (table 6). Although this relationship was extremely "noisy," it was evident in the map of average canopy cover (fig. 41). We included the average canopy cover map because it is useful for discerning where in the landscape the canopy cover is more likely to be relatively high or low. However, it can also give a false impression that the expected canopy cover composition of the landscape at any point in time is largely devoid of both high and low canopy cover patches, which is in fact not the case (e.g., fig. 36). The limitation associated with the "averaging" of canopy cover across timesteps is that it dampens the contrast between high and low canopy cover patches that typically exists within any one timestep (a problem known generally as "regression towards the mean").

Seral Stage Dynamics

The distribution of seral stages, representing the combination of developmental stage and canopy cover class pooled across cover types, rapidly achieved dynamic equilibrium in the simulation, after which the percentage of the landscape in each seral stage remained variable but stable (fig. 42). In general, this was true for most individual cover types; within a few decades the seral stage distribution achieved dynamic equilibrium. In the ultramafic cover types, however, equilibration took considerably longer. For example, in the Sierran Mixed Conifer – Ultramafic cover type, equilibration took more than 100 years (fig. 43). The longer "recovery" time for the ultramafic types undoubtedly reflected the longer FRP and slower rate of succession. We highlight this in our management implications section because it means that it will be considerably more difficult and take much longer to return the ultramafic sites to their HRV based solely on the restoration of natural disturbances. Active management may facilitate restoration of the seral stage distribution in these ultramafic cover types, but the rate at which mid-seral stages can succeed to late-development seral stages is ultimately constrained by the slow rates of succession on these nutrient-poor sites.

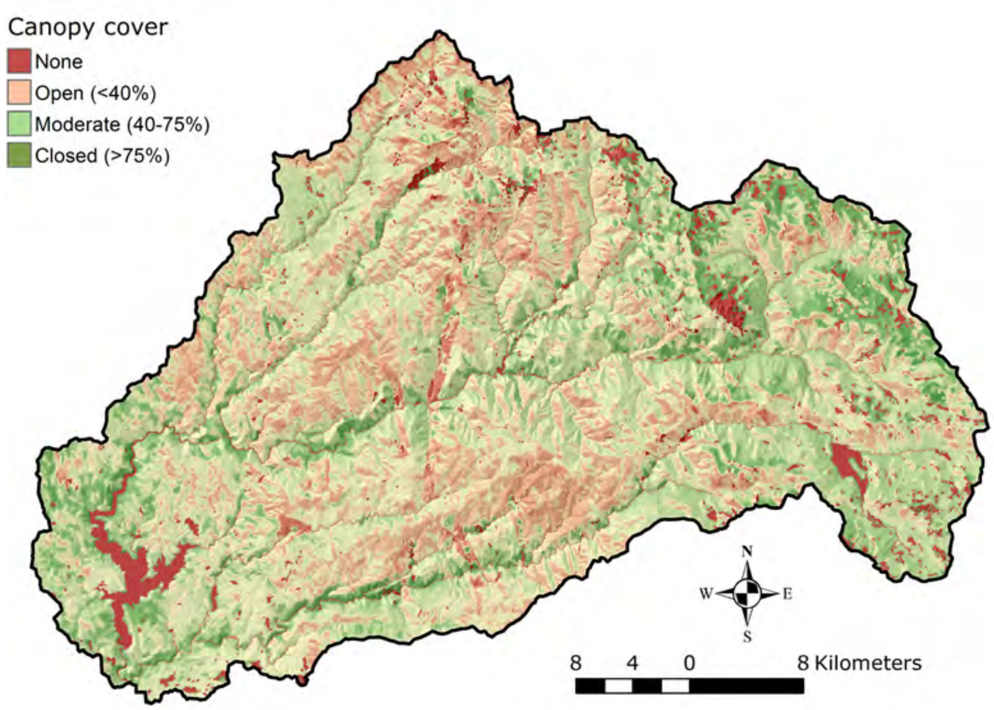


Figure 41—Average percent canopy cover (smoothed to facilitate interpretation) for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Note that the average canopy cover does not depict what the landscape might look like at any single point in time (see figure 36).

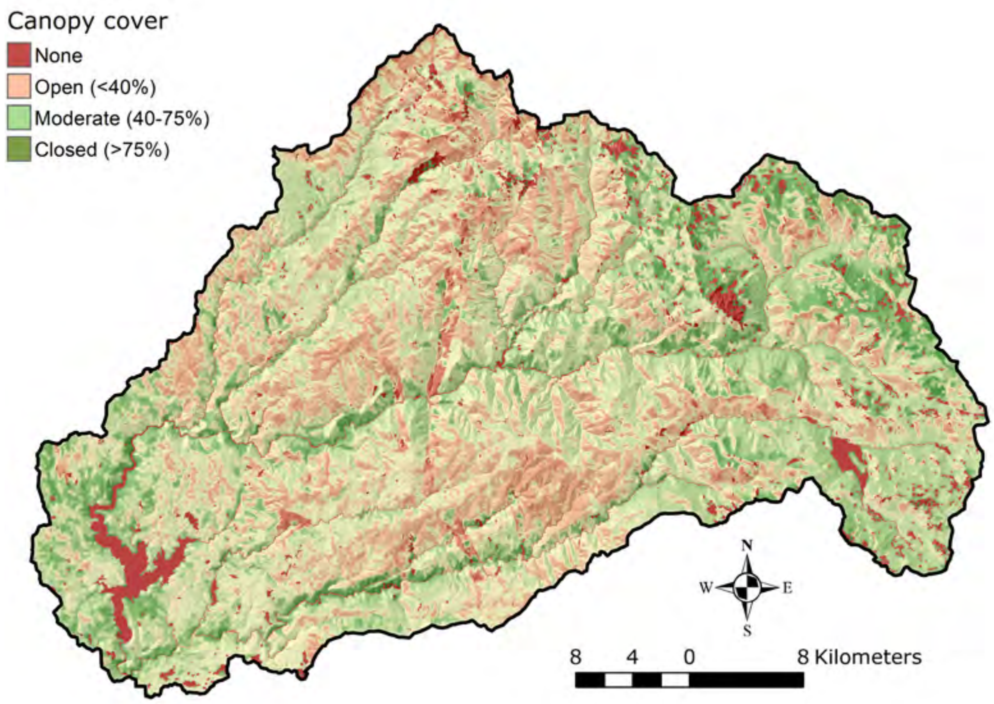


Figure 42—Simulated trajectory in the percentage of the eligible landscape (i.e., excluding nonseral and mixed conifer-aspen forest land cover types) in each seral stage (see *Methods* for definitions of seral stages) for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Note that the trajectory includes the current landscape (timestep = 0) and the equilibration period (timesteps 1–40) and the period used to compute the historical range of variability (timesteps 41–500).

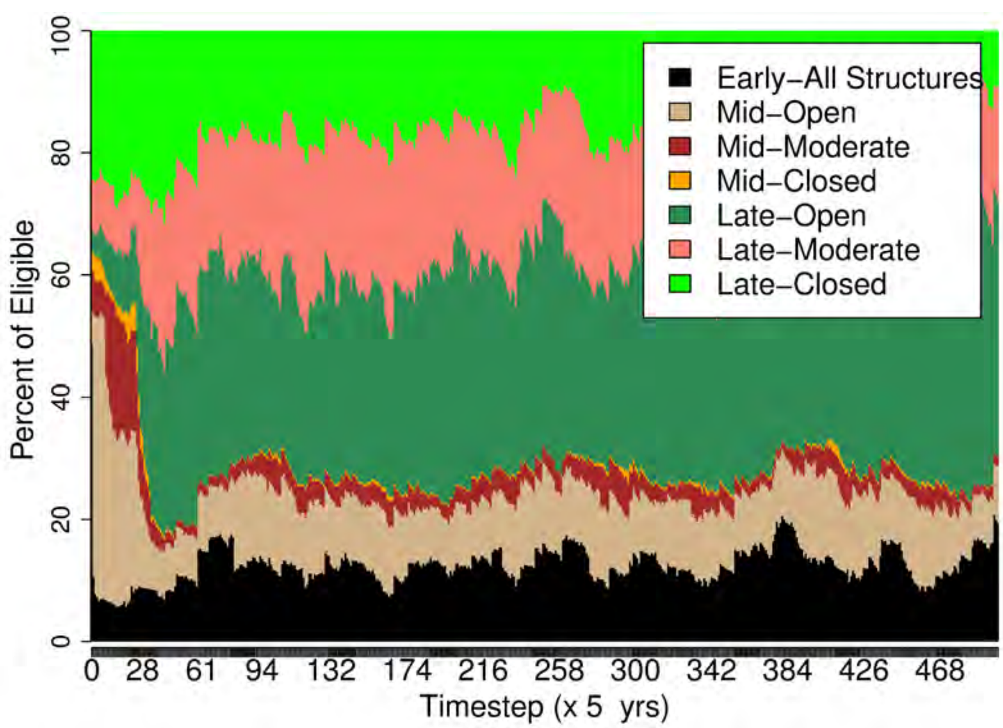


Figure 43—Simulated trajectory in the percentage of the Sierran Mixed Conifer – Ultramafic cover type in each seral stage (see *Methods* for definitions of seral stages) for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Note that the trajectory includes the current landscape (timestep = 0) and the equilibration period (timesteps 1–40) and the period used to compute the historical range of variability (timesteps 41–250).

The current landscape's overall seral stage distribution (i.e., pooled across all cover types) deviates considerably from the HRV (table 16, fig. 44), although this largely reflects the significant departure in developmental stage distribution. The current landscape has much more in the early – all structures seral stage, perhaps reflecting recent high-severity fires such as the Pendola fire and past land use practices (e.g., hydraulic mining). Such disturbances created large areas of early-seral chaparral that stagnated in the shrub-dominated vegetation condition. The current landscape also has much more in each of the mid-development seral stages and much less in each of the late-development seral stages. Moreover, in the late-development seral stages the proportional distribution among canopy cover classes deviates considerably from the HRV. Specifically, under the HRV, the ratio of open- to moderate- to closed-canopy conditions in the late-development stage was approximately 1:1:1.5, whereas in the current landscape the ratio is about 1:4:6. In other words, in the current landscape within the late-development stage there is much more in the moderate- and closed-canopy condition relative to the open-canopy condition. Overall, the greatest departure is in the late-development, open-canopy seral stage; in the current landscape this seral stage is dramatically underrepresented relative to the HRV due to both the paucity of late-development forest and the effective suppression of wildfires, which function to maintain open-canopy conditions. It is worth noting that although it is tempting to interpret current departure for the mixed conifer-aspen seral stages, we did not do so because of the small extent of these cover types in the project area.

The distribution of seral stages and current departure within each of the dominant cover types (i.e., those with ≥1,000 hectares in the project area) varied considerably from the overall patterns described earlier, warranting a separate interpretation for each cover type, as follows (see table D3 in Appendix D for the detailed results for individual cover types):

- *Mixed Evergreen (Mesic and Xeric)*—In the HRV, moderate-canopy conditions were more prevalent than either open- or closed-canopy conditions in the mid-development stage, whereas the current landscape contains a disproportionately high amount of closed canopy in this developmental stage. In the HRV, closed-canopy conditions were prevalent in the late-development stage, whereas in the current landscape the proportion in closed canopy is low (fig. 45a-b).
- *Oak-Conifer Forest and Woodland*—In the HRV, closed-canopy conditions were more prevalent than open-canopy conditions in both mid- and late-development stages. Current departure is dominated by the paucity of late-development seral stages in the current landscape (fig. 45c).
- *Oak-Conifer Forest and Woodland – Ultramafic*—The HRV distribution of canopy cover classes within developmental stages was opposite that of Oak-Conifer Forest and Woodland, with the open-canopy condition being more prevalent than the closed-canopy condition. Current departure is dominated by relatively much more closed-canopy condition in the mid-development stage and much less open-canopy condition in the late-development stage, with the latter being especially pronounced (fig. 45d).
- *Red Fir – Mesic*—In the HRV, closed-canopy conditions were much more prevalent than open-canopy conditions in both mid- and late-development stages. However, the current landscape is dominated by open- and moderate-canopy conditions in the mid-development stage and moderate-canopy condition in the late-development stage. Current departure is most pronounced in the proportional underrepresentation of closed-canopy conditions in both developmental stages in the current landscape (fig. 45e).
- *Red Fir – Xeric*—The HRV distribution of seral stages differed considerably from that of Red Fir – Mesic. The most notable differences are the relative preponderance of the early-seral stage and the prevalence of open-canopy conditions in the mid-development stage and, accordingly, less in the late-development, closed-canopy seral stage. Overall, current departure is much less pronounced in Red Fir – Xeric, with the only significant departure being the proportional underrepresentation of the late-development, closed-canopy seral stage (fig. 45f).
- *Sierran Mixed Conifer – Mesic*—Similar to Red Fir – Mesic, in the HRV closed-canopy conditions were more prevalent than open-canopy conditions in both mid- and late-development

stages. With respect to current departure, the current landscape has much more in the mid-development, open- and moderate-canopy conditions and much less in the late-development, open-canopy condition (fig. 45g).

- *Sierran Mixed Conifer – Ultramafic and Xeric*—In contrast to Sierran Mixed Conifer – Mesic, open-canopy conditions were more prevalent in the HRV than closed-canopy conditions in both mid- and late-development stages for the ultramafic variant and in the late-development stage for the xeric variant. Accordingly, with respect to current departure, the current landscape has proportionately less in the open-canopy conditions in both developmental stages. In addition, the current landscape has much more in the early-seral stage (fig. 45h-i).

Table 16—Historical range of variability (HRV) in vegetation seral stages (excluding those associated with mixed conifer-aspen cover types; see table 2 for acronyms), represented as the percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated cover types) for ca. 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV.

	Percentile of HRV							Current	
Seral stage	**0th**	**5th**	**25th**	**50th**	**75th**	**95th**	**100th**	**% eligible**	**% HRV**
ED	5.32	6.73	8.71	10.01	11.88	14.41	16.81	18.98	100
MDO	5.23	5.97	6.74	7.46	8.27	9.32	10.65	15.21	100
MDM	3.97	4.58	5.28	5.76	6.24	7.02	7.63	15.43	100
MDC	3.76	4.72	6.34	7.31	8.37	9.64	10.94	16.32	100
LDO	12.95	15.79	17.91	20.39	23.62	28.04	30.21	3.37	0
LDM	15.68	17.04	17.92	18.47	19.30	21.17	22.94	11.58	0
LDC	16.19	20.62	25.99	29.76	33.40	37.52	42.52	19.05	3

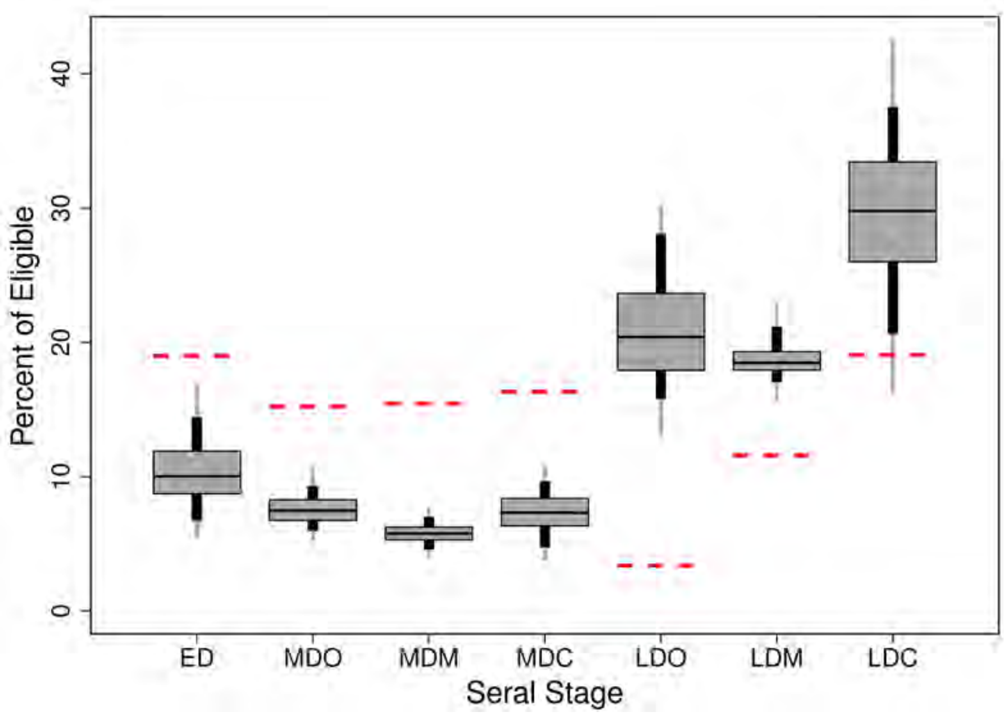


Figure 44—Graphical summary of the data in table 16 for percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated cover types) in each seral stage (excluding those associated with mixed conifer-aspen cover types) for the simulated historical range of variability (HRV) (ca. 1550–1850) in the upper Yuba River watershed. Boxes represent the interquartile range (25th–75th percentiles) of the HRV; the median is the dark horizontal line in the middle of the box. Thick, solid vertical lines represent the 5th–95th percentiles of the HRV, and the thin, gray vertical extensions represent the full range of the simulated HRV. Dashed, red horizontal lines represent the current condition of the landscape.

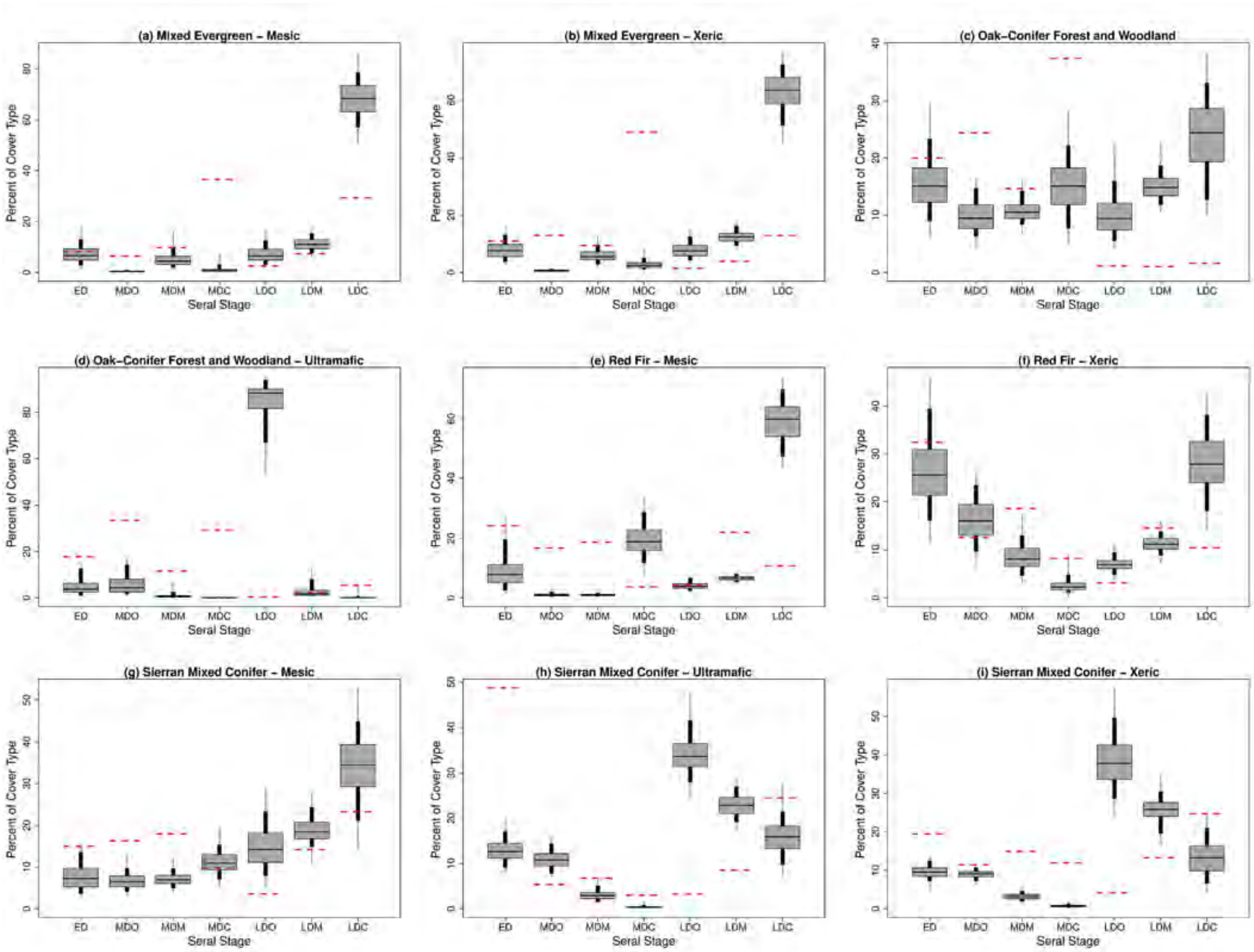


Figure 45—Graphical summary of the data in table D3 for the simulated historical range of variability in each vegetation seral stage and current departure for the major cover types (≥1,000 ha extent) in the upper Yuba River watershed. See figure 44 caption for details on interpretation. Note differences in y-axis.

Landscape Configuration

We have defined "landscape configuration" as the spatial pattern of the landscape mosaic. In this section, we describe the HRV in landscape configuration with respect to: (1) vegetation developmental stage, (2) canopy cover class, and (3) seral stage, and the degree of current landscape departure in each of these attributes (i.e., how much the current landscape, as it existed ca. 2010, deviates from the simulated HRV).

Importantly, although the simulated landscape configuration was clearly affected by the model parameterization, as discussed previously we did not calibrate the model to achieve any prespecified vegetation conditions. Therefore, we considered the simulated landscape configuration to be a result of the simulation, from which we can make inferences about HRV and current departure. However, the spatial patterns (i.e., landscape configuration) resulting from the simulated processes are much more sensitive to modeling artifacts than landscape composition. In particular, the fine-scaled spatial heterogeneity as measured by several of the landscape metrics is affected by the choice of cell size in the model. Consequently, we tempered our interpretation of the landscape configuration results as follows:

- We placed more emphasis on the interpretation of landscape metrics that measure the coarse-scale or larger patch structure, such as the area-weighted mean metrics, because these metrics are much less sensitive to the scale of the grid and the grid-based modeling approach. In particular, our input spatial layers (e.g., Eveg)—and therefore the current conditions—were relatively coarse-scaled, in contrast to the relatively fine-grained simulated output. Despite our efforts to minimize this discrepancy by coarsening the simulated output, a direct comparison is still challenging. Using coarse-scaled measurements of landscape configuration (i.e., those based on area-weighted means) resolves much of this issue, and is therefore more reliable for estimating curent departure.

- For the reasons discussed earlier, we describe a range of variability when interpreting the landscape metrics that measure the fine-scale spatial heterogeneity, such as those that are based on the mean or sensitive to the designation of edges. Accordingly, we refrained from drawing strong conclusions regarding current departure in these landscape metrics.

Developmental Stage Dynamics

For the developmental stage mosaic (pooled across all cover types), most of the landscape metrics measuring the coarse-scale structure of the mosaic achieved dynamic equilibrium in the simulation almost immediately (i.e., within 10–20 years), whereas the remaining metrics required 50–100 years to equilibrate (e.g., fig. 46).

In general, the HRV in landscape structure was characterized by very large (~13,000–35,000 hectares; 32,000–86,000 acres), extensive (~6,000–10,000 meters; 20,000–30,000 feet), and geometrically very complex matrix-forming patches of predominantly late-development stage vegetation; these patches varied considerably over time in response to periodic large disturbance events interspersed with long periods of recovery (table 17, fig. 47). Here, we use the term "matrix" to refer to very large and extensive patches that individually compose about 10 percent or more of the landscape and thus dominate the structure (and

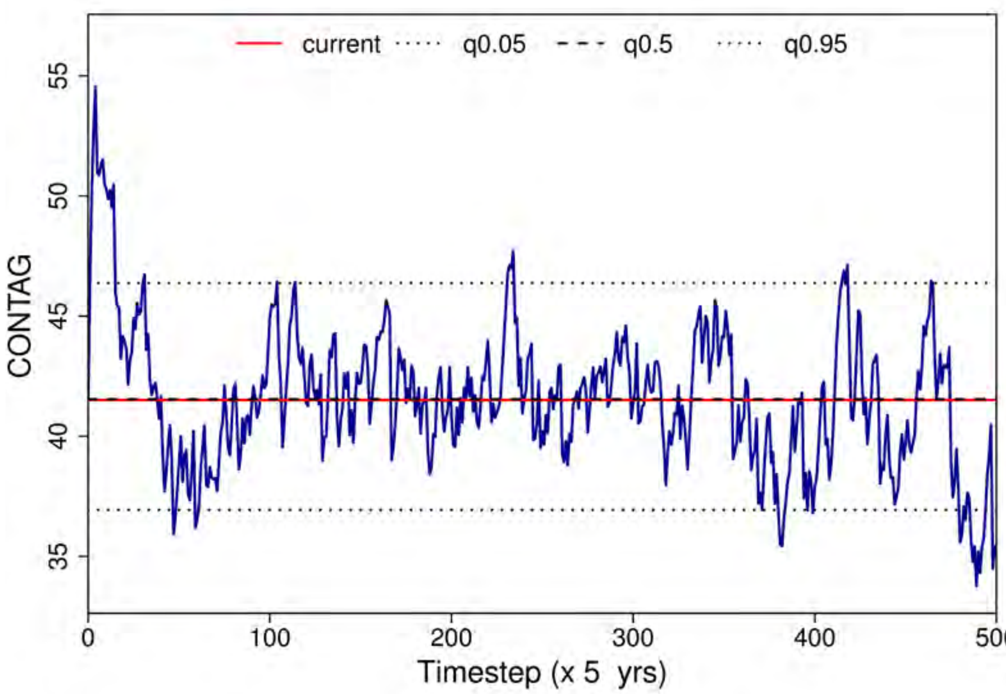


Figure 46—Simulated trajectory in the Contagion metric based on the landscape classified into vegetation developmental stages (none, early, mid, and late) for the simulated historical range of variability (ca. 1550-1850) in the upper Yuba River watershed. Note that the trajectory includes the current landscape (timestep = 0), the equilibration period (timesteps 1–40), and the period used to compute the historical range of variability (timesteps 41–500). The current landscape value and the 5th (q0.05), 50th (q0.5), and 95th (q0.95) percentiles of the simulated variability are also shown.

presumably function) of the landscape mosaic. This dynamic matrix was coupled with a tremendous and constant amount of fine-scale heterogeneity, including numerous high-contrast edges and small and intermediate-sized patches of early and mid-development embedded within the coarse-scale, late-development matrix. Thus, even though these matrix-forming patches were large and extensive, they were also extremely geometrically complex, resulting in an average of only 33 to 44 percent in core area. This geometric complexity was due to the myriad small patches created by many small disturbances and the high spatial heterogeneity in severity of the larger disturbances.

The current landscape configuration based on developmental stages deviates considerably from the HRV (table 17). Compared to the HRV, the larger patches in the current landscape are much smaller and less extensive. These patches are also less geometrically complex, resulting in a greater interior-to-edge ratio, and have less contrast along the edges. In addition, the developmental stages are more interspersed than under the HRV. The current landscape also has notably less fine-scale heterogeneity, for example as measured by edge density and the aggregation index, but some of this departure may be an artifact of the modeling, as discussed previously. Overall, therefore, the most notable departure in landscape configuration, and the departure we can infer with the most confidence, is the absence of very large, extensive, and geometrically complex matrix-forming patches of late development in the current landscape.

Canopy Cover Dynamics

We observed patterns in the canopy cover class mosaic (pooled across all cover types) similar to the patterns observed for developmental stage. Most of the landscape metrics measuring the coarse-scale structure of the mosaic achieved dynamic equilibrium in the simulation almost immediately (i.e., within 10–20 years), whereas the remaining metrics required 50–100 years to equilibrate (e.g., fig. 48).

Table 17—Historical range of variability (HRV) in landscape metrics (see Landscape Configuration under Methods for description and units for each landscape metric) computed on the basis of the landscape classified into vegetation developmental stages (none, early, mid, and late) for circa 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV.

	Percentile of historical range of vulnerability			Current	
Landscape metric	5th	50th	95th	% eligible	% HRV
LPI	17.94	29.87	38.72	5.72	0
AREA_AM	13,564.06	22,737.68	34,698.79	1,808.16	0
GYRATE_AM	5,954.86	8,009.40	9,825.99	2,397.36	0
SHAPE_AM	42.82	54.07	69.39	8.65	0
DCORE_AM	379.98	1,149.70	2,510.95	681.58	23
CAI_AM	33.53	39.69	44.44	62.03	100
TECI	44.80	46.50	48.79	44.43	3
IJI	60.00	65.61	69.64	84.95	100
AREA_MN	2.77	3.30	3.83	21.00	100
SHAPE_MN	1.32	1.33	1.33	1.63	100
DCORE_MN	3.41	4.68	5.73	12.30	100
CAI_MN	0.83	0.98	1.11	17.92	100
ED	135.17	148.59	168.54	70.95	0
CWED	62.16	70.04	81.29	32.25	0
AI	74.69	77.68	79.70	89.35	100
CONTAG	36.91	41.30	45.24	41.51	54

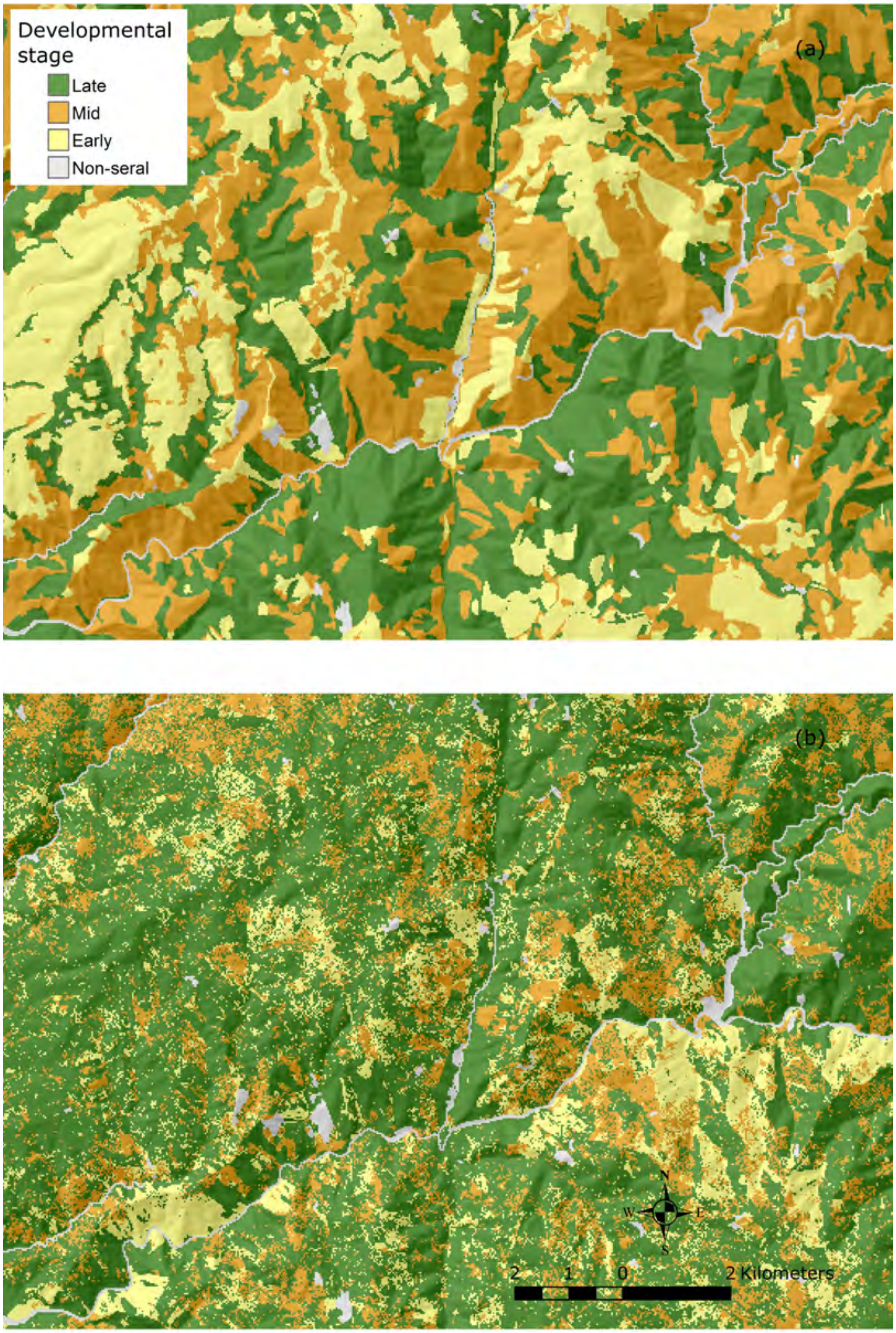


Figure 47—Snapshots of the vegetation developmental stage mosaic for (a) the current landscape and (b) the last timestep of the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed, shown here for a randomly selected location within the project area.

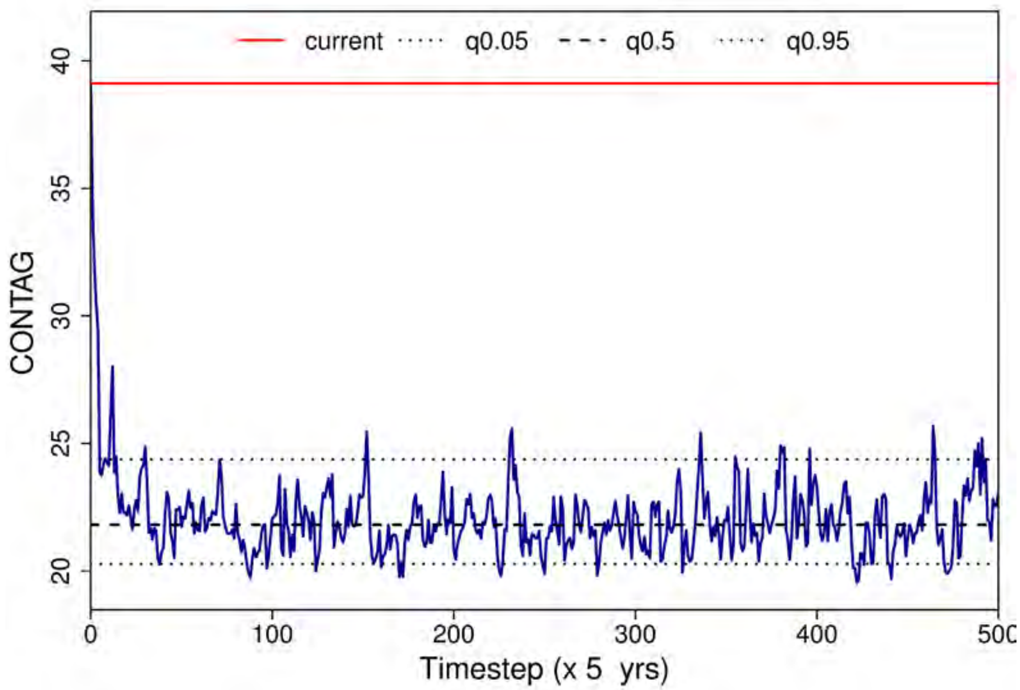


Figure 48—Simulated trajectory in the Contagion metric based on the landscape classified into canopy cover classes (none, open, moderate, closed) for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Note that the trajectory includes the current landscape (timestep = 0), the equilibration period (timesteps 1–40), and the period used to compute the historical range of variability (timesteps 41–500). The current landscape value and the 5th (q0.05), 50th (q0.5), and 95th (q0.95) percentiles of the simulated variability are also shown.

In general, the HRV in landscape structure was characterized by large (~1,500–7,500 hectares; 3,700–18,500 acres), extensive (~2,000–4,000 meters; 7,000–13,000 feet), geometrically very complex, but generally not matrix-forming patches of either open- or closed-canopy forest that varied considerably over time between a majority of open-canopy forest and a majority of closed-canopy forest. This large patch structure was coupled with a relatively high degree of interspersion of canopy cover classes and a tremendous and constant amount of fine-scale spatial heterogeneity in canopy cover (table 18, fig. 49). Compared to the developmental stage mosaic, the canopy cover mosaic was less dominated by matrix-forming patches (e.g., almost an order of magnitude smaller area-weighted mean patch size) and exhibited a much greater degree of fine-scale spatial heterogeneity (e.g., almost a twofold greater density of edges). Thus, the landscape overall exhibited much less contagion in canopy cover than in developmental stage. The greater degree of spatial heterogeneity in canopy cover compared to developmental stage was due to the large quantity of disturbances resulting in partial overstory mortality that did not change the developmental stage of the residual canopy. For example, most of the area burned in wildfires was classified as low mortality. The result in these areas was either no change in canopy cover class or a thinning of the overstory that produced a transition to a more open-canopy cover class, resulting in a spatially heterogeneous mosaic in canopy cover.

The current landscape configuration based on canopy cover classes deviates somewhat from the HRV (table 18). Compared to the HRV, the larger patches in the current landscape are on the small and less extensive side, but nonetheless still within the HRV. However, the larger patches in the current landscape are much less geometrically complex than under the HRV, resulting in a greater percentage of the patches in core area. In addition, the contrast along edges is greater in the current landscape and the canopy cover classes are more interspersed than under the HRV. As with developmental stage, the current landscape also has notably less fine-scale heterogeneity, for example as measured by edge density and the aggregation index, but again some of this observed departure may be due to modeling artifacts as discussed previously. Overall, departure in canopy cover appears to be mostly related to changes in the geometric complexity and fine-scale heterogeneity of the mosaic, and although we are confident in reporting this departure, we are hesitant to draw strong conclusions about the magnitude of the departure.

Seral Stage Dynamics

The seral stage mosaic (pooled across all cover types) exhibited HRV patterns similar to the patterns observed for developmental stage and canopy cover class. Most of the landscape metrics measuring the coarse-scale structure of the mosaic achieved dynamic equilibrium in the simulation almost immediately (i.e., within 10–20 years), whereas the remaining metrics required 50–100 years to equilibrate (e.g., fig. 50).

In general, the HRV in landscape structure was characterized by the absence of large, extensive, matrix-forming patches of a single seral stage. Instead, the landscape maintained a relatively high degree of spatial heterogeneity and variability over time in the larger patch structure, with the area-weighted mean patch size varying between about 290 and 916 hectares (717–2,263 acres). This larger patch structure was coupled with a relatively low magnitude of average contrast along edges, moderate degree of interspersion of seral stages, and a tremendous and constant amount of fine-scale spatial heterogeneity in seral stages (table 19, fig. 51). Overall, the picture of the HRV that emerges from the suite of landscape metrics describing the configuration and variability over time in the seral stage mosaic is one of a spatially heterogeneous mosaic of seral stage patches at fine to intermediate spatial scales (i.e., <1- to several hundred-hectare patches); large, matrix forming patches are rarely present.

Table 18—Historical range of variability (HRV) in landscape metrics (see Landscape Configuration under Methods for description and units for each landscape metric) computed on the basis of the landscape classified into canopy cover classes (none, open, moderate, closed) for ca. 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV.

	Percentile of historical range of vulnerability			Current	
Landscape metric	**5th**	**50th**	**95th**	**% eligible**	**% HRV**
LPI	4.06	8.57	16.39	5.97	25
AREA_AM	1,458.52	2,956.67	7,559.46	1,719.73	11
GYRATE_AM	2,041.19	2,654.64	4,036.39	2,302.38	21
SHAPE_AM	21.95	29.27	48.37	9.05	0
DCORE_AM	136.00	265.87	624.71	448.54	86
CAI_AM	16.47	20.22	23.97	60.70	100
TECI	42.74	43.99	44.99	46.07	100
IJI	70.30	72.27	73.02	87.14	100
AREA_MN	1.18	1.38	1.62	21.53	100
SHAPE_MN	1.29	1.32	1.34	1.68	100
DCORE_MN	1.17	1.55	1.98	10.17	100
CAI_MN	0.22	0.32	0.43	21.31	100
ED	237.86	257.78	280.16	74.08	0
CWED	105.09	113.59	124.83	34.88	0
AI	57.93	61.29	64.28	88.88	100
CONTAG	20.26	21.75	23.92	39.11	100

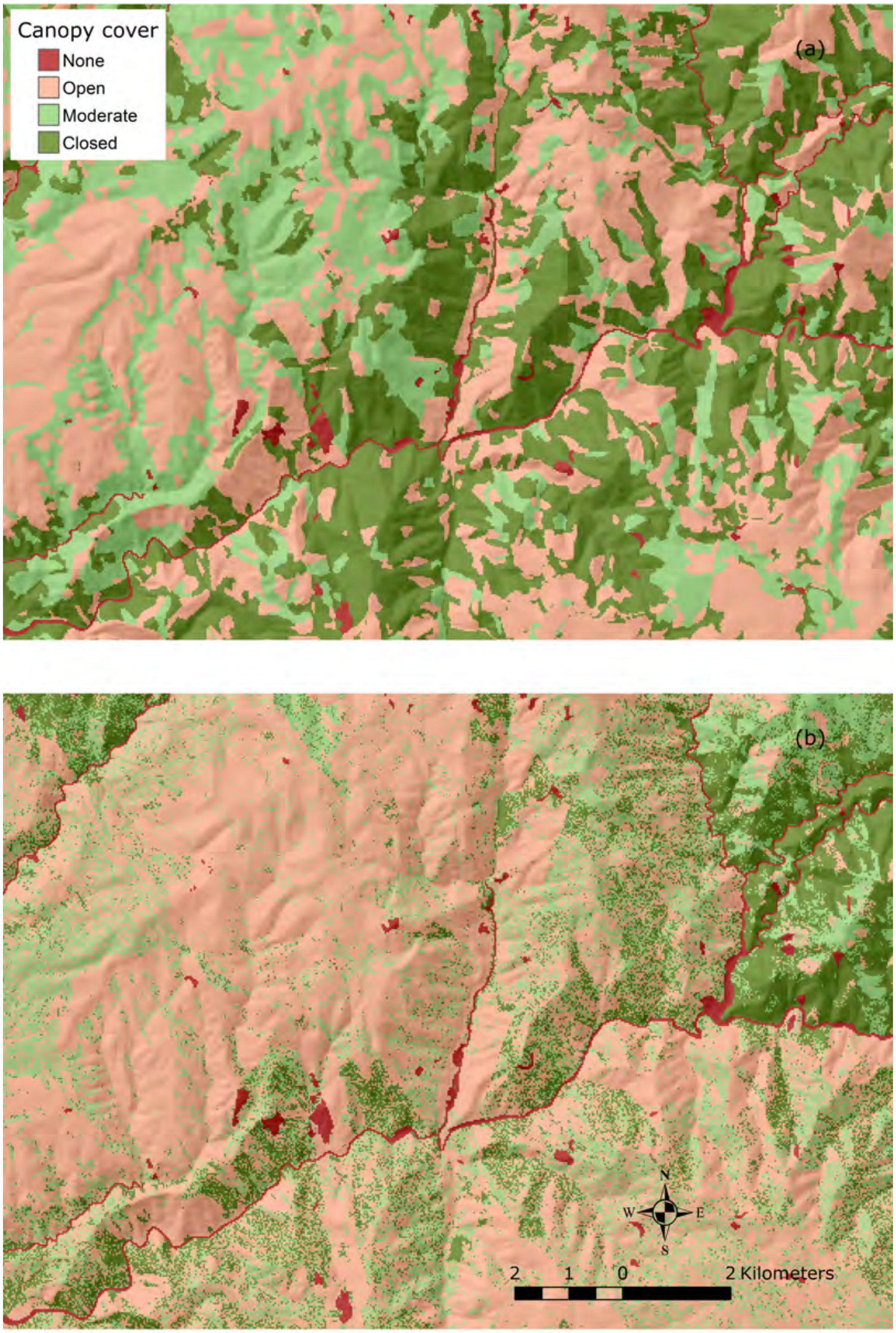


Figure 49—Snapshots of the canopy cover class mosaic for (a) the current landscape and (b) the last timestep of the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed, shown here for a randomly selected location within the project area.

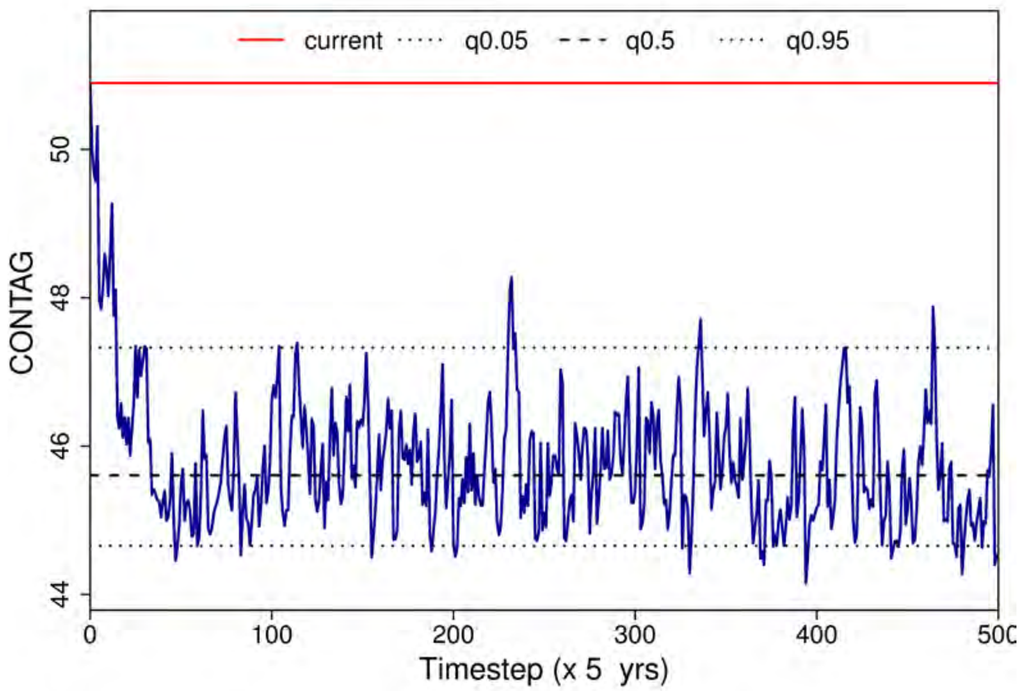


Figure 50—Simulated trajectory in the Contagion metric based on the landscape classified into seral stage classes (see *Methods* for classification) for the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed. Note that the trajectory includes the current landscape (timestep = 0), the equilibration period (timesteps 1–40), and the period used to compute the historical range of variability (timesteps 41–250). The current landscape value and the 5th (q0.05), 50th (q0.5), and 95th (q0.95) percentiles of the simulated variability are also shown.

Table 19—Historical range of variability (HRV) in landscape metrics (see *Landscape Configuration* under *Methods* for description and units for each landscape metric) computed on the basis of the landscape classified into seral stage classes (see *HRV Spatial Input Data* under *Methods* for classification) for ca. 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV.

	Percentile of HRV			Current	
Landscape metric	**5th**	**50th**	**95th**	**% eligible**	**% HRV**
LPI	2.50	2.58	5.06	2.50	35
AREA_AM	289.85	500.44	915.57	302.57	7
GYRATE_AM	942.18	1,138.37	1,447.33	1,054.98	27
SHAPE_AM	8.92	10.81	13.66	4.52	0
DCORE_AM	90.08	120.92	192.03	92.69	8
CAI_AM	4.29	7.04	10.36	33.16	100
TECI	26.37	27.72	29.70	37.84	100
IJI	64.81	66.96	69.26	75.31	100
AREA_MN	0.63	0.73	0.84	10.83	100
SHAPE_MN	1.25	1.27	1.28	1.63	100
DCORE_MN	0.78	1.19	1.57	4.59	100
CAI_MN	0.05	0.09	0.13	9.95	100
ED	293.88	318.64	344.07	96.30	0
CWED	79.61	88.68	100.90	37.06	0
AI	48.36	52.18	55.90	85.60	100
CONTAG	30.91	32.88	35.43	46.63	100

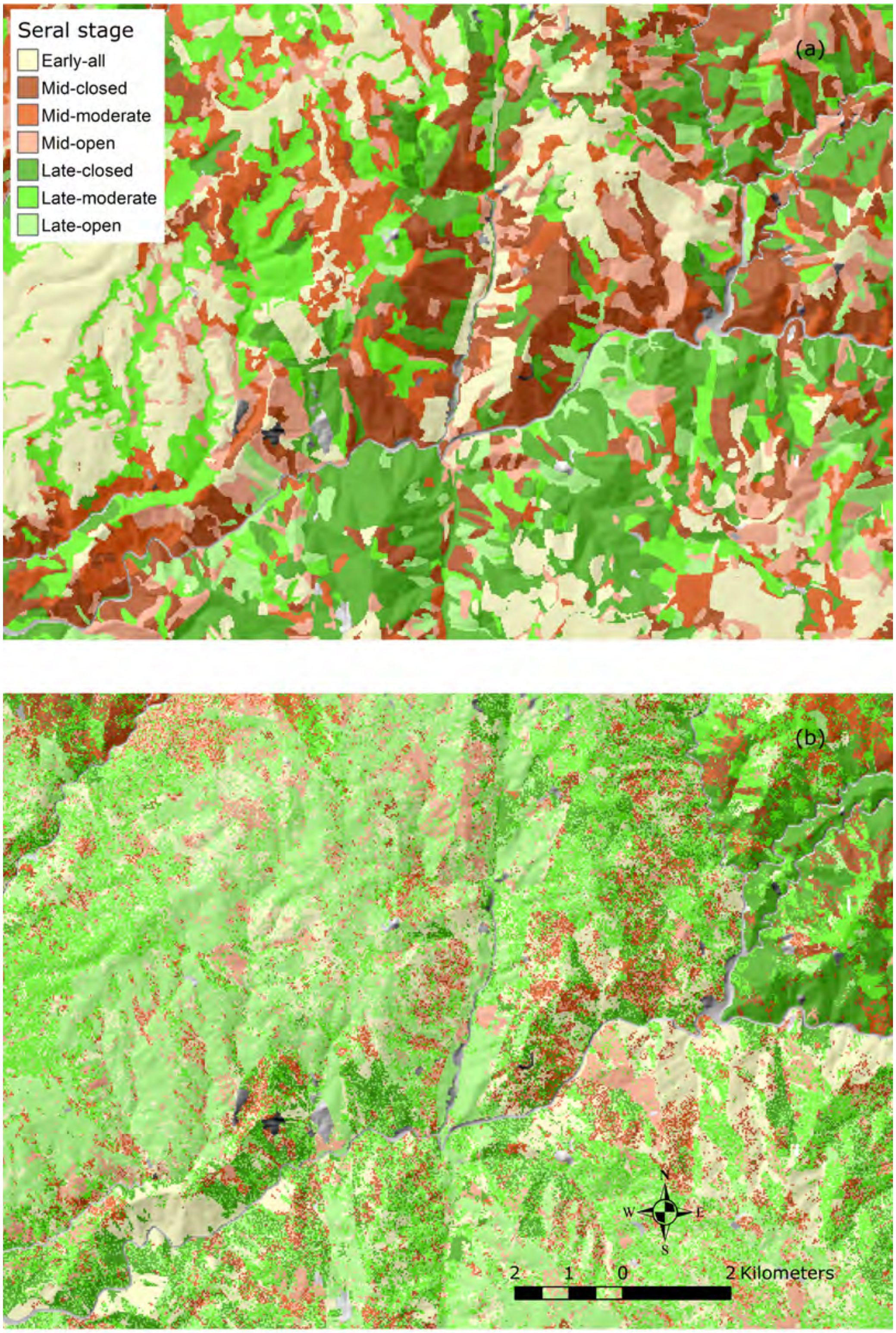


Figure 51—Snapshots of the seral stage mosaic for (a) the current landscape and (b) the last timestep of the simulated historical range of variability (ca. 1550–1850) in the upper Yuba River watershed, shown here for a randomly selected location within the project area. Note that for simplicity the four seral stages associated with mixed-conifer aspen cover types are not shown.

The complex interaction between widely varying disturbance sizes, heterogeneous severity patterns within disturbance events, and varying rates of succession produces and maintains this heterogeneous patch mosaic.

The current landscape configuration based on seral stages deviates somewhat from the HRV in a manner very similar to that of canopy cover (table 19). As with canopy cover, the larger patches in the current landscape are on the small and less extensive side, but nonetheless still within the HRV. However, the larger patches in the current landscape are much less geometrically complex than under the HRV, resulting in a greater percentage of the patches in core area. In addition, the contrast along edges is greater in the current landscape, and the seral stages are more interspersed than under the HRV. As with both developmental stage and canopy cover, the current landscape also has notably less fine-scale heterogeneity, but this may partly be a modeling artifact as discussed previously. Overall, like canopy cover, departure in seral stage appears to be mostly related to changes in the geometric complexity and fine-scale heterogeneity of the mosaic, and although we are confident in reporting this departure, we are hesitant to draw strong conclusions about the magnitude of the departure.

The results were very similar for the landscape classified into 151 unique combinations of cover type and seral stage; the main difference was that the absolute range of values of the metrics reflected the greater spatial heterogeneity of the more finely resolved landscape mosaic (table 20). The landscape maintained a relatively high degree of spatial heterogeneity and variability over time in the larger patch structure, with the area-weighted mean patch size varying between about 126 and 196 hectares (311–484 acres), coupled with a relatively low magnitude of average contrast along edges, moderate degree of interspersion of seral stages, and a tremendous and constant amount of fine-scale spatial heterogeneity in seral stages.

Table 20—Historical range of variability (HRV) in landscape metrics (see *Landscape Configuration* under *Methods* for description and units for each landscape metric) computed on the basis of the landscape classified into combinations of cover type and seral stage classes (see *HRV Spatial Input Data* for classification) for ca. 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV.

	Percentile of HRV			Current	
Landscape metric	**5th**	**50th**	**95th**	**% eligible**	**% HRV**
LPI	2.08	2.08	2.08	2.08	98
AREA_AM	126.21	151.47	196.42	118.92	2
GYRATE_AM	587.68	636.03	693.89	615.93	24
SHAPE_AM	5.17	5.63	6.19	3.27	0
DCORE_AM	96.68	121.21	152.13	45.27	0
CAI_AM	5.22	7.42	10.28	38.78	100
TECI	21.72	22.22	22.98	26.14	100
IJI	54.90	55.81	56.78	63.80	100
AREA_MN	0.51	0.58	0.67	3.60	100
SHAPE_MN	1.23	1.24	1.26	1.42	100
DCORE_MN	0.89	1.17	1.46	2.26	100
CAI_MN	0.16	0.28	0.48	18.78	100
ED	312.13	335.58	360.03	139.71	0
CWED	69.20	75.04	81.42	36.96	0
AI	46.11	49.79	53.32	79.33	100
CONTAG	44.65	45.54	46.92	50.89	100

The absolute range of variability in contagion was greater for the cover-seral mosaic than the pooled seral stage mosaic. This was because the cover-seral mosaic exhibited much less interspersion (55–57 percent) than the pooled seral stage mosaic (65–69 percent), which more than compensated for the lower aggregation of the cover-seral mosaic.

As with seral stage pooled across cover types, the larger patches in the current landscape are on the small and less extensive side, but nonetheless still within the HRV, and the larger patches in the current landscape are much less geometrically complex than under the HRV, resulting in a greater percentage of the patches in core area. In addition, the contrast along edges is greater in the current landscape and the seral stages are more interspersed than under the HRV. The current landscape also has notably less fine-scale heterogeneity, but again this may partly be a modeling artifact.

Alternative Management Scenarios

For consistency with the HRV section, we divided the results of the alternative management scenarios into three major sections corresponding to the disturbance regime, landscape composition, and landscape configuration. Here, we focus on the comparison among the management scenarios (MS1–MS7) and HRV, and the degree to which the management scenarios moved the current landscape toward the HRV in each of the measured attributes. We report the disturbance results because they represent how much disturbance was actually realized in the simulation, but do not analyze them further because they are a direct reflection of our model parameterization. The simulated landscape composition and configuration represent a set of results of the simulation from which we can make inferences. We have higher confidence in the comparative results than in the absolute results of any single scenario, because our focus here is on the comparison among scenarios that were subject to the same modeling assumptions and limitations. Thus, even if our modeling assumptions are not accurate, the biases resulting from those assumptions should be consistent across scenarios, making the comparative results reliable.

Disturbance Regime

In this section, we distinguish between "wildfires" and "prescribed fires." The HRV and no treatment (MS1) scenarios involved only wildfires, whereas the other management scenarios (MS2–MS7) involved both wildfires and prescribed fires.

Wildfire Frequency

The simulated number of individual wildfires per 5-year timestep differed between the HRV and management scenarios as expected given the model parameterization (fig. 52). Taking into account the modern fire size distribution, we reduced the disturbance rate calibration coefficient in the management scenarios as necessary to approach the target modern wildfire FRP of 152 years for MS1. The net result was a reduction in the average number of wildfires per 5-year timestep initiating within the 181,556-hectare project area from 194 in HRV to 119 in MS1—a 39-percent reduction. The average number of wildfires per timestep in the management scenarios was directly related to the intensity of prescribed fire treatments, with the fewest wildfires occurring in the scenarios with the greatest intensity of prescribed fire (MS3a,b). This additional reduction to as low as 78 in M3a (34 percent fewer than MS1) was due solely to the reduced vegetation susceptibility to wildfire caused by the vegetation treatments (including prescribed fire).

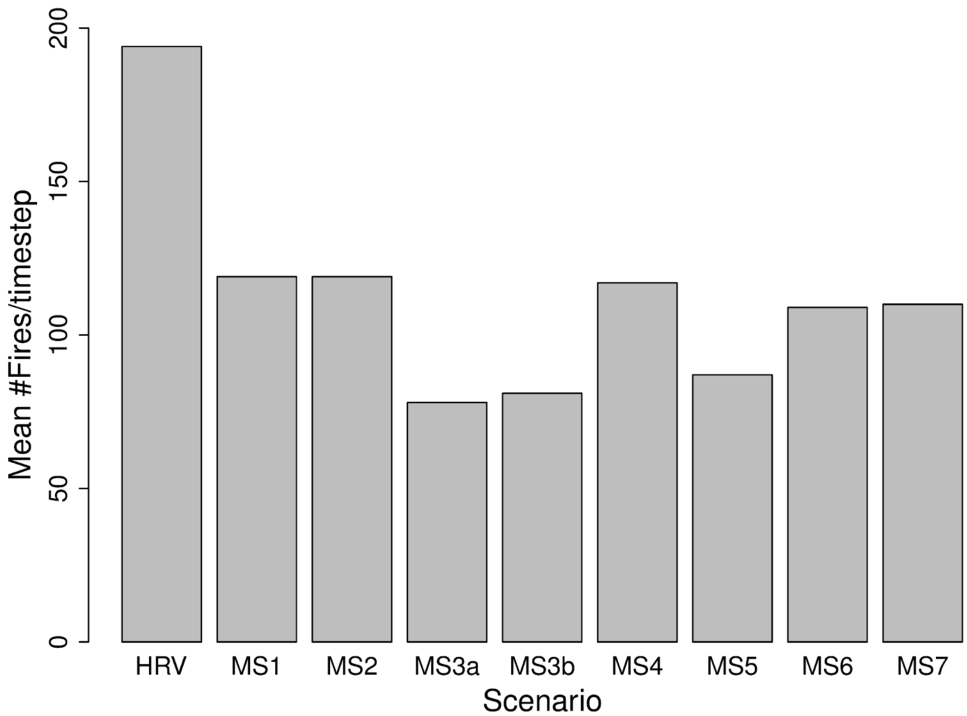


Figure 52—Mean number of wildfires per 5-year timestep for the simulated historical range of variability (ca. 1550–1850; mean is across 460 timesteps) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) (mean is across 20 replicate 100-year simulations with 10-year timesteps; N = 200) in the upper Yuba River watershed (see *Methods* for description of scenarios).

<u>Area Burned</u>

The percentage of the eligible landscape (174,830 hectares) burned by wildfires in each 5-year timestep under the FRV scenarios was more than 80 percent lower than under the HRV, as expected given the model parameterization (table 21). The area burned by wildfires was reduced even further under the management scenarios involving vegetation treatments (MS2–MS7). As with wildfire frequency, the reduction was directly related to the intensity of prescribed fire treatments. As before, this reduction was due solely to the effect of the vegetation treatments (including prescribed fire) on susceptibility to wildfire. In addition, the simulated fire size distribution shifted between the HRV and management scenarios, as expected given the model parameterization, such that a greater proportion of wildfires was in the smallest size class under the management scenarios (fig. 53). The dramatic reduction in area burned by wildfires under the management scenarios was due to the reduction in fire frequency (fig. 52) and the reduced average fire size (table 22), both of which were the direct result of model parameterization. However, even though the total area burned and the mean wildfire size were dramatically smaller under the management scenarios, the area-weighted mean wildfire size was greater (table 22), indicating that more of the total area that burned under the management scenarios did so during larger wildfires. This result was not directly due to model parameterization but rather emerged as an outcome of the interaction between fire and vegetation.

The same patterns were evident in the exceedance curves, which represent the probability in any one timestep of the total area burned by wildfires exceeding a certain percentage of the landscape. Exceedance probability decreased much more rapidly under the management scenarios compared to the HRV scenario (fig. 54). For example, under the HRV scenario there was a 25-percent chance of more than 25 percent of the eligible landscape burning in wildfires in any one timestep, but under the management scenarios there was less than a 3-percent chance of more than 25 percent of the eligible landscape burning in any one timestep.

Table 21—Percentage of the eligible landscape burned by wildfires per 5-year timestep for the simulated historical range of variability (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) (see *Management Scenarios* under *Methods* for descriptions) in the upper Yuba River watershed.

	Percentage burned per timestep		
Scenario	**Min**	**Mean**	**Max**
HRV	0.06	17.52	73.63
MS1	0.02	3.39	44.02
MS2	0.03	2.94	49.89
MS3a	0.01	1.69	40.98
MS3b	0.01	1.99	37.97
MS4	0.03	3.13	53.09
MS5	0.01	2.25	34.25
MS6	0.02	2.19	35.65
MS7	0.03	2.96	46.97

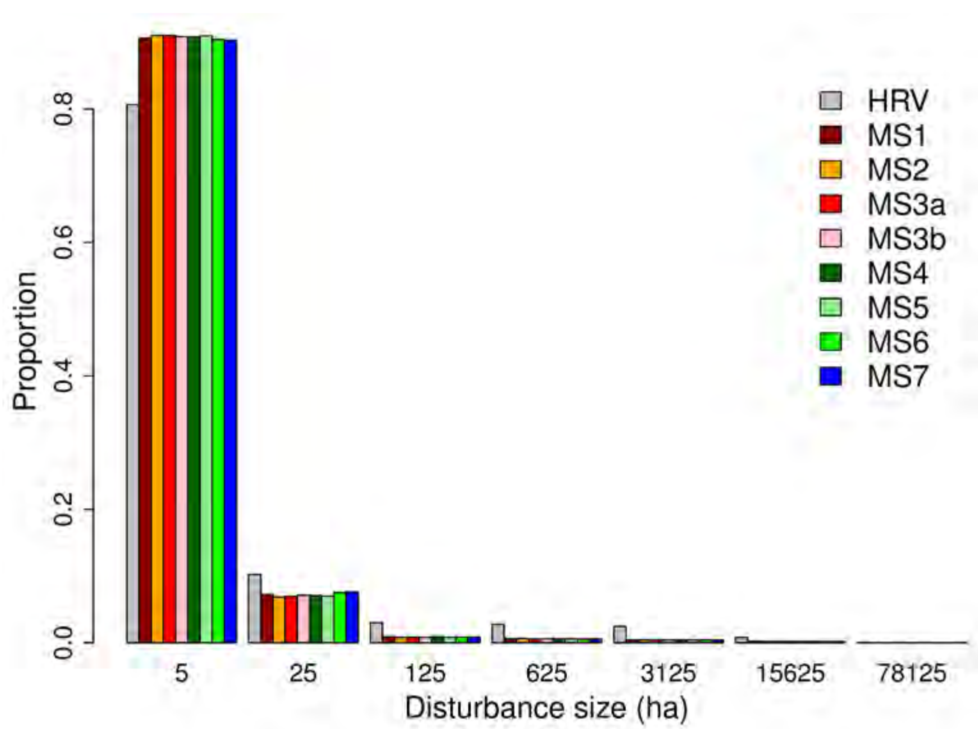


Figure 53—Distribution of simulated wildfire sizes for the simulated historical range of variability (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed (see *Methods* for description of scenarios). Note that the x-axis is geometrically scaled.

Table 22—Wildfire sizes under the simulated historical range of variability (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) (see *Management Scenarios* under *Methods* for descriptions) in the upper Yuba River watershed.

	N		Fire size					
			Mean		Area-weighted mean		Max	
Scenario	**(ha)**	**(ac)**	**(ha)**	**(ac)**	**(ha)**	**(ac)**	**(ha)**	**(ac)**
HRV	220,900	545,844	181	447	38,146	94,259	139,369	344,381
MS1	107,534	265,717	56	138	53,662	132,599	147,460	364,374
MS2	106,706	263,671	48	119	38,925	96,184	125,865	311,012
MS3a	91,052	224,989	48	119	40,078	99,033	126,139	311,689
MS3b	92,047	227,448	55	136	49,484	122,275	128,659	317,916
MS4	106,342	262,771	54	133	46,615	115,186	147,810	365,239
MS5	94,774	234,187	55	136	53,268	131,625	136,874	338,216
MS6	103,193	254,990	47	116	44,370	109,638	140,839	348,013
MS7	103,459	255,647	57	141	54,360	134,324	125,205	309,382

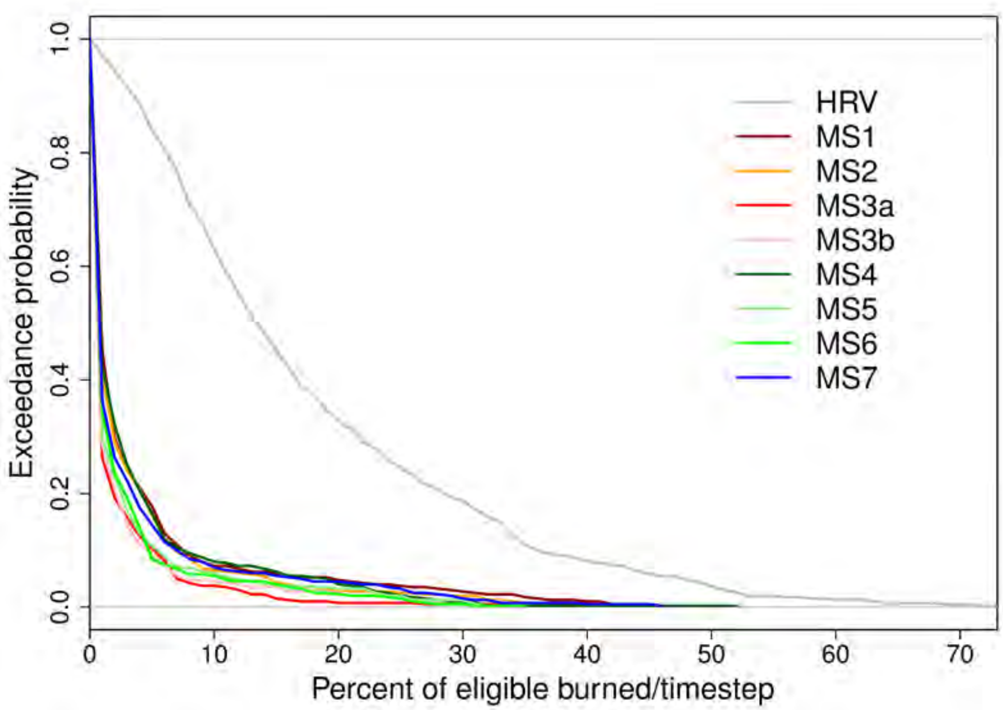


Figure 54—Exceedance probability of simulated wildfires (i.e., probability of ≥any percent of the eligible landscape being burned in any timestep) for the simulated historical range of variability (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed (see *Methods* for description of scenarios).

Fire Rotation Period

Reflecting model parameterization, wildfire FRP increased fivefold from the HRV scenario (29 years) to the MS1 scenario (147 years) (table 23). The wildfire FRPs under the other management scenarios increased even further—to as high as 296 years under the MS3a scenario—and these increases were due to the reduced vegetation susceptibility to wildfire caused by the vegetation treatments. Thus, despite having the same wildfire regime parameters, the vegetation treatments reduced the total occurrence of wildfire by up to 100 percent, depending on the intensity of treatment.

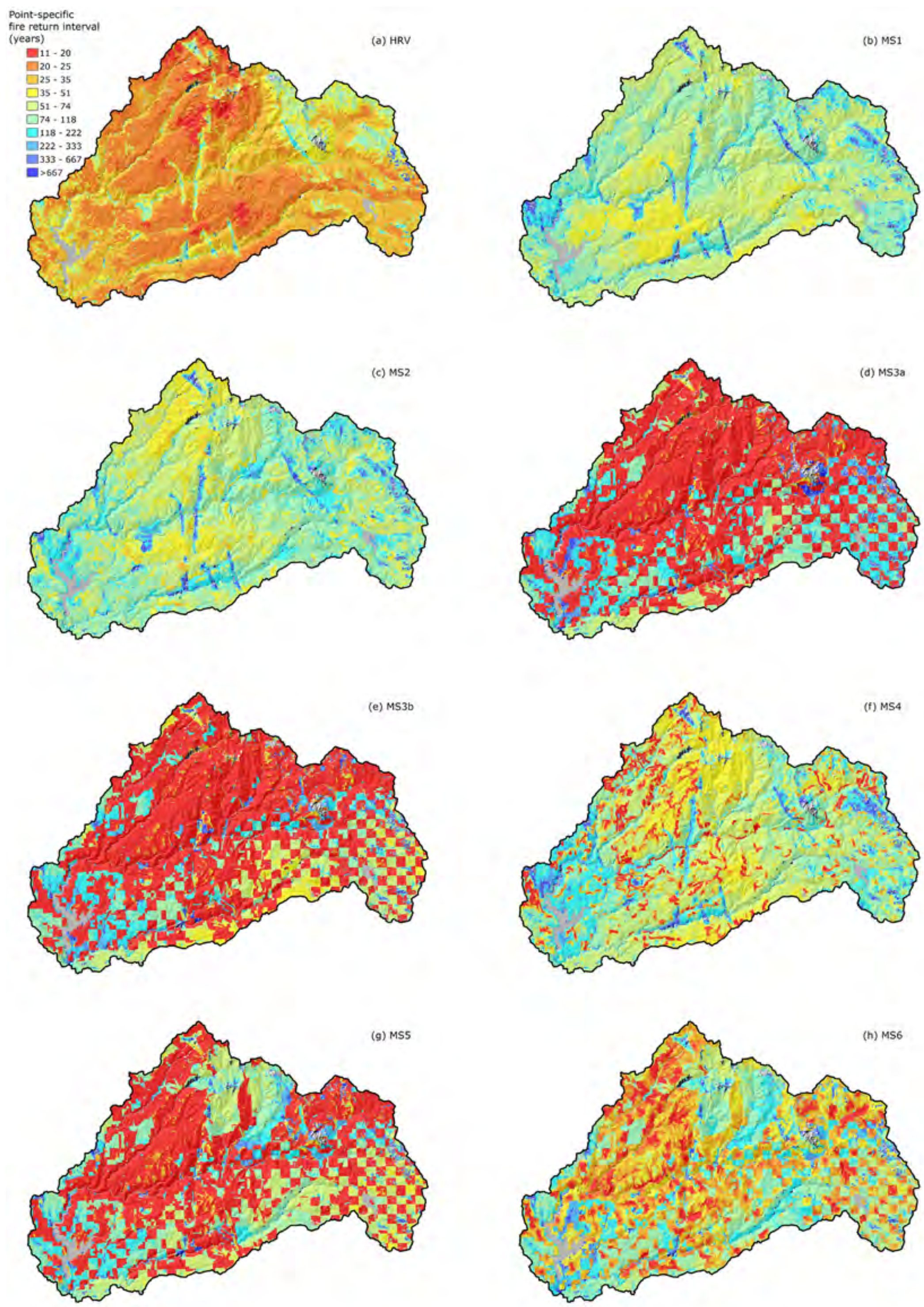
Table 23—Fire rotation periods (FRPs) (yr) for wildfires of "any" mortality level (i.e., severity) for all of the dynamic cover types for the simulated historical range of variability (HRV) (ca. 1550–1850), and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) (see *Management Scenarios* under *Methods* for descriptions) in the upper Yuba River watershed. Note that we considered FRPs for cover types with <1,000 ha (2,500 ac) extent in the project area as unreliable, but we included them here for completeness.

			Scenario								
Cover type	**Area (ha)**	**Area (ac)**	**HRV**	**MS1**	**MS2**	**MS3a**	**MS3b**	**MS4**	**MS5**	**MS6**	**MS7**
Sierran Mixed Conifer – Mesic	57,853	142,288	27	140	156	274	213	151	197	209	156
Sierran Mixed Conifer – Xeric	52,198	128,981	24	127	144	236	209	131	184	191	143
Oak-Conifer Forest and Woodland	23,279	57,522	25	129	160	246	231	146	204	209	154
Red Fir – Mesic	8,563	21,159	63	252	302	1,031	766	305	527	491	323
Red Fir – Xeric	7,493	18,515	43	149	175	420	385	156	264	250	181
Mixed Evergreen – Mesic	7,273	17,972	48	268	316	711	568	370	548	496	337
Mixed Evergreen – Xeric	6,768	16,724	37	178	225	495	468	217	403	321	239
Sierran Mixed Conifer – Ultramafic	4,124	10,190	57	430	543	1,186	1,096	518	1,105	895	585
Oak-Conifer Forest and Woodland – Ultramafic	1,060	2,619	40	257	355	803	949	366	705	586	422
Lodgepole Pine	837	2,068	51	330	358	748	410	348	337	370	285
Montane Riparian	732	1,809	52	250	280	518	375	281	295	342	258
Subalpine Conifer	638	1,576	277	1,443	1,616	2,568	1,291	1,466	1,185	1,485	1,223
Mixed Evergreen – Ultramafic	604	1,492	110	767	1,124	4,367	3,951	1,134	4,460	2,055	1,716
Red Fir – Ultramafic	294	726	123	740	730	5,554	4,213	800	2,553	1,177	956
Western White Pine	273	675	90	884	722	1,517	804	866	580	769	573
Sierran Mixed Conifer with Aspen	58	143	31	140	169	493	285	140	209	241	164
Red Fir with Aspen	31	77	60	256	356	1,624	1,880	230	1,274	456	336
Oak Woodland	19	47	25	132	170	233	260	150	237	217	169
Curl-Leaf Mountain Mahogany	18	45	78	591	569	849	476	590	308	656	428
Lodgepole Pine with Aspen	8	20	48	235	342	913	620	286	414	396	310
Total[a]	174,830		29	147	170	296	251	159	222	229	169
All fires (wild and prescribed)	174,830	432,005	29	147	134	24	23	76	27	49	49

[a] Total includes static vegetated cover types that were allowed to burn (e.g., grasslands, meadows).

Importantly, the longer wildfire FRPs under the management scenarios do not take into account prescribed fires. The combined fire (wild and prescribed) FRPs for the management scenarios with intensive use of prescribed fire (MS3a,b and MS5) were in fact comparable to the HRV (table 23). Thus, prescribed burning roughly compensated for the reduction in wildfires under these particular management scenarios. These differences among scenarios were generally consistent across all major cover types, although Oak-Conifer Forest and Woodland – Ultramafic and Sierran Mixed Conifer – Ultramafic exhibited a 6.5- and 7.5-fold (rather than the average fivefold), respectively, increase in wildfire FRP from the HRV to MS1 scenario (table 23).

Recall that FRP reflects the average point-specific fire return interval (FRI), but says nothing about its variance. After pooling wildfires and prescribed fires, we noted substantial spatial variability in FRIs across the landscape both within and among scenarios (fig. 55).



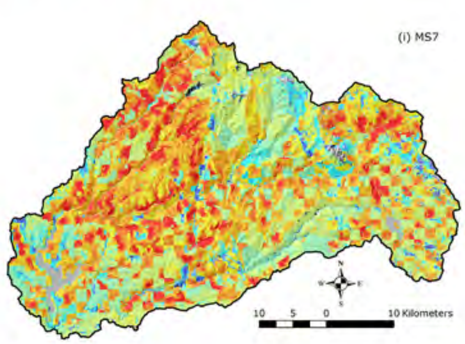


Figure 55—Simulated point-specific fire return interval for wildfires and prescribed fires combined under (a) the simulated historical range of variability (ca. 1550–1850) and a variety of management scenarios with a modified fire regime reflecting aggressive fire suppression in the upper Yuba River watershed: (b) MS1 — no treatment; (c) MS2 — current Land Management Plan (LMP); (d) MS3a — prescribed fire only; (e) MS3b — prescribed fire only, with "hotter" burns; (f) MS4 — LMP moderate intensity; (g) MS5 — Sierra Conservancy; (h) MS6 — balanced scenario; (i) MS7 — our final scenario (see *Methods* for description of scenarios).

This variability resulted not only from the choice of treatments, but also from gradients in cover types with varying propensities to burn, reflecting complex interactions among fire, vegetation, and terrain that emerged from the simulation. The difference between the HRV and MS1 scenario was largely one of reduced frequency of fire under the latter scenario resulting in considerably longer fire FRIs, but the spatial heterogeneity in FRIs was similar between scenarios. The low-intensity mixture of mechanical and prescribed fire treatments in the MS2 scenario resulted in little overall difference from MS1 even though the average FRI was 23 years longer (fig. 55c). In contrast, the high-intensity prescribed fire-only scenarios (MS3a,b) homogenized the short FRIs across national forest lands and exacerbated the differences between national forest lands and other ownerships (fig. 55d–e).

The moderate-intensity mixture of mechanical and prescribed fire treatments in MS4 resulted in a striking pattern of short FRIs along roads where the hand cut, pile, and burn treatments were conducted and much longer FRIs elsewhere (fig. 55f). The high-intensity treatments dominated by prescribed fire in MS5 resulted in a pattern similar to the prescribed fire-only scenarios (MS3a,b), with the exception of the roadless areas that remained untreated in MS5 and thus exhibited considerably longer FRIs (fig. 55g). Last, the high-intensity treatments in MS6 and MS7 consisting of an equal mixture of mechanical and prescribed fire resulted in very high spatial heterogeneity in FRIs (fig. 55h; note that MS7 is not shown but is almost indistinguishable from MS6).

Wildfire Severity

Recall that at the cell level, fires caused either low or high mortality of the overstory vegetation, which we defined as less than or greater than 75 percent of the canopy, respectively. Also recall that one of the key model parameters was the probability of a high-mortality response, which we specified separately for each unique combination of cover type and seral stage, as modified by topographic position, as part of the state-and-transition models (Appendix B). Therefore, the realized percentage of high-mortality fire largely reflected the model parameterization. Nonetheless, we report it as a description of how often fire caused an immediate state transition to the early-development seral stage. The realized percentage of high-mortality fire was at least partly an emergent property of the simulation because it reflected both the model parameterization and the unspecified proportion of time each cover type spent in each seral stage. Thus, scenarios that increased the proportion of time vegetation was in a closed-canopy condition were associated with greater realized percentages of high-mortality wildfire.

The realized percentage of high-mortality wildfire differed slightly among scenarios (table 24). The overall percentage of high-mortality wildfire increased from 14.6 percent under the HRV scenario to a high of 20.2 percent under the MS2 scenario, but when averaged across all management scenarios it increased only slightly to 17.2 percent. The increased propensity for high-mortality wildfire under the no treatment scenario (MS1) was driven primarily by the increased vegetation susceptibility to fire. The greater extent of closed-canopy forest, which resulted from less fire, led to higher susceptibility to fire. The 90-percent range of variability over time increased between the HRV (7–21 percent) and the management scenarios (5–25 percent), with the latter reflecting the wide range of vegetation conditions resulting from different treatment intensities and types.

Vegetation Treatment

The realized treated area and allocation among treatment types for the various management scenarios are given in table 8. Treament intensities were almost constant across all scenarios for private industry and other lands and for mixed conifer-aspen forest on national forest lands. Treatment intensities for conifer-dominated forest on national forest

Table 24—High-mortality wildfire rates (percentage of burned cells exhibiting high mortality effect: >75 percent canopy cover mortality) for the forested cover types for the simulated historical range of variability (HRV) (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) (see *Management Scenarios* under *Methods* for descriptions) in the upper Yuba River watershed.

	Scenario								
Cover type	**HRV**	**MS1**	**MS2**	**MS3a**	**MS3b**	**MS4**	**MS5**	**MS6**	**MS7**
Lodgepole Pine	18.5	13.4	18.1	22.7	22.4	14.1	12.3	17.2	30.3
Lodgepole Pine with Aspen	19.4	75.0	17.2	NA	26.7	36.2	0.0	42.6	100.0
Mixed Evergreen – Mesic	17.4	14.9	19.6	19.6	22.5	21.1	23.9	31.5	19.3
Mixed Evergreen – Ultramafic	16.9	22.5	23.7	7.4	5.9	6.2	24.7	23.3	9.4
Mixed Evergreen – Xeric	13.8	13.9	14.9	8.4	17.0	15.8	13.4	20.7	13.3
Montane Riparian	49.2	36.6	49.3	55.7	46.9	52.1	44.5	47.3	38.1
Oak Woodland	18.2	33.5	40.2	0.0	47.7	39.9	0.0	5.9	NA
Oak-Conifer Forest and Woodland	20.7	20.7	22.6	25.5	23.1	15.7	22.5	21.9	23.4
Oak-Conifer Forest and Woodland – Ultramafic	4.1	17.5	12.4	8.8	9.4	5.1	4.6	4.9	6.7
Red Fir with Aspen	29.2	47.6	42.0	91.7	0.0	48.8	43.3	0.0	0.0
Red Fir – Mesic	25.0	40.9	25.8	37.1	37.7	24.9	27.5	27.6	24.0
Red Fir – Ultramafic	26.4	0.0	26.2	100.0	0.0	21.0	53.4	11.1	7.1
Red Fir – Xeric	34.2	35.1	24.9	30.7	23.8	24.9	24.2	28.9	29.3
Subalpine Conifer	77.7	76.6	78.8	79.8	79.1	76.0	71.7	79.2	72.7
Sierran Mixed Conifer with Aspen	24.1	45.0	33.9	55.6	37.1	24.1	70.8	20.7	60.0
Sierran Mixed Conifer – Mesic	13.4	17.4	22.9	12.6	20.9	14.9	15.6	17.7	16.2
Sierran Mixed Conifer – Ultramafic	12.6	9.9	13.7	15.7	9.7	6.5	19.0	6.5	13.8
Sierran Mixed Conifer – Xeric	9.2	10.8	12.4	9.0	9.6	9.1	11.5	13.1	13.7
Western White Pine	17.7	51.0	20.1	17.1	13.3	15.6	11.0	12.2	2.3
Total	14.6	16.2	20.2	13.6	18.8	15.3	16.9	19.4	17.3

lands differed considerably among scenarios as intended. Treatment intensities ranged from an average of 3,451 hectares (8,527 acres) treated per timestep over the replicate 100-year simulations, representing a treatment rate of approximately 2.5 percent every 5 years (or 0.5 percent per year), in the current LMP scenario (MS2) to about 34,180 hectares (84,459 acres) treated per timestep, representing a treatment rate of approximately 27.5 percent every 5 years (or 5.5 percent per year) for the prescribed fire-only scenarios (MS3a,b).

Landscape Composition

Developmental Stage Dynamics

All of the management scenarios moved the current landscape closer to the HRV distribution of developmental stages pooled across cover types. In fact, with the exception of the no treatment scenario (MS1), most of the management scenarios roughly emulated the HRV (fig. 56). In both the HRV and management scenarios, we observed a shift from the current mid-development forest-dominated landscape to a landscape dominated by late-development forest. This was due to the high number of low-mortality wildfires and prescribed fires, as well as the use of largely non-stand replacing vegetation treatments in the management scenarios, which allowed the mid-development stands in the current landscape to succeed to late development. The no treatment scenario least emulated the HRV, resulting in less early- and mid-development and more late-development forest than the HRV. Conversely, all of the management scenarios involving active vegetation management emulated the HRV fairly well, although the Sierra Conservancy scenario (MS5) probably came the closest to emulating the HRV across all three developmental stages.

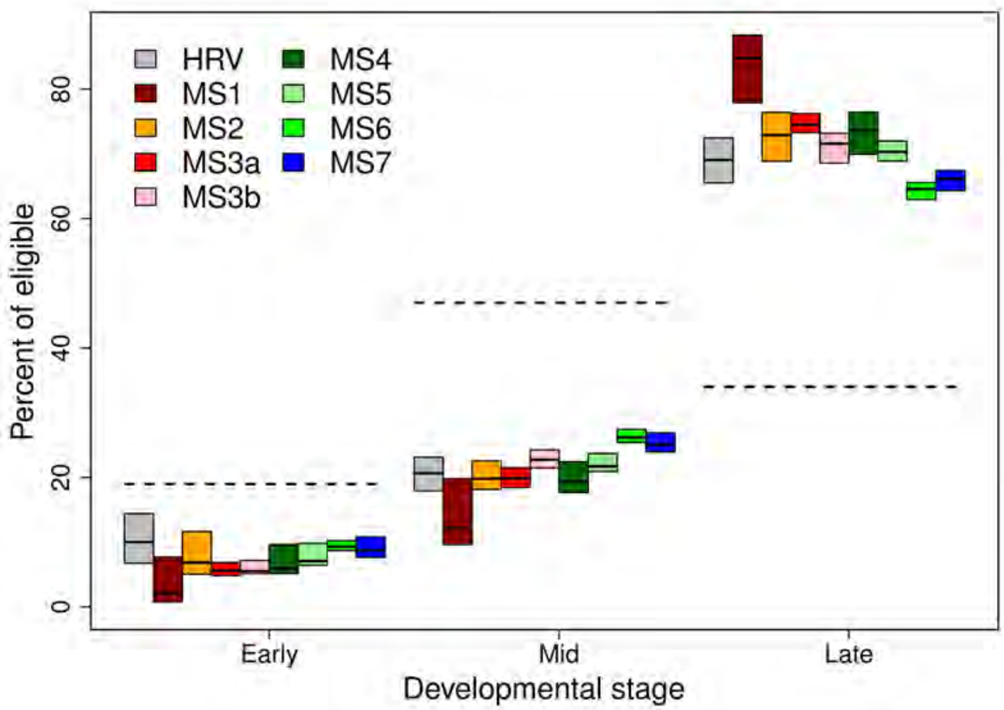


Figure 56—Range of variability in vegetation developmental stages, represented as the percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated land cover), for the simulated historical range of variability (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed (see *Methods* for description of scenarios). Box represents the 5–95th percentiles, solid horizontal line the 50th percentile, and dashed horizontal line the current landscape condition.

These patterns were generally consistent across the dominant cover types (see table D4 in Appendix D for cover type-specific results), with the following exceptions. The management scenarios did not emulate the HRV very closely in the Oak-Conifer Forest and Woodland – Ultramafic and Sierran Mixed Conifer – Ultramafic cover types. In both cases, the management scenarios produced less area in late-development and more area in mid-development forest than the HRV. This was in part due to the priorities for treatments that resulted in creating a large number of early-development patches via group cuts in these ultramafic cover types, and is something that could be rectified by adjusting the priorities accordingly.

Canopy Cover Dynamics

Recall that the current landscape was well within the HRV in the overall canopy cover class distribution (i.e., pooled across all cover types). The management scenarios differed considerably in how much they moved the current distribution of canopy cover classes away from the HRV (fig. 57). In particular, the no treatment scenario (MS1) caused the current landscape to move far outside the HRV in all canopy cover classes, producing much less open- and moderate-canopy cover and much more closed-canopy cover than we observed under the HRV. This shift to a dominance of closed-canopy conditions was due to the reduction in the rate of wildfire disturbance and the natural succession to closed canopy in the absence of disturbance. The active management scenarios (MS2–MS7), on the other hand, progressively improved in emulating HRV. Our final scenario (MS7) emulated HRV closely, producing a 35:25:40 ratio of open to moderate to closed canopy compared to the 38:24:37 ratio we observed under the HRV. Overall, the mixture of mechanical and prescribed fire treatments in our final scenario more than doubled the proportion of the landscape in open and moderate canopy cover conditions over the no treatment scenario.

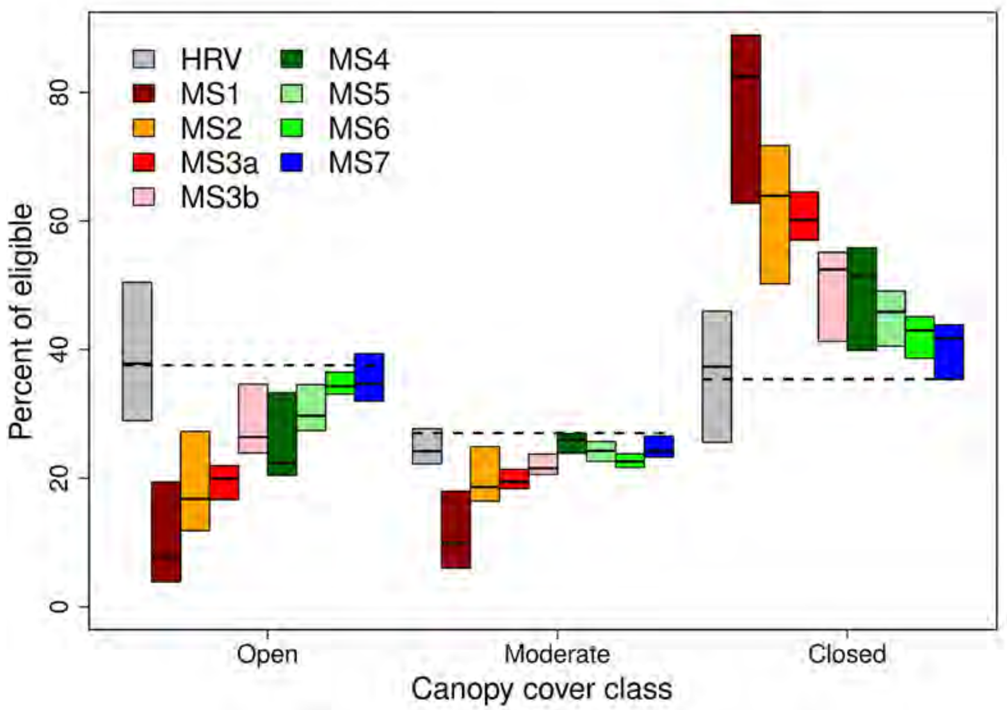


Figure 57—Range of variability in vegetation canopy cover classes, represented as the percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated land cover), for the simulated historical range of variability (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed (see *Methods* for description of scenarios). Box represents the 5–95th percentiles, solid horizontal line the 50th percentile, and dashed horizontal line the current landscape condition.

These patterns were generally consistent across the dominant cover types (see table D5 in Appendix D for cover type-specific results), with two notable exceptions:

- Among cover types, our final scenario resulted in less area in closed canopy in Mixed Evergreen (mesic and xeric variants) and Red Fir – Mesic forests than we observed under the HRV. This resulted from an excess of thinning and prescribed fire treatments that reduced canopy cover in these cover types, which could easily be rectified by adjusting the treatment priorities.
- In contrast, our final scenario resulted in less area in open canopy and, conversely, more area in closed canopy in Oak-Conifer Forest and Woodland – Ultramafic forests than we observed under the HRV. This resulted from a paucity of thinning and prescribed fire treatments in this cover type, which could easily be rectified by adjusting the treatment priorities.

<u>*Seral Stage Dynamics*</u>—The current landscape's overall seral stage distribution (i.e., pooled across all cover types) deviates considerably from the HRV, most of which is due to significant departure in the developmental stage distribution, as described previously. It is perhaps more instructive to compare the HRV scenario to the management scenarios (fig. 58). In general, with the exception of the no treatment scenario (MS1), all of the active management scenarios (MS2–MS7) emulated the HRV relatively well in the early- and mid-seral stages, but they varied considerably in emulating HRV in the late-seral stages. Our final scenario (MS7), however, emulated HRV relatively well in all of the seral stages, suggesting that an active management strategy involving a mixture of mechanical treatments and prescribed fire can accomplish the goal of emulating HRV in terms of landscape composition. These patterns differed somewhat across the dominant cover types as reported in table D6 in Appendix D.

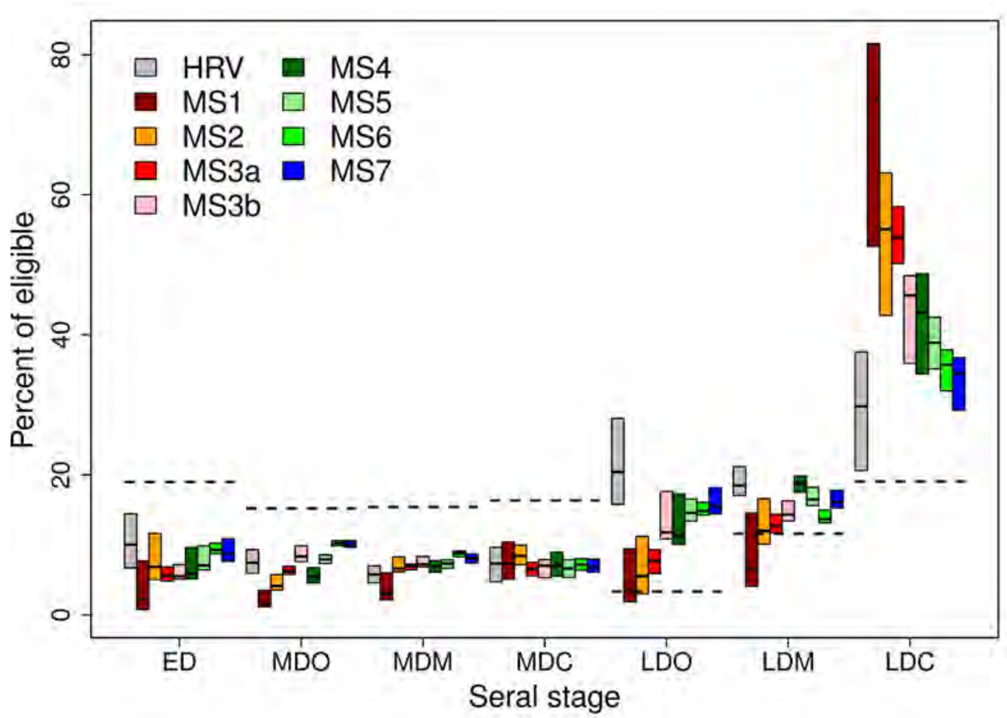


Figure 58—Range of variability in vegetation seral stages, represented as the percentage of the eligible landscape (i.e., excluding nonseral and nonvegetated land cover), for the simulated historical range of variability (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed (see *Methods* for description of scenarios). Box represents the 5–95th percentiles, solid horizontal line the 50th percentile, and dashed horizontal line the current landscape condition.

Landscape Configuration

Developmental Stage Dynamics

A complete summary of the landscape metrics by scenario for the developmental stage mosaic is presented in table D7 in Appendix D. Here we only briefly summarize the major results as illustrated by a smaller set of the metrics.

Compared to HRV, the no treatment scenario (MS1) produced considerably less spatial heterogeneity in the developmental stage mosaic (fig. 59). In contrast, the active management scenarios varied considerably in how well they emulated the HRV in both coarse- and fine-grained spatial heterogeneity in developmental stage. Our final scenario (MS7), in particular, did well in emulating both the coarse- and fine-grained patch structure of the HRV (fig. 59).

These differences among scenarios are reflected well in the landscape metrics (fig. 60). In particular, compared to HRV the coarse patch structure was much larger and geometrically simpler under the no treatment scenario, with the area-weighted mean patch size roughly twice, and the area-weighted mean shape index roughly half, that produced under the HRV scenario. This simplification resulted in roughly a doubling of the percentage of the larger patches in core (i.e., patch interior) under the no treatment scenario. In addition, the fine-scale heterogeneity was considerably less pronounced under the no treatment scenario, as exemplified by a sevenfold increase in the mean patch size. Overall, the no treatment scenario produced a much simpler patch mosaic than the HRV scenario due to the reduced rate of disturbance.

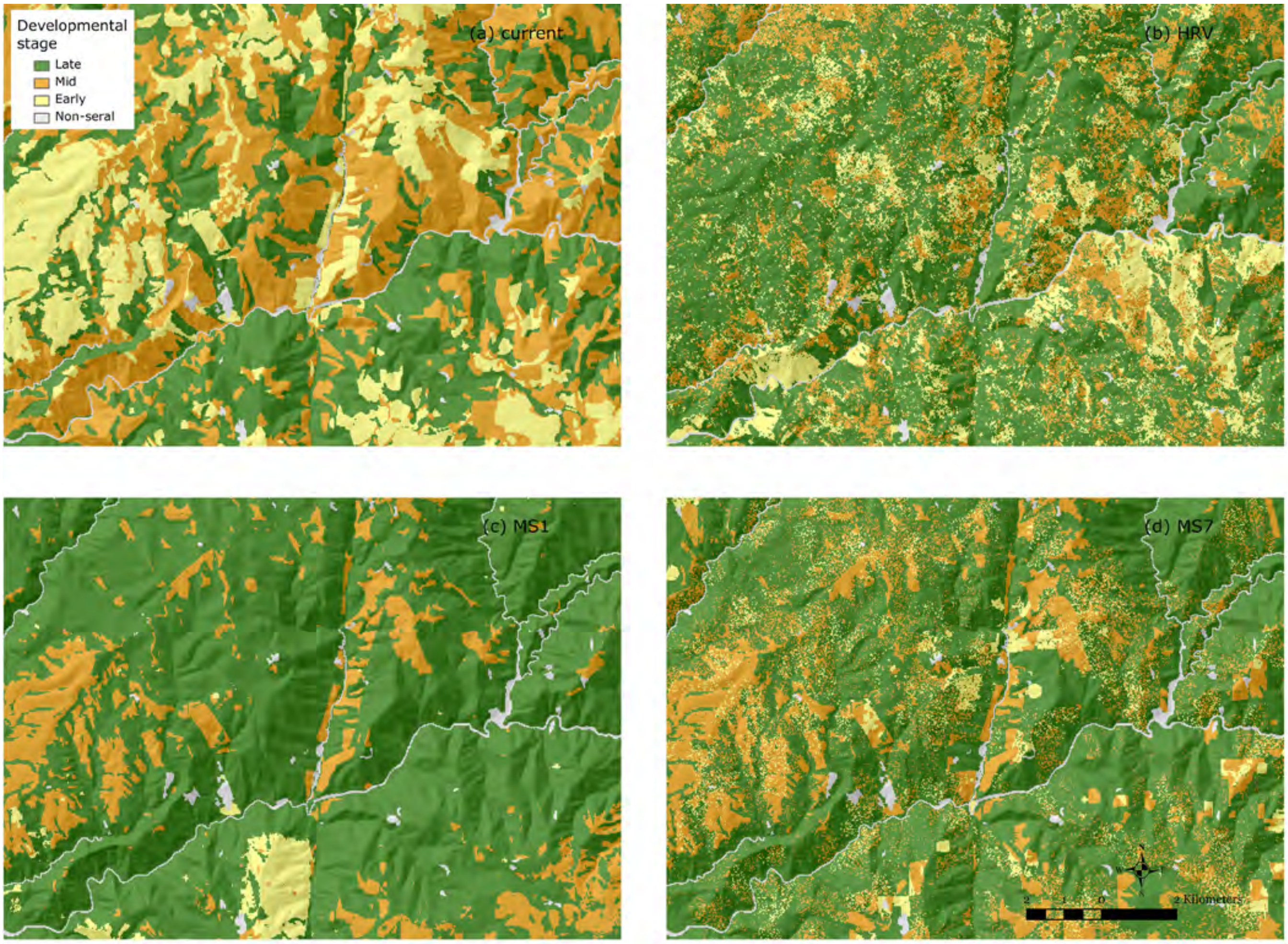
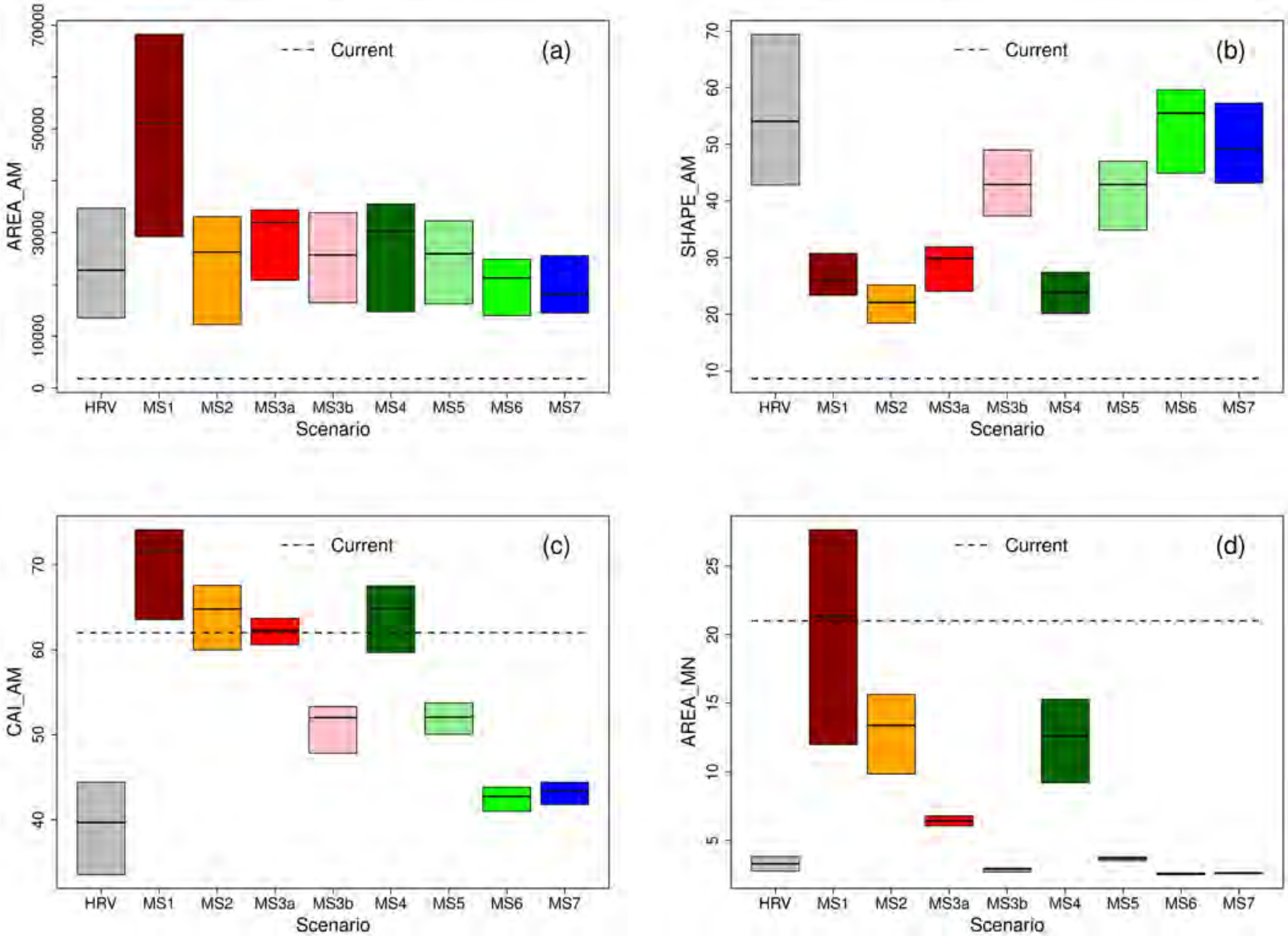


Figure 59—Snapshots of the vegetation developmental stage mosaic for (a) the current landscape and the last timestep of the simulated (b) historical range of variability (ca. 1550–1850) and range of variability under (c) the no treatment scenario (MS1), representing a modified wildfire regime without vegetation treatments, and (d) our final scenario (MS7), representing a modified wildfire regime combined with moderately intensive mechanical and prescribed fire treatments. Snapshots are shown for a randomly selected location in the upper Yuba River watershed and the last timestep of the respective simulations.

Compared to the no treatment scenario, our final scenario involving moderately intensive mechanical and prescribed fire treatments produced considerably less variability in the patch structure over time (fig. 60). Moreover, the large patches were considerably more complex geometrically, with the area-weighted mean shape index roughly double that of the no treatment scenario, which resulted in much less in core area under our final scenario. The vegetation treatments also produced much greater fine-scale heterogeneity than the no treatment scenario, as exemplified by the mean patch size metric. Overall, the vegetation treatments in our final scenario emulated HRV in all aspects of landscape configuration, with the only notable difference being a reduced range of variability in the metrics. The reduction in variability over time is perhaps not surprising given the regularity of treatments implemented in the model, compared to the more episodic nature of wildfire disturbances under the HRV. Overall, these results demonstrate that an active management scenario has the potential to emulate the HRV in landscape configuration (as well as landscape composition, as demonstrated previously). It is also worth noting that active management scenarios can also be devised that poorly emulate the HRV.



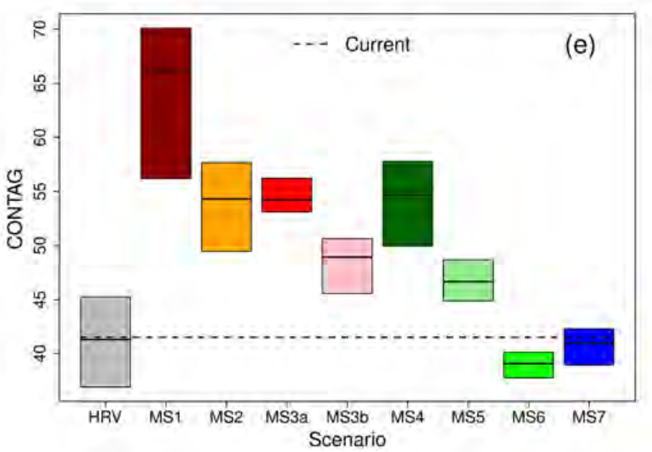


Figure 60—Range of variability in selected landscape metrics for the developmental stage mosaic (none, early, mid, and late) for the simulated historical range of variability (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed (see *Methods* for description of scenarios): (a) area-weighted mean patch size, (b) area-weighted mean shape index, (c) area-weighted mean core area index, (d) mean patch size, and (e) contagion (see *Methods* for description and units for each landscape metric). Box represents the 5–95th percentiles, solid horizontal line the 50th percentile, and dashed horizontal line the current landscape condition.

Canopy Cover Dynamics

A complete summary of the landscape metrics by scenario for the canopy cover class mosaic is presented in table D8 in Appendix D. Here we provide only a brief summary of the major results, as illustrated by a smaller set of the metrics.

As with the developmental stage mosaic, compared to the HRV the no treatment scenario (MS1) produced considerably less spatial heterogeneity in the canopy cover mosaic (fig. 61). Similarly, the active management scenarios varied considerably in how well they emulated the HRV in both coarse- and fine-grained spatial heterogeneity. As with the developmental stage mosaic, our final scenario (MS7), in particular, did well in emulating both the coarse- and fine-grained canopy cover mosaic of the HRV (fig. 61); only the prescribed fire-only scenario involving "hotter" fires (MS3b) did a better job of emulating the HRV in the canopy cover mosaic.

These differences among scenarios are reflected well in the landscape metrics (fig. 62). In particular, compared to the HRV the coarse patch structure was much larger and the landscape was more contagious under the no treatment scenario, with the area-weighted mean patch size and contagion index about two to several times greater than that produced under the HRV.

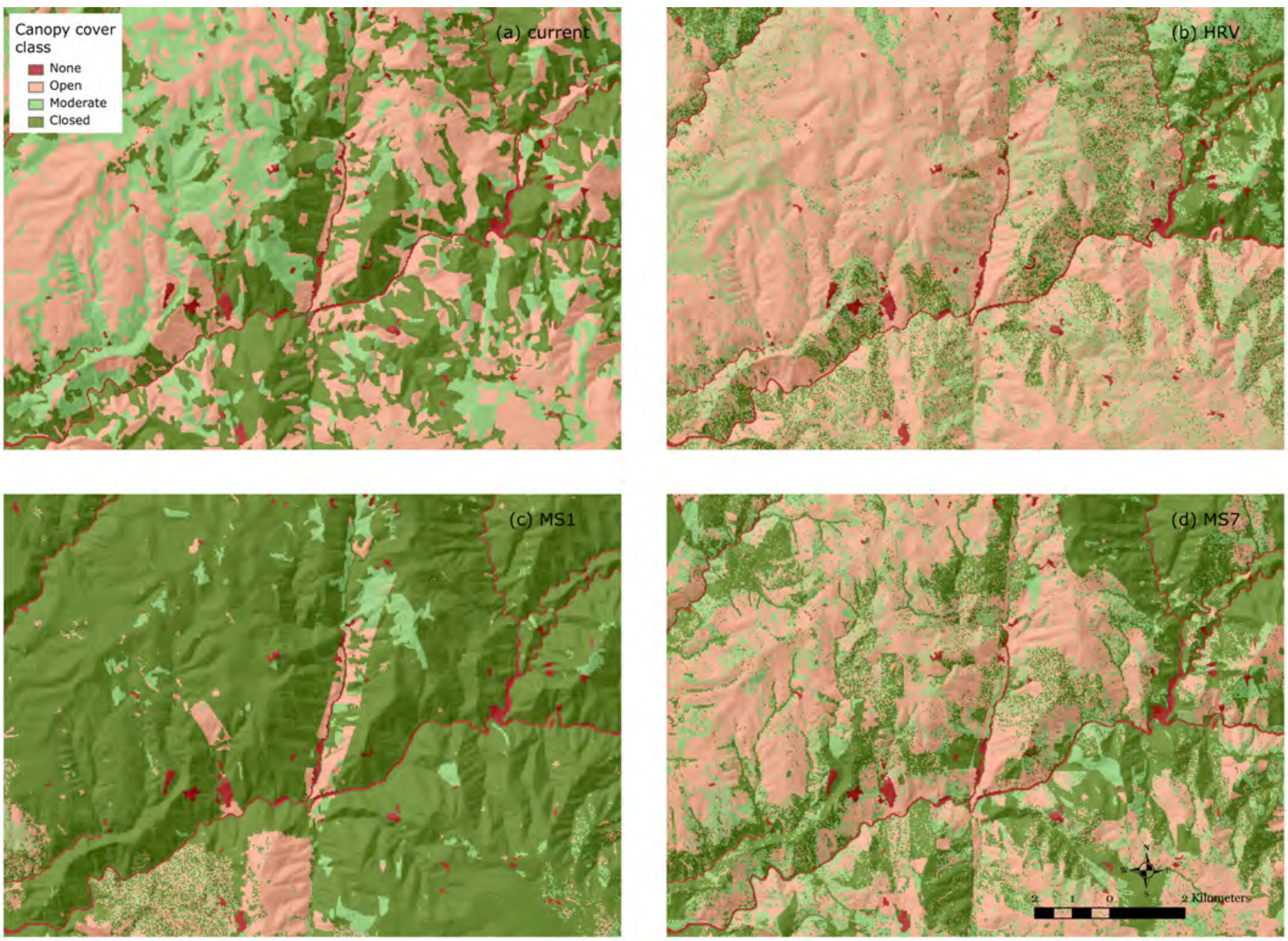
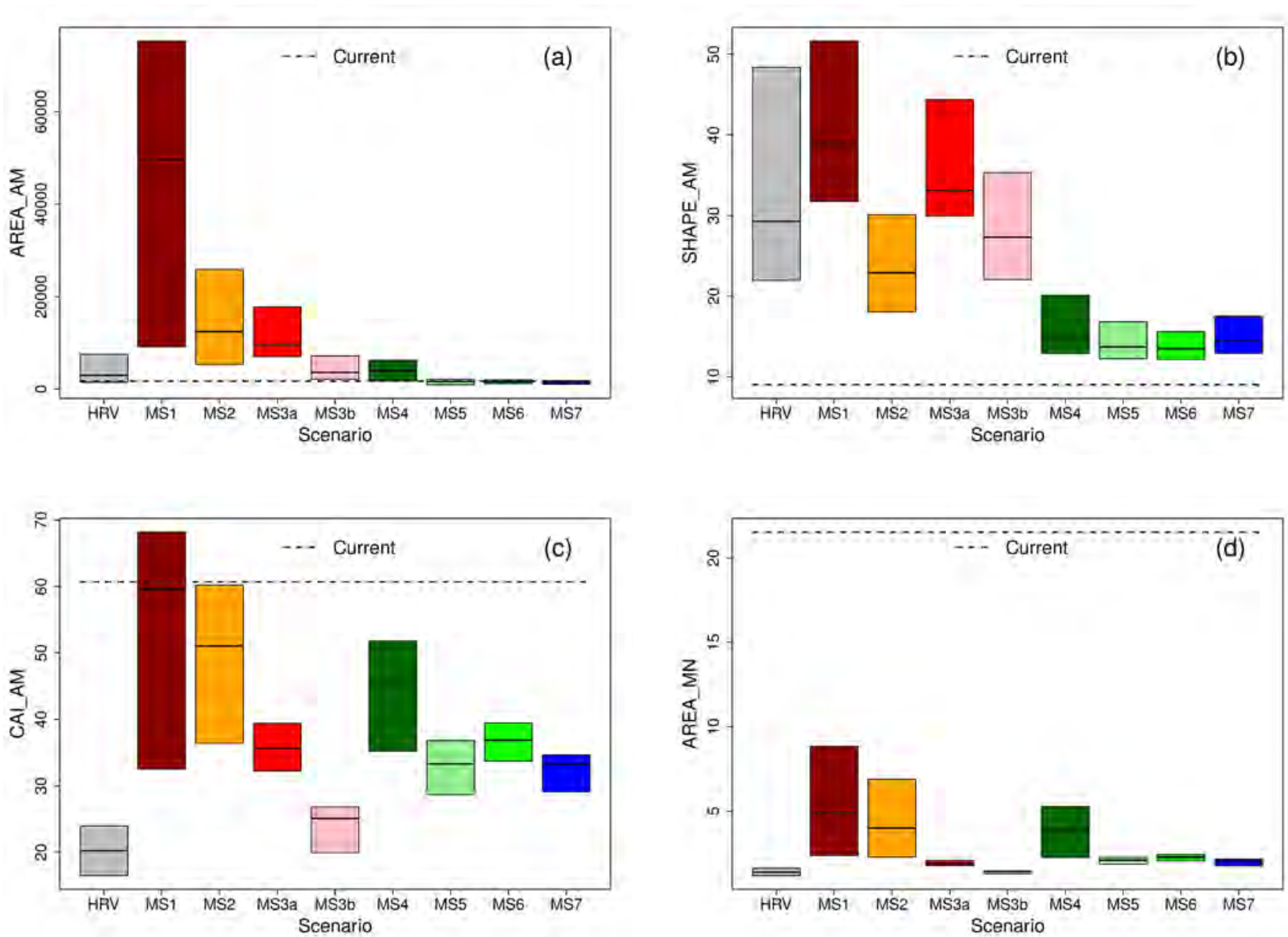


Figure 61—Snapshots of the vegetation canopy cover class mosaic for (a) the current landscape and the last timestep of the simulated (b) historical range of variability (ca. 1550–1850) and range of variability under (c) the no treatment scenario (MS1), representing a modified wildfire regime without vegetation treatments, and (d) our final scenario (MS7), representing a modified wildfire regime combined with moderately intensive mechanical and prescribed fire vegetation treatments. Snapshots are shown for a randomly selected location in the upper Yuba River watershed and the last timestep of the respective simulations.

This simplification of the landscape pattern resulted in about two to three times more core area under the no treatment scenario. In addition, the fine-scale heterogeneity was considerably less pronounced under the no treatment scenario, as exemplified by a several-fold increase in mean patch size. Overall, the no treatment scenario produced a much simpler canopy cover mosaic than the HRV, and one dominated by closed-canopy conditions due to the reduced rate of disturbance. Perhaps as important, under the no treatment scenario the canopy cover configuration fluctuated much more dramatically over time (i.e., greater range of variation) than it did under the HRV.



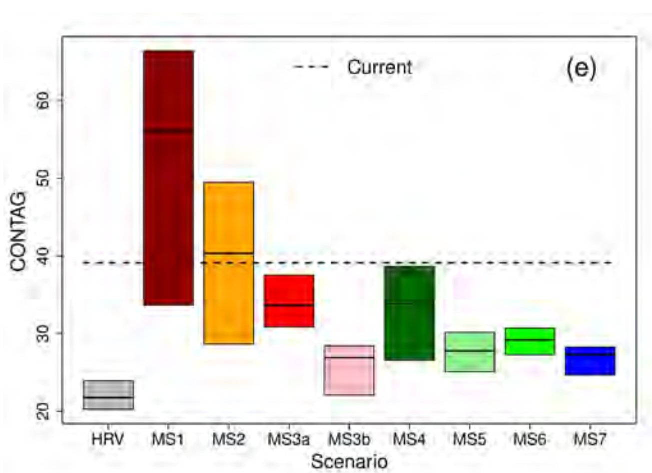


Figure 62—Range of variability in selected landscape metrics for the canopy cover class mosaic (none, open, moderate, and closed) for the simulated historical range of variability (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed (see *Methods* for description of scenarios): (a) area-weighted mean patch size, (b) area-weighted mean shape index, (c) area-weighted mean core area index, (d) mean patch size, and (e) contagion (see *Methods* for description and units for each landscape metric). Box represents the 5–95th percentiles, solid horizontal line the 50th percentile, and dashed horizontal line the current landscape condition.

As with the developmental stage mosaic, compared to the no treatment scenario our final scenario involving moderately intensive mechanical and prescribed fire treatments produced considerably less variability in the canopy cover mosaic over time (fig. 62). Moreover, the large canopy cover patches were considerably smaller with less core area than under the no treatment scenario, resulting in significantly less contagion. In addition, our final scenario produced much greater fine-scale heterogeneity than the no treatment scenario, as exemplified by the mean patch size metric.

Overall, the vegetation treatments in our final scenario moved the current landscape much closer to the HRV in the configuration of the canopy cover mosaic, although most of the landscape metrics fell short of closely emulating the HRV. In particular, the large patch structure of the canopy cover mosaic was smaller than under the HRV, but the patches were less complex geometrically. They contained a greater proportion of core area, creating a more contagious canopy cover mosaic than under the HRV. Larger, geometrically more complex treatment units embedded with an increased number of small patches of varying canopy cover classes would be likely to move our final scenario to within the HRV in all aspects of landscape configuration. It is perhaps not too surprising that only the prescribed fire-only scenario employing "hotter" burns (MS3b) closely emulated the HRV in most configurational aspects of the canopy cover mosaic, because this is the only scenario using approximately the same disturbance regime as the HRV. However, it is important to note that our final scenario moved the current landscape very close to the HRV but with considerably less area treated (MS7 = 22,167 hectares [54,775 acres] vs. MS3b = 34,178 hectares [84,454 acres]).

Seral Stage Dynamics

A complete summary of the landscape metrics by scenario for the seral stage mosaic is presented in table D9 in Appendix D. Here we provide only a brief summary of the major results, as illustrated by a smaller set of the metrics.

As with the developmental stage and canopy cover mosaics, compared to the HRV the no treatment (MS1) scenario produced considerably less spatial heterogeneity in the seral stage mosaic (fig. 63). Similarly, the active management scenarios varied considerably in how well they emulated the HRV in both coarse- and fine-grained spatial heterogeneity. As with the developmental stage mosaic, our final scenario (MS7), in particular, did well in emulating both the coarse- and fine-grained canopy cover mosaic of the HRV (fig. 63). In contrast to the results for the canopy cover mosaic, with the seral stage mosaic our final scenario was superior to the prescribed fire-only scenario involving "hotter" fires (MS3b).

These differences among scenarios are reflected well in the landscape metrics (fig. 64). As with the developmental stage and canopy cover mosaics, compared to the HRV the coarse patch structure was much larger and the landscape was more contagious under the no treatment scenario, with the area-weighted mean patch size as much as 50 times greater and the contagion index 2 to several times greater than that produced under the HRV. This simplification in landscape pattern resulted in roughly four to five times more core area under the no treatment scenario. In addition, the fine-scale heterogeneity was considerably less pronounced under the no treatment scenario, as exemplified by a several-fold increase in the mean patch size. Overall, the no treatment scenario produced a much simpler seral stage mosaic than the HRV, and one dominated by late-development, closed-canopy conditions, due to the reduced rate of disturbance. Perhaps as important, as with the developmental stage and canopy cover mosaics, the seral stage configuration fluctuated much more dramatically over time (i.e., greater range of variability) under the no treatment scenario than under the HRV.

As with the developmental stage and canopy cover mosaics, our final scenario involving moderately intensive mechanical and prescribed fire treatments produced considerably less variability in the seral stage mosaic over time compared to the no treatment scenario. Moreover, the large seral stage patches were considerably smaller with less core area than under the no

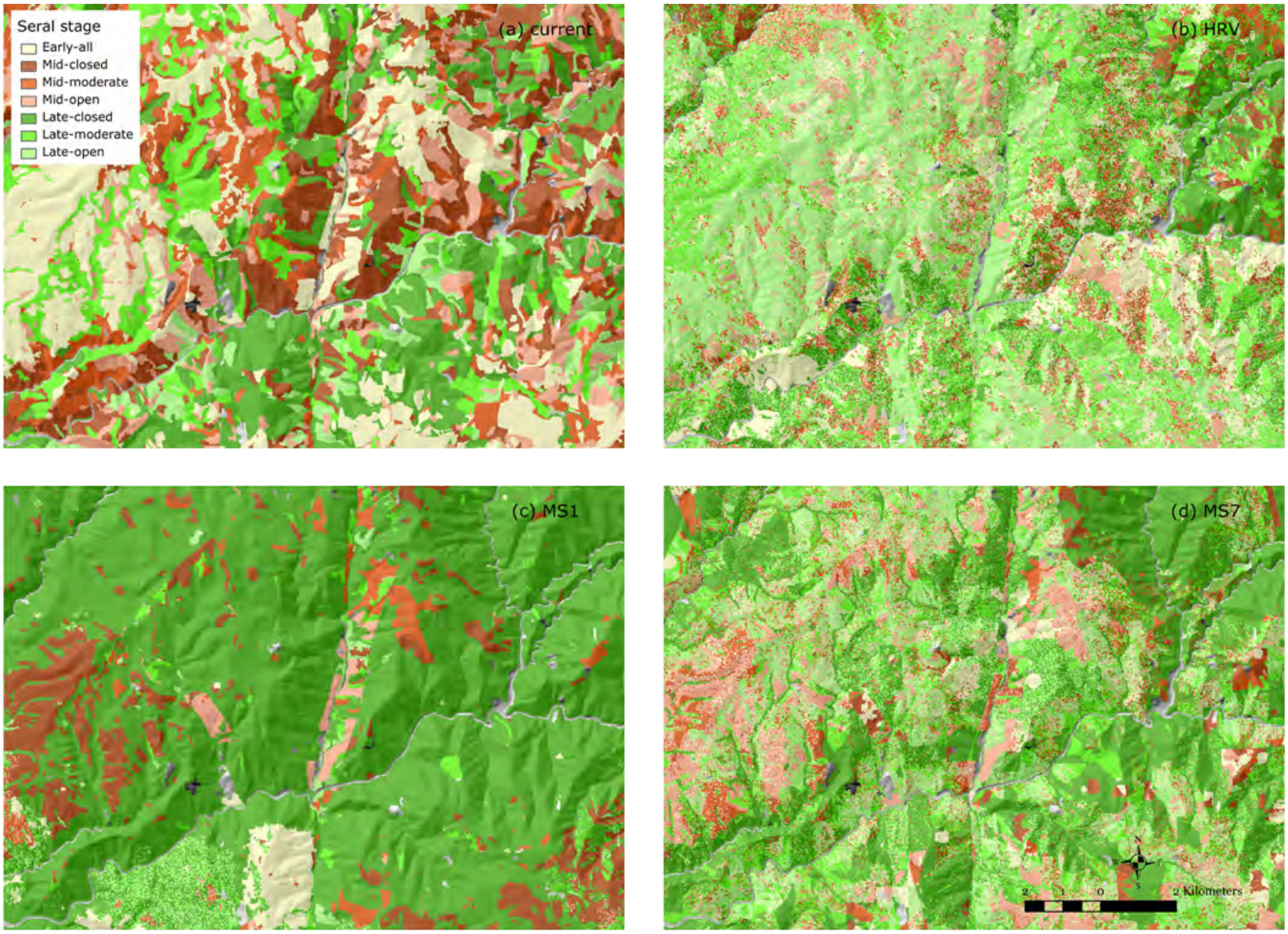
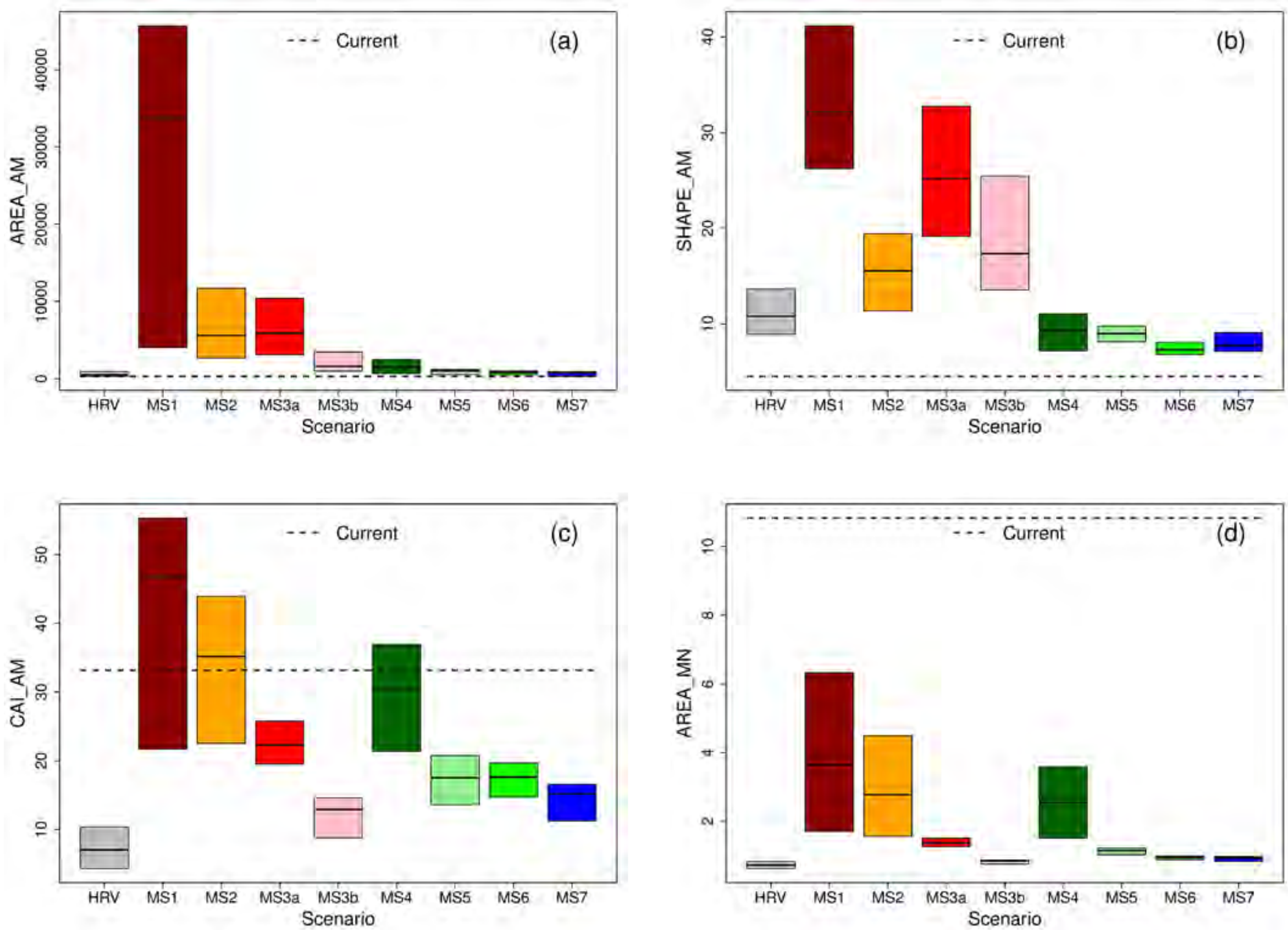


Figure 63—Snapshots of the vegetation seral stage mosaic for (a) the current landscape and the last timestep of the simulated (b) historical range of variability (ca. 1550—1850) and range of variability under (c) the no treatment scenario (MS1), representing a modified wildfire regime without vegetation treatments, and (d) our final scenario (MS7), representing a modified wildfire regime combined with moderately intensive mechanical and prescribed fire vegetation treatments. Snapshots are shown here for a randomly selected location in the upper Yuba River watershed and the last timestep of the respective simulations.

treatment scenario, resulting in significantly less contagion. In addition, our final scenario produced much greater fine-scale heterogeneity than the no treatment scenario, as exemplified by the mean patch size metric.

Overall, the vegetation treatments in our final scenario emulated the HRV in seral stage configuration reasonably well. Although the larger, matrix-forming patches were slightly less complex geometrically, resulting in proportionately more core area, the overall configuration of the seral stage mosaic was remarkably close to the HRV.

These patterns were also generally true for the landscape mosaic defined on the basis of unique combinations of cover type and seral stage—the most refined thematic resolution that we have available. The detailed results are available in table D10 in Appendix D. Naturally, given the much finer thematic resolution of the cover-seral stage mosaic, the grain of the patch mosaic was much finer across all of the scenarios (fig. 65). Nevertheless, the relative comparison among scenarios was essentially the same. The range of variability for many of the landscape metrics under our final scenario was similar to or overlapped that of the HRV scenario, indicating that the vegetation treatments were able to create patterns roughly comparable to that of the HRV even though the landscape composition differed between scenarios, as described previously.



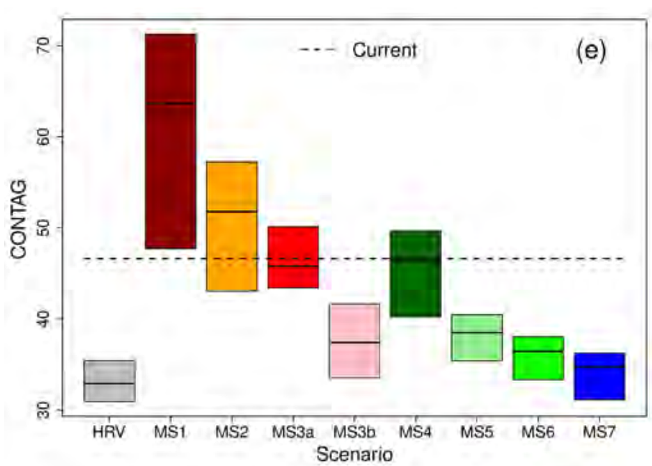


Figure 64—Range of variability in selected landscape metrics for the seral stage mosaic (see text for classes) for the simulated historical range of variability (ca. 1550—1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2—MS7) in the upper Yuba River watershed (see *Methods* for description of scenarios): (a) area-weighted mean patch size, (b) area-weighted mean shape index, (c) area-weighted mean core area index, (d) mean patch size, and (e) contagion (see *Methods* for description and units for each landscape metric). Box represents the 5—95th percentiles, solid horizontal line the 50th percentile, and dashed horizontal line the current landscape condition.

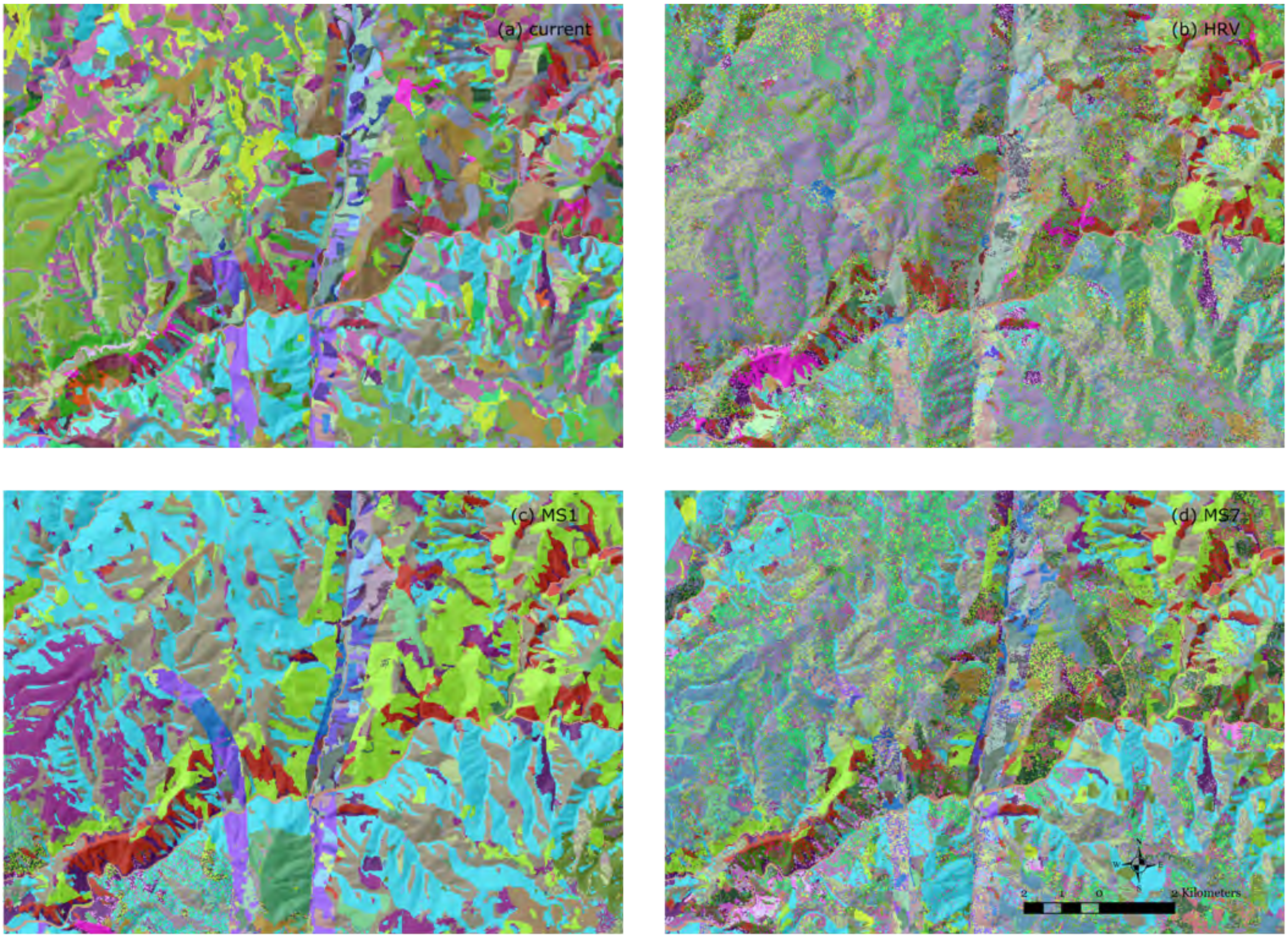


Figure 65—Snapshots of the vegetation cover type and seral stage mosaic (without a legend due to the number of classes) for (a) the current landscape and the last timestep of the simulated (b) historical range of variability (ca. 1550—1850) and range of variability under (c) the no treatment scenario (MS1), representing a modified wildfire regime without vegetation treatments, and (d) our final scenario (MS7), representing a modified wildfire regime combined with moderately intensive mechanical and prescribed fire vegetation treatments. Snapshots are shown here for a randomly selected location in the upper Yuba River watershed and the last timestep of the respective simulations.

MAJOR FINDINGS AND MANAGEMENT IMPLICATIONS

Our intent in this section is to provide a synopsis of what we learned from this project in the form of major "take-home" lessons for public land management professionals. We emphasize general findings that pertain to the landscape as a whole, as derived from results pooled across cover types. Specific findings pertaining to individual cover types are not covered in this section due to the excessive detail required, except as used to illustrate general findings. Readers seeking these more detailed cover type findings are referred to the detailed *Results* section and Appendix B.

We base our major findings and their management implications on the underlying assumption that the historical range of variability (HRV) is a useful reference for evaluating the ecological condition of the current landscape (i.e., current departure). Accordingly, we posit that native biodiversity is well adapted to the fluctuating ecological conditions of the historical reference period and that any significant departure from the HRV is therefore likely to have significant ecological consequences to native biodiversity. We also posit that conditions close to the HRV are most likely to maximize ecological integrity, which is a major focus of Forest Service management. Consequently, if management goals include maintaining native biodiversity and maximizing ecological integrity, the HRV may provide useful guidance to inform the description of desired future conditions. Although there are always socioeconomic, political, and even ecological (e.g., changing climate) reasons for establishing desired future conditions that do not closely conform to the HRV, we posit that moving the current landscape toward the HRV offers the best chance of maintaining the ecological integrity and native biodiversity of the landscape.

Major Findings

1. The study landscape during the historical reference period was best characterized as a shifting mosaic of vegetation types and conditions.

One of the most useful outcomes of this project is a robust depiction of the landscape as a constantly shifting mosaic of vegetation composition and structure occurring at multiple scales that provides a clear example of the range of variability concept. Figure 66 depicts the historical landscape as a shifting mosaic of vegetation developmental stages (nonseral, early, mid-, and late development), which can be illustrated equally well for the other landscape definitions (e.g., canopy cover classes, seral stages).

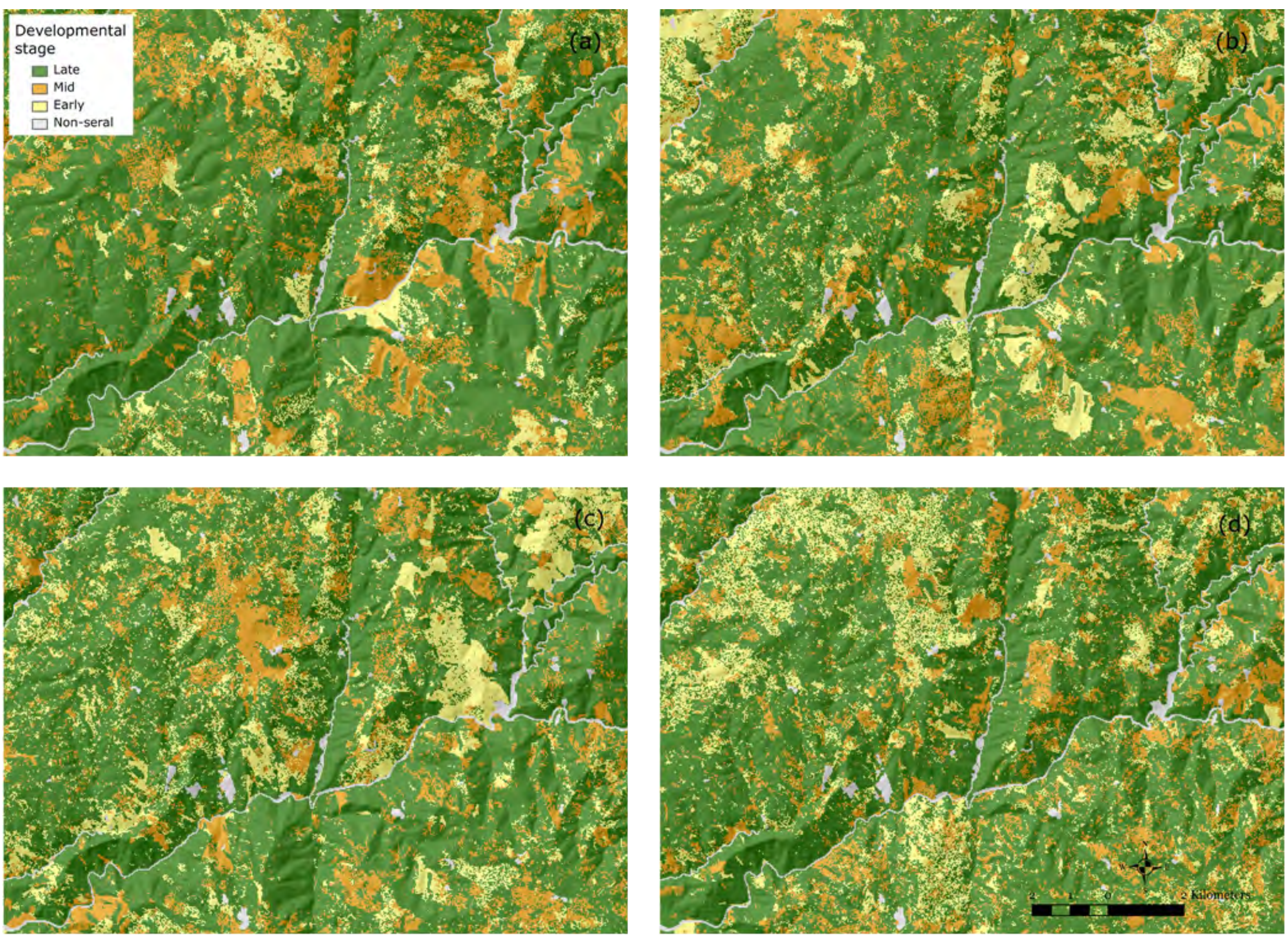


Figure 66—Snapshots of the vegetation developmental stage mosaic taken at (a–d) four different (random) timesteps of the simulated historical range of variability (ca. 1550—1850) for a randomly selected location in the upper Yuba River watershed.

Management Implications

Although this shifting mosaic in vegetation composition and structure is simply a reflection of the spatially explicit simulation of stochastic disturbance and succession processes (and thus not too surprising), it nonetheless illustrates and highlights the dynamic nature of the landscape to the public, which often perceives landscapes as static. Communicating this information to the public is critically important because it helps to build understanding and support for disturbance (both natural and anthropogenic) as a positive force for maintaining resilient landscapes that sustain native biodiversity and ecological integrity.

2. During the historical reference period, the study landscape was subject to a remarkably high wildfire disturbance rate.

Another important outcome of this project is the depiction of how prevalent wildfire was during the historical reference period. Under the HRV, the percentage of the landscape eligible to burn (i.e., supporting vegetation) that burned every 5 years averaged about 18 percent (~30,000 hectares [74,130 acres] of the 174,830 hectares [432,005 acres] eligible to burn). But this proportion varied dramatically over time, ranging from less than 1 percent (~100 hectares [250 acres]) to almost 74 percent (~129,000 hectares [319,000 acres]) (fig. 26), driven largely by fluctuations in climate and vegetation conditions. This translates to roughly 3.5 percent of the landscape, on average, burning every year. Another way of looking at this is that in any given 5-year period there was a 63-percent chance of burning more than 10 percent of the eligible landscape and a 4-percent chance of burning more than 50 percent of the eligible landscape.

The disturbance rate resulted in a **fire rotation period** (FRP), or the time required to burn a cumulative area equal to the project area, of 29 years. Note that this is equivalent to the average point-specific **fire return interval** (FRI), or the average (expected) time between fires at a single point on the ground. The average FRI is often much longer than the composite fire return intervals (for varying units of space) as often reported in the literature. Importantly, even though the overall FRP was 29 years, the realized average FRI to points on the ground varied dramatically across the landscape, reflecting spatial variability in vegetation and terrain (fig. 29).

The percentage of high-mortality fire (>75 percent canopy mortality) varied over time from a low of about 2 percent to a high of 24 percent, but averaged around 13 percent per timestep (fig. 31). The 95-percent range of variability was about 7 to 21 percent high mortality. This variability was driven primarily by the variation in climate over time, but it also reflected the interaction between climate and the changing seral stage composition over time.

Management Implications

These results quantify the very high rate of wildfire disturbance that was necessary to achieve the scientifically derived (largely from fire history studies) historical fire disturbance rates for this landscape. Although these rates were based on information in the fire history studies, their values may surprise the casual observer. The primary implications are as follows:

- Historically, wildfire was a dominant driver of the landscape dynamics, and therefore the local vegetation communities coevolved with wildfire and were presumably well adapted to a frequent fire regime. Consequently, it is reasonable to assume that major deviations in the historical fire regime are likely to have major ecological consequences. The highly modified contemporary fire regime resulting from a century of fire suppression and both past and present human land use is therefore likely to have significant ecological effects.
- Given the preceding implication, any desired future conditions intended to restore the

historical landscape structure and function will require the extensive use of fire and fire surrogates, ideally involving prescribed fire or managed wildfire for resource benefit—most likely both. Of course, the magnitude of fire needed to restore the historical landscape structure (see following) would be challenging to implement given today's socioeconomic and political constraints. Unfortunately, assuming those constraints remain fixed, silvicultural treatments alone would almost certainly be insufficient to restore the historical landscape structure.

3. The current landscape departs from the historical range of variability in the composition of the vegetation mosaic, and more so in some attributes than others.

A major outcome of this project is a detailed, specific, and quantitative description of the HRV and current departure in **landscape composition**—referring to the amount of each vegetation class without consideration of the spatial arrangement of the mosaic.

Under the HRV, the landscape exhibited very little variability in the composition of vegetation **developmental stages**, maintaining a nearly constant 10:20:70 ratio of early- to mid- to late-development stages. Although this ratio differed somewhat among cover types, reflecting differences in the prevalence of high-mortality (i.e., stand-replacing) fire and fire rotation periods, overall the landscape across all cover types was dominated by late-development vegetation. The current landscape deviates dramatically from this HRV, containing much more than the HRV in the early- and mid-development stages and much less than the HRV in the late-development stage (fig. 33). This departure undoubtedly reflects the human land use history of this landscape, including intensive timber harvesting on private lands, and past widespread timber harvesting on public lands in which the older, mature forest was extensively harvested during the early and mid-20th century. Other practices such as hydraulic mining created large areas of early-seral chaparral that stagnated in a shrub-dominated (i.e., early-seral) vegetation condition. In addition, the recent human-caused Pendola fire created large areas of early-seral vegetation. The legacy of these human land use practices and human disturbances is a landscape today that is dominated by early- and mid-seral forest.

Under the HRV, the percentage of the landscape in each **canopy cover class** was variable but stable around a 38:24:37 ratio of open to moderate to closed canopy. In general, the landscape fluctuated over time between having an approximately equal mixture of open, moderate, and closed canopy and one slightly dominated by either open canopy or closed canopy (fig. 36). The current landscape as a whole does not differ much from this HRV, falling within the 95-percent range of variability for all three canopy cover classes (fig. 37). At first, this result seems somewhat surprising given the popular belief that the current landscape has an uncharacteristic predominance of closed-canopy forest. However, it is important to recognize that this result applies to the landscape as a whole, pooled across all cover types and ownerships, which is being driven by the excess of early-development stands (which are classified as open canopy) in the current landscape. This result masks some important differences among individual cover types and developmental stages, as follows.

First, the HRV distribution of canopy cover classes varied substantially among cover types, with the xeric and ultramafic cover types typically maintaining a preponderance of open- and moderate-canopy conditions and the mesic cover types typically maintaining a preponderance of closed-canopy conditions, although this was not true for all cover types. Similarly, the magnitude of current departure also varies considerably among cover types, with some cover types exhibiting little departure (e.g., Mixed Evergreen Forest), others exhibiting moderate departure (e.g., Sierran Mixed Conifer Forest), and still others showing major departure (e.g., Red Fir – Mesic).

Second, this result for the landscape as a whole is masking important canopy cover departures occurring within individual developmental stages (fig. 39). In particular, in late-development stands, the proportional distribution of canopy cover classes deviates considerably from the HRV. Specifically, under the HRV the ratio of open to moderate to closed canopy in the late-development stage was roughly 1:1:1.5, whereas in the current landscape the ratio is roughly 1:4:6. In other words, within the late-development stage the current landscape contains far too much in the moderate- and closed-canopy condition relative to the open-canopy condition. In addition, canopy cover departure within individual developmental stages is more apparent in some cover types than others. Thus, despite the result for the landscape as a whole, the results by cover type and developmental stage suggest that for several of the major cover types the current landscape contains relatively too much closed and moderate canopy and too little open canopy.

Management Implications

These results indicate that the current landscape composition departs dramatically from the HRV in developmental stage distribution and, depending on the cover type and developmental stage, departs considerably in canopy cover class distribution as well. These findings have important management implications, as follows.

- Restoring the HRV in the landscape composition of vegetation developmental stages would require the following:
    - Decreasing the amount of early-development vegetation—moving from the current approximately 20 percent of the landscape to about 5 to 15 percent of the landscape.
    - Decreasing the amount of mid-development vegetation—moving from the current approximately 50 percent of the landscape to about 15 to 25 percent of the landscape.
    - Increasing the amount of late-development vegetation—moving from the current approximately 35 percent of the landscape to about 65 to 75 percent.
- Achieving a restoration of the HRV would require allowing existing mid-development stands to succeed to late-development conditions, which could take several decades. But it could also be facilitated by the following management actions:
    - Limit the occurrence of high-mortality disturbances by controlling the amount of stand-replacing silvicultural treatments (e.g., group cuts) and managing fuels to reduce the future occurrence of high-mortality wildfire. Wildfire will continue to create early-seral conditions on the landscape, so the focus on national forest lands should mostly be the provision of the late-development vegetation.
    - Promote (with the intention of accelerating) the succession of early- and mid-development stands to late-development stage structure via appropriate silvicultural treatments (e.g., thinning to promote diameter growth) and managing fuels to minimize the risk of high-mortality wildfire.
- Restoring the HRV in the landscape composition of canopy cover classes would require the following:
    - Examining canopy cover departure for individual cover types and developmental stages, because the landscape pooled across all cover types and developmental stages exhibits no apparent departure. In general, the results by cover type and developmental stage suggest that for several of the major cover types (e.g., Sierran Mixed Conifer – Mesic, the dominant cover type) the current landscape contains relatively too much closed or moderate canopy and too little open canopy, and this is especially true in the late-development stage.
- Achieving this goal through active management would require judicious application of appropriate silvicultural treatments in each cover type. Moreover, it would require

examing current departure for the entire seral stage distribution (not just a single seral stage), and any management actions aimed at adjusting the seral stage distribution would also need to account for the expected successional changes over time. For example, the HRV seral stage distribution and current departure in the Sierran Mixed Conifer – Mesic cover type is shown in figure 67. Given the apparent departure of each seral stage and the expected successional changes over the next several decades (i.e., succession of early to mid-, and mid- to late development), mechanical thinning and prescribed fire treatments should be focused on maintaining the open- and moderate-canopy cover in the mid-development stands, while over time succession should rectify the departures in the late-development stage. Similarly, given the expected succession of early-seral stands to mid-development closed-canopy stands on private lands, national forest lands should focus treatments in early-seral stands on maintaining open-canopy conditions as these stands succeed to mid-development.

4. The current landscape departs from the historical range of variability in the spatial configuration of the vegetation mosaic, and more so in some attributes than others.

One of the unique outcomes of this project is a detailed, specific, and quantitative description of the HRV and current departure in **landscape configuration**—referring to the spatial pattern of the vegetation mosaic. Most past efforts to quantify the HRV and current departure have focused solely on landscape composition and ignored the importance of landscape configuration. Here, because we used a spatially explicit landscape disturbance-succession model, we were able to quantify landscape configuration as well.

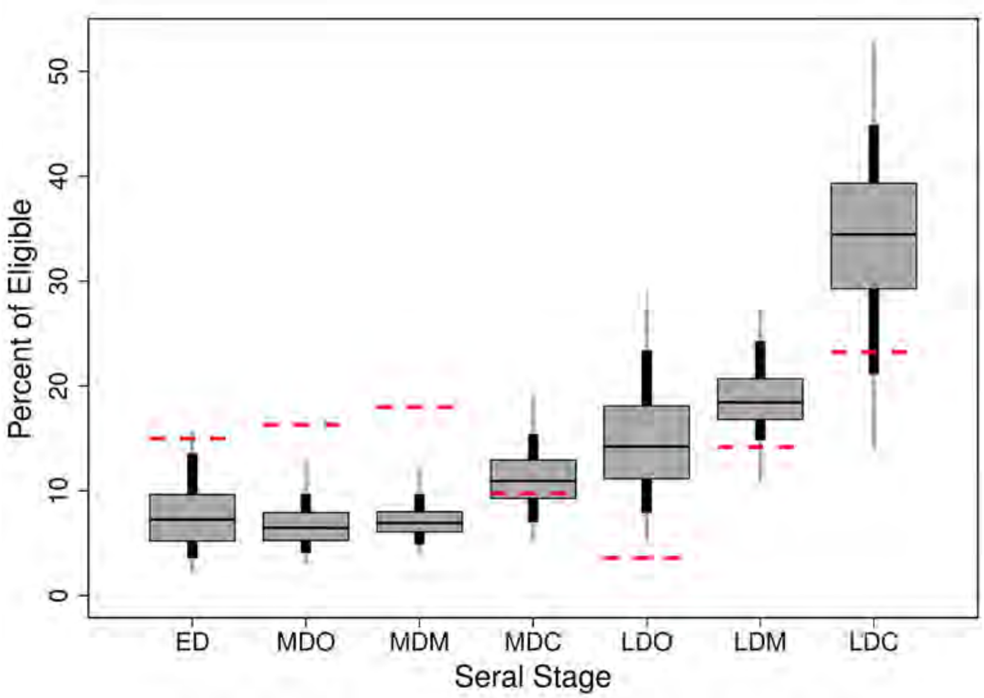


Figure 67—Range of variability in vegetation seral stages (ED = early all, MDO = mid-development open-canopy, MDM = mid-development moderate-canopy, MDC = mid-development closed-canopy, LDO = late-development open-canopy, LDM = late-development moderate canopy, and LDC = late-development closed-canopy) in the Sierran Mixed Conifer – Mesic cover type for the simulated historical range of variability (HRV) (ca. 1550–1850) and current landscape in the upper Yuba River watershed. Boxes represent the interquartile range (25th–75th percentiles) of the HRV; the median is the dark horizontal line in the middle of the box. Thick, solid vertical lines represent the 5th–95th percentiles of the HRV, and the thin, gray vertical extensions represent the full range of the simulated HRV. Dashed, red horizontal lines represent the current condition of the landscape.

Under the HRV, the general picture that emerges of the shifting landscape mosaic is as follows:

- The landscape maintained a matrix of late-development vegetation, with individual matrix patches extending for up to 10 kilometers (6 miles) and encompassing tens of thousands of hectares.
- Within these matrix-forming late-development patches there existed large patches of either open- or closed-canopy forest that extended for up to a few kilometers and encompassed up to several thousand hectares. The larger patches of open canopy mostly (but not exclusively) existed on steeper, south- and west-facing, upper slopes, and the larger patches of closed canopy mostly (but not exclusively) existed on gentle, north- and east-facing, lower slopes and valley bottoms.
- Over time, the late-development matrix shifted from being slightly dominated by patches of closed-canopy forest to being dominated by patches of open-canopy forest and back again, but at no time was the matrix composed of mainly one canopy cover class. Indeed, our simulations suggest the landscape as a whole probably never fell below about 25–30 percent in each of the three canopy cover classes. These fluctuations were probably driven by periodic large disturbance events interspersed with longer periods of recovery.
- The matrix-forming late-development vegetation and the extensive patches of open or closed canopy embedded within the matrix were geometrically complex; they contained highly convoluted edges and were themselves embedded with many small and irregularly shaped patches of differing developmental stages and canopy cover classes. Indeed, the late-development matrix maintained only about 30–40 percent in core area (defined as the interior of patches farther than a specified depth of edge effect from the patch boundary, with edge depths appropriately defined; a detailed technical report is forthcoming), and the large open- or closed-canopy patches maintained only about 15–25 percent in core area. Thus, most of the landscape was affected by the edges formed by adjacent patches of different developmental stages and canopy cover classes.
- In comparison to the developmental stage mosaic, the canopy cover mosaic was less dominated by extensive, matrix-forming patches (e.g., almost an order of magnitude smaller area-weighted mean patch size) and exhibited a much greater degree of fine-scale spatial heterogeneity (e.g., almost a twofold greater density of edges). Thus, the landscape overall exhibited much less contagion (i.e., overall aggregation or clumpiness) in canopy cover than in developmental stage. The greater degree of spatial heterogeneity in canopy cover was undoubtedly due to the preponderance of wildfire disturbances that resulted in partial overstory mortality without changing the developmental stage of the residual canopy. For example, most of the area burned in wildfires had low mortality and did not undergo stand initiation; instead, wildfires more often acted to thin the overstory and create more moderate- and open-canopy conditions, resulting in a spatially heterogeneous mosaic in canopy cover but not changing the overall dominance by late-development vegetation.
- Although this characterization helps to describe the landscape pattern at any one point in time, it is important to recognize that as patches of early-seral forest succeeded to mid- and then late-development stands, the late-development matrix shifted in spatial configuration over time. Similarly, as patches of open canopy sometimes succeeded to moderate and then closed canopy after escaping subsequent wildfires for a prolonged period, the larger patches of open- or closed-canopy forest embedded within the late-development matrix also shifted in configuration over time. Moreover, although these general patterns held true for the landscape as a whole, these patterns varied somewhat across the landscape in relation to the distribution of major cover types.

The current landscape deviates considerably from the HRV picture described, but more so in some attributes than others. Compared to the HRV, the larger developmental stage patches in the current landscape are much too small, less extensive, and less geometrically complex (resulting in a much greater interior-to-edge ratio), and have slightly less contrast (i.e., the magnitude of differences in vegetation structure) along the edges (fig. 59). In addition, the developmental stages are more interspersed today than under the HRV, probably due to the more regular distribution of anthropogenic disturbances (e.g., timber harvesting) than occurs with natural disturbances. The current landscape also has notably less fine-scale heterogeneity. We must note, however, that it is unclear how much of this departure is real versus an artifact of the modeling despite our attempts to minimize these modeling artifacts by coarsening the simulation output grids to more closely match the resolution of the input grids. Overall, therefore, the most notable and reliable departure is the absence of very large, extensive, and geometrically complex matrix-forming patches of late development in the current landscape.

The magnitude of current departure for the canopy cover and seral stage mosaics is less pronounced. Compared to the HRV, the larger canopy cover and seral stage patches in the current landscape are somewhat smaller and less extensive but nonetheless still within the HRV (figs. 61, 63). However, these patches are much less geometrically complex than under the HRV, resulting in a greater percentage of the patches in core area. In addition, the contrast along edges is greater in the current landscape and the canopy cover and seral stage classes are more interspersed than under the HRV, again probably owing to the distribution of anthropogenic disturbances and management practices. As with developmental stage, the current landscape also has notably less fine-scale heterogeneity in canopy cover and seral stage, but again it is unclear how much of this departure is real versus an artifact of the modeling. Overall, therefore, departure in the canopy cover and seral stage mosaics is less clear. Most of the observed major departure is in the fine-scale heterogeneity that we cannot be certain is real given the limitations of the input spatial data layers (although other considerations of Sierra Nevada mixed conifer forest have also focused on a modern lack of fine-scale heterogeneity, e.g., North et al. 2009; Safford and Stevens 2017).

Management Implications

The preceding results describe the ways in which the current landscape configuration departs from the HRV. These findings have important management implications, as follows.

- Restoring the HRV in landscape configuration would require the following:
    - Promoting the development of very large (~13,000–35,000 hectares) and extensive (~6–10 kilometers) matrix-forming patches of late-development stage vegetation.
    - Creating geometrically very complex matrix-forming patches resulting in about 30 to 40 percent in core area (i.e., interior forest environment). This could be achieved by creating small (~1–200 hectares; 2–500 acres), irregularly shaped patches of early-seral vegetation that would eventually succeed to mid-development forest, within and between these larger, matrix-forming late-development patches.
    - Creating relatively large (~1,500–7,500 hectares; 3,700–18,500 acres) and extensive (~2–4 kilometers; 1–2 miles), but not necessarily matrix-forming, patches of both open- and closed-canopy forest well interspersed with each other and with moderate-canopy cover.
    - Creating geometrically very complex large patches of open- and closed-canopy forest resulting in about 15 to 25 percent in core area (i.e., interior forest environment).
    - Within and between these large canopy cover patches, creating much fine-scale spatial heterogeneity in the canopy cover mosaic.

- Restoring the HRV in landscape configuration is likely to take a great deal of time (decades), effort (management), and creative landscape design. In the absence of natural disturbances to recreate the spatial and temporal heterogeneity in landscape structure, it would require substantial active management as a surrogate, which could be facilitated by the following management actions:
    - Locating vegetation treatments that promote late-development vegetation (e.g., thinning, fuels reduction in mid-development stands) so as to eventually connect existing late-development stands and create larger, continuous stands of late-development vegetation to form a matrix.
    - Within and between these matrix-forming late-development patches, creating numerous small patches of early- and mid-development stands of varying sizes and shapes. The most practical way to do this would be to create small irregularly shaped patches of early development, especially embedded within mid-development stands. However, given the current surplus of early-development vegetation, to do so would exacerbate the current departure in the amount of early-development vegetation. Thus, it would be more prudent in the short term to design silvicultural treatments in mid-development stands aimed at promoting late-development conditions. This step would be intended to eventually create a matrix of late-development stands embedded with many small irregularly shaped residual patches of dense, mid-development forest.
    - Locating vegetation treatments that create large and geometrically complex patches of open- or closed-canopy forest where these conditions are most likely to occur under a natural disturbance regime. In this regard, a map of the average percent canopy cover under the HRV (fig. 41) could provide a useful spatial template for where to promote the larger patches of open- and closed-canopy forest through active management.
- Our modeling suggests (but does not confirm) that the HRV landscape contained far more fine-scale heterogeneity than exists today. This was consistent regardless of how we defined the landscape (i.e., based on developmental stage, canopy cover, seral stage, or even unique combinations of cover type and seral stage). This agrees with other recent studies of forest structural conditions, such as North (2012), North et al. (2009), and Safford and Stevens (2017). Emulating this fine-scale heterogeneity would require some changes in common vegetation treatment prescriptions. In particular, prescribed fire and low- and moderate-severity managed wildfire, with or without mechanical treatment of fuels, are the treatment types most likely to increase fine-scale heterogeneity. Thus, given the area affected, modifying prescribed fire prescriptions to promote variable overstory mortality is likely to have the greatest effect on increasing the fine-scale heterogeneity in the vegetation mosaic.
- Overall, emulating the HRV in landscape configuration through active forest management would require translating the strategic guidance provided by this study into a spatially and temporally explicit landscape design that specifies what treatments to do where and when. In particular, the landscape design would specify the location of treatments (and the type of treatments needed) to promote the creation of the late-development matrix and the large open- and closed-canopy patches embedded within the matrix that conforms to the terrain and existing distribution of vegetation types.

5. Scenario analysis revealed the comparative effects of alternative management strategies on landscape composition and configuration.

In this study we demonstrated how scenario analysis can be used to examine the potential effects of alternative management strategies on landscape structure. Not only can scenario analysis inform us as to the potential consequences of a no treatment or "business as usual" management strategy, but it also allows us to derive management scenarios that strive to achieve detailed, specific, and quantitative desired outcomes. In this regard, we examined eight different management scenarios, each of which was simulated for 100 years. At the end of the 100 years we summarized the variability in landscape structure among 20 replicate runs.

One of the scenarios (MS1) explored a no treatment alternative involving only aggressive fire suppression, reflecting the modern fire regime. A second scenario (MS2) explored a "business as usual" alternative in which treatment intensity and types followed the existing land management plan (LMP) guidelines. The remaining six scenarios explored more intensive treatment options that varied in the amounts and types of treatments, ranging from prescribed fire only (MS3a,b) to varying mixtures of mechanical and prescribed fire treatments (MS4–MS7). These latter scenarios were devised to explore various "what if" alternatives that sought to determine: (1) What management actions would be required to move the current landscape to within the HRV in landscape composition and configuration, and (2) what mixture of mechanical and prescribed fire treatments would best achieve this goal. Although we realize that these latter scenarios far exceed the current level of active management on public lands, and may seriously challenge what is currently deemed socially and politically acceptable, we believe that they provide a useful barometer for how much disturbance is needed to move the current landscape closer to the HRV.

Our results demonstrated that both the no treatment scenario and the current LMP (or "business as usual") scenario not only failed to move the current landscape closer to the HRV in landscape structure in most attributes, but actually caused the current landscape to move even further away from the HRV in many attributes. The no treatment scenario did allow the landscape to restore a more "natural" distribution of developmental stages, but ultimately it produced much less in the early- and mid-development stages and much more in the late-development stage compared to the other scenarios (figs. 56, 59). This scenario also moved the current landscape furthest away from the HRV distribution in canopy cover classes, producing far less open- and moderate-canopy forest and far more closed-canopy forest (figs. 57, 61). In addition, this scenario resulted in a greatly simplified (i.e., more homogeneous) landscape configuration that differed dramatically from the HRV, as represented by any of the landscape definitions and landscape metrics (e.g., fig. 64). None of these outcomes was surprising given the dramatic reduction in wildfire occurrence as the sole source of disturbance. The "business as usual" scenario involved 3,451 hectares (8,524 acres) of treatments per 5-year timestep, representing a treatment rate of 2.78 percent of the national forest land area every 5 years, or 0.5 percent per year. This relatively low intensity of treatments in addition to the reduced wildfire occurrence did result in moving the current landscape closer to the HRV, but ultimately it failed to closely emulate the HRV in most attributes.

The higher intensity treatment scenarios (MS3–MS7) were comparatively more successful in moving the current landscape closer to the HRV and produced several important findings:

- The intensity and types of treatments affected how well a scenario emulated the HRV in each of the landscape attributes. For example, all of the higher intensity treatment scenarios did a reasonably good job of emulating the HRV in the distribution of developmental stages (figs. 56, 59), but they varied considerably with respect to most other attributes (e.g., figs. 57, 61, 64).
- The prescribed fire-only scenarios (MS3a,b) required a much greater treatment intensity than the scenarios involving a mixture of mechanical and prescribed fire treatments (MS4–MS7) to achieve a similar outcome, and the "hotter" prescribed fires (MS3b) did a much better job of emulating the HRV than the "cool" prescribed fires (MS3a) (figs. 59, 61, 64). Note that the "hotter" prescribed fires involved allowing three times as much canopy mortality than is typically prescribed.
- It is possible to achieve the desired outcome with lower treatment intensity through careful selection of treatment types and regimes. In general, our balanced and final

scenarios (MS6–MS7), which involve a suite of mechanical and prescribed fire treatments at the rate of 3.6–3.9 percent of the Tahoe National Forest treated per year did as well or better in emulating the HRV in most landscape attributes than the higher intensity scenarios (MS3 and MS5) treated at the rate of 5.0–5.5 percent of the Forest per year (figs. 59, 61, 64).

- It is possible to construct a management scenario that closely emulates the HRV in most attributes of landscape structure. Our final scenario was constructed after examining the results of the a priori scenarios and the results of our first attempt to design a scenario (MS6) that would emulate the HRV in all landscape attributes. Our final scenario involved a mixture of nine different treatment types, including "hotter" prescribed fires, in which the dynamic constraints and priorities were adjusted slightly to rectify the shortcomings of the "balanced" scenario (a detailed technical document is forthcoming). Although our final scenario did not perfectly emulate the HRV across all attributes (e.g., figs. 56–65), especially at the level of individual cover types (see tables D4–D10 in Appendix D), it came very close to doing so and thus represents an approximation of what it might take to move the current landscape close to the HRV. Moreover, it would certainly be feasible to further tune this scenario in order to home in on emulating the HRV closely in all landscape attributes, even at the level of individual cover types.

Management Implications

These findings have several important management implications:

- If the desired future condition is to move the current landscape closer to HRV, then the no treatment strategy is not an option. The modern fire regime alone, assuming continued effective fire suppression, is likely to eventually result in too much of the landscape in a late-development, closed-canopy seral stage and would almost certainly result in too little spatial heterogeneity compared to the HRV in landscape structure. Similarly, the "business as usual" strategy based on the current LMP is likely to fall far short of the goal of closely emulating the HRV. The relatively low rate of treatment under this scenario (0.5 percent per year), even in combination with the expected wildfire disturbances under the modern fire regime, falls far short of the rate of natural wildfire disturbance characteristic of the historical reference period. If we choose to adopt this management scenario, then we must be willing to accept dramatic departure from the HRV in many landscape attributes and accept the ecological consequences. Note also that our scenarios assume continuation in the current rate of success in suppressing fires and do not include insect outbreaks. Current trends in fire occurrence and severity and insect outbreaks suggest that the even greater forest densities and canopy cover that would occur under the no treatment and "business as usual" scenarios could ultimately lead to large losses of forest cover in high-severity disturbances.
- If prescribed fire treatments are to play an important role in the mixture of treatments used to restore the HRV in landscape structure, then we must recognize that "hotter" fires than are typical of current prescriptions are needed to create the spatial heterogeneity in developmental stage and canopy cover that is typical of the low- and moderate-severity fires common under the HRV. For example, in Sierran Mixed Conifer – Mesic forests, our "cool" burn scenarios allowed for about 3–5 percent canopy mortality, whereas our "hotter" burn scenarios allowed for about 6–15 percent canopy mortality. Although this falls short of what we estimated the mortality rate to be for wildfires under the HRV, it comes much closer to creating the fine-scale heterogeneity in developmental stage and canopy cover that was probably characteristic of the landscape under the HRV.
- Our scenario analysis demonstrates that active vegetation management involving a combination of mechanical and prescribed fire treatments has the potential to emulate

many aspects of landscape structure that would occur under a natural disturbance regime, but it would require a much higher intensity of treatment than we are accustomed to—perhaps as much as 10 times the current treatment rate. Although this is a highly ambitious goal given contemporary socioeconomic, political, and logistical constraints on planning and implementing vegetation treatments, it is nonetheless important to realize what it would take to meet the goal of emulating the HRV—even if we choose to do otherwise.

- Given the mixed ownership of our study landscape—in which 32 percent of the land is privately owned and managed—it is perhaps not realistic to believe that any public land management strategy could completely emulate the HRV in landscape structure. Indeed, given these constraints, it is in fact remarkable how well our final scenario did in emulating the HRV in landscape structure. Thus, land managers should perhaps not expect to completely emulate the HRV, if that is the ultimate goal, but instead strive to move the landscape steadily closer to the HRV. In addition, in designing the landscape to achieve desired future conditions, public land managers may want to account for the management occurring on private lands to the extent possible and strive to complement those activities. For example, it is reasonable to assume that in our study landscape the private industrial forest lands will continue to be managed to maximize economic returns from timber production. Managers of these lands are likely to continue to use clearcutting as the principal regeneration method and strive to maintain full stocking levels as stands grow to economic maturity. Consequently, we might expect the private industrial forest lands to sustain the level of mid-development closed-canopy forest (and some of the early-seral vegetation, where heavy brush control is not implemented) needed to emulate the HRV. Then management of public lands could focus on providing late-development and open-canopy conditions.

6. The quantitative approach used here demonstrates the feasibility of creating detailed, specific, and quantitative desired future conditions, and monitoring progress toward achieving those conditions.

The 2012 Planning Rule (NFMA, 2012 Planning Rule 2015) and the final planning directives in Forest Service Handbook 1909.12 (https://www.fs.usda.gov/detail/planningrule/home/?cid=stelprd3828310) are largely couched in an adaptive management framework requiring detailed, specific, and quantitative desired future conditions and periodic monitoring of progress toward achieving those conditions. Moreover, the planning directives recommend using "natural" range of variability (where "natural" is generally interpreted as some appropriately defined historical reference period, or an appropriate alternative) as the basis for establishing desired future conditions and using the composition and configuration of ecosystems (i.e., landscape structure) as key state variables (among others). Importantly, adaptive management requires that the desired future conditions be detailed, specific, and quantitative so as to allow for unambiguous effectiveness monitoring and feedback.

In this project, we used the HRV in several detailed, specific, and quantitative measures of landscape composition and configuration to describe the ecological conditions that are presumed to confer landscape ecological integrity and sustain native biodiversity. We used these measures to evaluate the current landscape condition relative to the HRV (i.e., current departure). In addition, we used the HRV in each of these measures to establish desired future conditions and then simulated alternative management strategies aimed at achieving these desired future conditions. Because these measures were detailed, specific, and quantitative, we were able to quantitatively evaluate the success of each management scenario in achieving the desired future conditions.

Although this exercise focused solely on landscape structure dynamics, and did not consider other important ecological variables (e.g., focal wildlife species, ecosystem services), it nonetheless demonstrates the feasibility of using a landscape disturbance-succession model to help inform the establishment of detailed, specific, and quantitative desired future conditions. Moreover, it demonstrates the feasibility and added value of using a spatially explicit landscape disturbance-succession model to quantify both landscape composition and configuration.

NEXT STEPS

In this project we demonstrated the practicality of using a spatially explicit landscape disturbance-succession model to characterize the historical range of variability in landscape structure and compare it to the current landscape (i.e., current departure) and several alternative management scenarios in the upper Yuba River watershed. Although these results are based on a model, and thus limited by the quality of the input data and modeling framework as discussed previously, we believe that these results are useful and can lead to more informed and better management. However, there are some important next steps to improve the quality and reliability of these results and to extend their applicability, as follows:

- One of the obvious next steps is to expand the geographic scope of the modeling to the entire district, forest, or other ecological or administrative units. Strictly speaking, because landscapes are idiosyncratic (i.e., have unique ecological settings and history), our specific results pertain only to the upper Yuba River watershed project area. However, our general findings certainly pertain to other similar surrounding landscapes and probably can be safely extrapolated to some extent. Nevertheless, to the extent that detailed quantitative results are desired for other geographies, a separate modeling exercise should be undertaken. Fortunately, much of the work to develop spatial input data layers and to parameterize the model has been done and can easily be adapted to other nearby similar ecological settings.
- Another important next step is to expand the ecological scope of the modeling to include future climate and insect outbreaks in combination with vegetation management. We conducted some preliminary modeling of future climate impacts on range of variability in landscape structure, but not in combination with vegetation management (Mallek 2016). In addition, for this study we focused exclusively on wildfire as the dominant disturbance process, but insect outbreaks may increasingly affect vegetation patterns in the future (Bentz et al. 2010). Despite great uncertainty in how wildfire and insect disturbance regimes may vary under future climate conditions, which presents some difficult modeling challenges, this remains an important topic for further investigation.
- A practical next step is to translate the strategic findings of this study into a landscape design to guide project-level planning within the landscape. Specifically, we described the HRV in landscape composition and configuration and current departure for the upper Yuba River watershed, and made several management recommendations for moving the current landscape to its HRV. These general guidelines must be translated into a spatially and temporally explicit design for what treatments to do where and when. This landscape design would provide the guidance needed for project-level layout and implementation of treatments aimed at restoring the HRV for the landscape as a whole.
- One of the greatest limitations of the current analysis is the relatively poor spatial resolution of the spatial input layers pertaining to vegetation cover type and seral stage. In particular, the relatively coarse spatial resolution of the seral stage data makes it difficult to compare the spatial configuration of the current landscape (which is relatively coarse) to that generated by the simulation model (which is relatively fine). This compromises the interpretation of current departure, which relies on the comparability of the input layers

(to characterize the current landscape) and the model output layers (to characterize range of variability). This is especially problematic for comparisons of spatial patterns—most notably measures of fine-scale heterogeneity; hence our caution in overinterpreting departure for the landscape configuration metrics that measure fine-scale heterogeneity. Although we took steps to minimize this bias by rescaling the simulation output grids—dissolving patches below a minimum size—to more closely match the input grids, our adjustment was not entirely satisfactory. One potential solution to this problem is to create an accurate fine-resolution vegetation map by using a combination of spectral and LiDAR data to serve as the input layers for the current landscape. Indeed, such a product was recently developed for the Tahoe National Forest. The analyses we conducted in this project could be replicated with the new and improved vegetation layers. Unfortunately, nothing is as simple as it sounds. There is not a one-to-one crosswalk between vegetation seral stages (or stand structures) as currently defined and used in this project and those defined in the new and improved vegetation layers. Therefore, substantial work would be required to parameterize the model for these new cover type and seral stage descriptions, essentially developing new state-and-transition models for each cover type.

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APPENDIX A: Spatial Data Layers

RMLands uses raster GeoTiffs (.tif files) as its data structure. Rasters are based on uniform square units called cells (or pixels). Each cell represents an actual portion of geographic space. In this application, we used the Universal Transverse Mercator projection Zone 10 North. The extent of a raster is rectangular although the project area was not. Cells outside of the buffered project area were assigned a null value. For this project, each grid cell was 30 meters (100 feet) on a side (i.e., 900 square meters or 0.09 hectares; 10,000 square feet or 0.2 acres), and the input grid measured 2,910 pixels × 2,245 pixels.

RMLands requires that all input grids be perfectly aligned. We accomplished this by setting the Extent and Snap Raster to the same parameters whenever we manipulated the layers in ArcMap. This "base" spatial layer was created by taking the primary elevation layer used on the Tahoe and Plumas National Forests, resampling it to a 30-meter grid, and clipping its extent to match that of the buffered project area. Each cell was assigned a single class value, where valid class values were positive nonzero integers. Integer values were mapped to more descriptive class names by using comma-separated value files with names identical to the grid name. All grids were created in ArcMap and saved as GeoTiff files before being loaded into the model.

The following is a description of nine of the key spatial input layers and how we derived them.

Cover Type

Cover type was based on the potential or current natural vegetation of a site and included both natural and anthropogenic cover types. For example, cover types included not only Lodgepole Pine, Sierran Mixed Conifer, and Red Fir, but also Barren and Agriculture. Succession pathways were defined uniquely for each cover type, susceptibility to natural disturbances varied among cover types, and suitability or eligibility for various vegetation treatments varied among cover types. Cover was treated as a static (constant) grid and therefore provided a fixed template upon which disturbance and succession processes played out over time.

The source for the cover layer was the Forest Service Region 5 existing vegetation layer ("EVeg"), first mapped to the CALVEG classification developed by the region's Ecology program in 1978. When we were deciding on land cover types, including determining xeric and mesic subtypes, our focus was to best represent the project area and the surrounding landscape. We used the CALVEG mapping zone boundary for the North Sierra (fig. A1) as our focus for defining vegetation and disturbance, including susceptibility, response to fire, and fire size and distribution. Within the project area, the EVeg layer was developed based on three separate efforts: a satellite-based imagery analysis in 2000, and two orthoimagery analyses completed by contracting firms in 2005. Generally, specific cover type names were derived from the California Fire Return Interval Departure (FRID) report by Van de Water and Safford (2011). We also considered information from A Guide to Wildlife Habitats of California (Mayer and Laudenslayer 1988, as periodically updated), popularly known as the "Wildlife Habitat Relationship" (WHR) cover types.

Our team originally intended to use two separate cover layers: one for the historical reference period, and one for the current period to be used in projections of future scenarios. Two layers were identified as potentially suitable for the historical analysis: a map created from forest survey and inventory efforts under Albert Wieslander conducted between 1928 and 1940 ("Wieslander") (Thorne et al. 2006), and a map of potential natural vegetation (PNV) created by a Forest Service Enterprise Team for the Tahoe National Forest in the 2000s (Forest Service internal GIS data). Our intent was to use the PNV or Wieslander, or a combination thereof, to derive the land cover layer for the HRV phase of the project.

To validate the historical maps, we needed to develop a crosswalk between the vegetation type methodologies for the EVeg, PNV, and Wieslander maps. We also examined the spatial consistency in cover types across the maps. We attempted to create a crosswalk from these maps to the set of land cover types to be used in the project. However, we were unable to develop a consistent and comprehensive set of rules for this purpose. A major reason for this is that both the PNV and Wieslander maps used species lists, rather than assemblages (as in CALVEG and LandFire). For example, Sierran Mixed Conifer Forests do not appear as a dominant "cover type" in the PNV map. The Wieslander maps do contain an internal crosswalk to a mixed conifer alliance, but only occasionally.

Figure A.1—CALVEG Mapping Zones (i.e., ecological provinces). These zones meet USDA Forest Service standards at national and regional levels. In addition, these zones are associated with dozens of vegetation alliances, which are used to classify vegetation in spatial data products. We used vegetation alliance definitions for the North Sierran zone to classify the land cover spatial data shared by the Forest Service.

In addition, the PNV map contained a more significant error: We learned that, for the purposes of the modeling used to create the PNV map, "potential natural vegetation" meant the so-called "climax" community that would develop in the complete absence of disturbance, regardless of whether that disturbance was human caused or natural. We were seeking to mimic the natural historical range of variability, so we decided to discard this layer. The Wieslander map had its own issues. Most problematic was the nonsystematic spatial error of up to 300 meters (1,000 feet), which meant it would not be suitable for comparing specific locations. In addition, crosswalking precisely was impossible because coded vegetation was not necessarily in order of most prevalent vegetation, but instead prioritized tree species over shrubs, and commercially important trees over others. As an example from the handbook, a plot consisting of 75 percent *Quercus kelloggii* (California black oak), 15 percent *Pinus ponderosa* (ponderosa pine), and 10 percent *Pinus lambertiana* (gray pine) would be coded as ponderosa pine, gray pine, black oak. Finally, the Wieslander maps were developed from surveys done in the 1930s, decades after the huge influx of settlers in the 1850s; by the 1930s, vegetation patterns may have already been significantly altered (Thorne et al. 2006). Consequently, the Wieslander map was also not a reliable predictor of land cover type without extensive review of the original data and maps, which was beyond the scope of this project.

To confirm these problems, we examined the overlap in land cover types between different maps in ArcGIS. In general, the overlap between EVeg and either the PNV or the Wieslander layers was no better than random, and in many cases it was worse. Consequently, we decided to proceed using only the EVeg map, and omit the calibration period of the model from our analysis of the characteristics of the HRV.

In the early stages of this project, we created a suite of land cover types based roughly on the WHR types used in California and by Forest Service managers and planners. These consisted of the WHR types with a few more types where additional specificity or refinement was desired. For example, Red Fir was split into two subtypes. The original concept was to begin with the WHR types and modify them as needed based on other attributes in the EVeg layer. However, creating a crosswalk from WHR to the project-specific types also proved problematic. First, we realized that the WHR values were actually derived from the CALVEG species alliances included in the EVeg layer, but the methodology used was unavailable or missing. The crosswalks we did find were not mutually exclusive and all-inclusive, and did not always make ecological sense (California Department of Fish and Game 2005; de Becker and Sweet 1988; Keeler-Wolf 2007). This is probably due in part to the fact that WHR is not a mapping classification. It is always derived secondarily. So we were unable to create consistent rules for mapping from WHR to other types. Others have encountered similar issues:

WHR has been less successful in differentiating between vegetation types. Because the habitat types are inconsistently defined, a broad familiarity with its detailed descriptions is needed to differentiate among types of similar structure. Although mappers have constructed rules for discriminating among types, difficulties still remain because species dominance varies substantially within some types and broad overlaps in dominant plants occur among types. Other problems arise due to the small number of classes and the inconsistencies in scale among them. (Keeler-Wolf 2007: 23)

We decided to instead base our land cover types on, at the first order, Presettlement Fire Regime (PFR) types as defined in the Fire Return Interval Departure (FRID) report by Van de Water and Safford (2011). The PFR types, as part of the FRID, were developed through the scientific process and underwent peer review. We used the methodology from the FRID rather than using the second-order WHR classification and trying to reverse-engineer it to fit into our custom land cover types. Thus, we created a new structure of cover types in a nested regime, moving from PFR (the coarsest aggregation of CALVEG types, which included a direct crosswalk from them to PFR types), to Biophysical Settings from LandFire (which were also crosswalked to PFR types in the FRID report), and finally to various local types not otherwise represented, such as xeric and mesic variants of cover types (e.g., Mixed Evergreen), and aspen variants (e.g., Red Fir – Aspen). A mutually exclusive and all-inclusive crosswalk for each land cover type used in this analysis to a single LandFire Biophysical Setting and Presettlement Fire Regime type thus exists.

Extensive geoprocessing was required to prepare the EVeg layer for use in RMLands. Beyond converting the vector data to a raster format, further analysis was required to distinguish eastside and westside areas from one another, and generate the cover type modifications that the team agreed on. Aspen types were created by overlaying an aspen layer onto the vegetation layer and creating combined types ("[type] – Aspen") where appropriate. Areas mapped as a vegetation type characteristic of early seral vegetation (e.g., chaparral) were analyzed and assigned an appropriate forested cover type. Ultramafic types were created by overlaying a geology layer onto the vegetation layer and performing a similar processing step to create "[type] – Ultramafic." Finally, for the Sierran Mixed Conifer and Red Fir cover types, which cover broad swaths of land across elevation and aspect, a xeric to mesic gradient was developed in conjunction with local experts and applied, creating "[type] – Mesic" and "[type] – Xeric."

Ultimately, 31 cover types were generated for the buffered project area, although most occupy a small extent (see table A1). The cover types with an extent of less than 1,000 hectares (2,500 acres) within the core project area may have statistically unreliable results; this problem increases as the extent of given cover type decreases. We caution against attempting to make inferences for these less common cover types. However, because the nine cover types that do occupy 1,000 or more hectares represent approximately 93 percent of the core project area, we have high confidence in the landscape-level results. These nine cover types were considered our focal cover types, and were all fully analyzed as part of the historical range of variability assessment.

Seral Stage

Seral stage classes combine developmental stage and canopy cover, and were defined for all cover types that undergo succession. Seral stages in this application were based on LandFire vegetation classes, and were further modified based on local expertise. In RMLands, susceptibility to and mortality from natural disturbances vary among seral stages. Unlike the cover grid, the seral stage grid changes dynamically over time in response to simulated succession and disturbance events. The combination of cover type and seral stage formed the basis for characterizing vegetation patterns and dynamics.

The source for the seral stage layer was the Region 5 EVeg Layer. We considered potential attributes to be used for this classification and ultimately chose tree diameter at breast height and cover from above to classify pixels into early, mid-, or late development, and open, moderate, and closed canopy. This classification system was used for most of the forest cover types; aspen and shrubland cover types were classified differently. See Appendix B for the classification and description of the seral stages for each of the major cover types.

Extensive geoprocessing was required to prepare this layer for RMLands. Beyond converting the vector data to a raster format, further analysis was required to update the layer to a year 2010 condition. Spatial data on fire and timber management history were used to provide a more accurate assessment of seral stage based on estimated stand age. In addition, areas currently mapped as chaparral in the EVeg layer were assigned to the early-development stage.

Age

Age represents the number of years since the last stand-replacing disturbance (high-mortality fire). In the model, age affected successional transitions and susceptibility to disturbance. Because the characteristic species of a given cover type may not immediately establish after a stand-replacing fire, it is likely that the age value recorded in the model is larger than the actual age of the oldest individuals in a stand. Several of the cover types in this area may go through a chaparral-dominated early-development stage; in those cases the oldest trees in the stand could be decades younger than the formal stand age. Nevertheless, due to the lack of comprehensive fire history data, we were forced to assign initial age to each cell based on an interpolation of stand age in stand exams, which is based on the actual age of dominant and codominant individuals, but modified by data on recent fire and timber management history where it existed.

In the HRV analysis, the initial age value assigned to a given cell is not necessarily important to the outcome of the simulation, due to the exclusion of the model equilibration period (first 40 timesteps in our case) from the analyzed results. However, in the future vegetation treatment scenario analysis, the initial age value carries more weight because the total simulation length is only 18 timesteps.

In this application, we used data from stand exams dating to the 1960s and from recent Region 5 Ecology Group survey plots to estimate stand age across the buffered project area. We then interpolated that information across the landscape. Due to insufficient data, we were unable to disaggregate the data below the landscape scale to cover type or another more finely resolved classification. We also acknowledge that the stand exam and modern vegetation plots do not constitute a true sample. They were conducted almost exclusively in mid-mature and mature stands of commercially viable trees, thus skewing the results to some unquantifiable degree. We updated the interpolated data with fire and timber management history, and assigned ages to types coded as chaparral in the EVeg layer to the midpoint of the age spread of early development for the forest cover type to which it was converted. Remaining ages out of compliance with allowed ages for the corresponding seral stage of a given cell were modified to be in compliance, based on the assumption that the seral stage assignment was more accurate than the interpolated age information. Last, in this application, we rounded all modeled and derived ages to the nearest 5 years (the length of one timestep).

Seral Stage Age

Seral stage age represents the age since transitioning to the current seral stage, that is, how long a cell has been in the current seral stage. In RMLands, seral stage age can affect transitions between seral stages; typically, there is a threshold seral-stage age below which transitions do not occur. After creating both the seral stage and age layers, we derived seral stage age based on the youngest possible age for a cell of that cover and seral stage. For example, if we determined that a particular cell on the landscape had a cover type of Lodgepole Pine, seral stage of mid-development closed, and age of 50 years, we took the minimum age for that cover-seral stage combination (10 years old), and subtracted it from the age to arrive at a seral stage age of 40. Given that each seral stage also belongs to a developmental stage (early, mid-, or late development), we also derive development age (i.e., how long a cell has been in the current developmental stage) from seral stage age and track it in the simulation.

Elevation

Elevation represents the height above sea level in meters. In RMLands, elevation can affect disturbance spread. The elevation grid used in this analysis was a digital elevation model provided by the Tahoe National Forest and resampled to 30-meter pixels.

Slope

Slope represents the steepness of a cell as measured in percent. In RMLands, slope can affect disturbance spread. The slope grid used in this analysis was derived from the elevation grid just described.

Aspect

Aspect represents the direction a cell is facing in terms of eight cardinal directions, plus flat. In RMLands, aspect can affect disturbance spread via an interaction with wind direction during an event. The aspect grid used in this analysis was derived from the elevation layer described earlier.

Topographic Position Index

Our topographic position index (TPI) combines heat load, which is based on aspect and slope, with slope position. High values for TPI are correlated with locations on steep, south- and west-facing, upper slopes. Low values are correlated with locations on gentle, north- and east-facing, lower slopes, and valley bottoms. Values in between occur along a gradient of these characteristics. Our TPI is scaled to the project area (including the buffer), and is therefore a local index only. In RMLands, TPI can affect disturbance susceptibility and mortality.

Streams

Streams represent linear hydrological features, classified as small, medium, or large based on stream order. In RMLands, they can affect the spread of disturbance depending on both stream size and disturbance size. For this application, the streams layer was created from the Tahoe National Forest hydrography dataset. Note that to function as a potential barrier, cells coded as streams in the stream raster must share a side, rather than only a vertex. All “large” streams were represented as Water in the cover type layer.

Table A.1—Cover types in the upper Yuba River watershed project area, including the formal project area and the simulation area (project area plus 10-km [6-mi] buffer), given in rank order of extent within the core project area (source: McGarigal et al. 2018).

Cover type	Abbreviation	Project area (ha)	Project area (ac)	Simulation area (ha)	Simulation area (ac)
Sierran Mixed Conifer – Mesic	SMC_M	57,853	142,955	133,920	330,916
Sierran Mixed Conifer – Xeric	SMC_X	52,198	128,981	91,443	225,956
Oak-Conifer Forest and Woodland	OCFW	23,279	57,522	56,987	140,815
Red Fir – Mesic	RFR_M	8,563	21,159	19,626	48,496
Red Fir – Xeric	RFR_X	7,493	18,515	9,989	24,683
Mixed Evergreen – Mesic	MEG_M	7,273	17,972	13,548	33,477
Mixed Evergreen – Xeric	MEG_X	6,768	16,724	13,774	33,036
Sierran Mixed Conifer – Ultramafic	SMC_U	4,124	10,190	9,774	24,152
Water[a]	WAT	4,058	10,027	8,157	20,156
Barren[a]	BAR	2,665	6,585	8,751	21,624
Grassland[a]	GRASS	1,379	3,408	4,617	11,409
Meadow[a]	MED	1,201	2,968	3,435	8,488
Oak-Conifer Forest and Woodland – Ultramafic	OCFW_U	1,060	2,619	2,185	5,399
Lodgepole Pine	LPN	837	2,068	2,816	6,958
Montane Riparian	MRIP	732	1,809	2,216	5,476
Subalpine Conifer	SCN	638	1,576	2,044	5,051
Mixed Evergreen – Ultramafic	MEG_U	604	1,492	1,655	4,090
Red Fir – Ultramafic	RFR_U	294	726	321	793
Western White Pine	WWP	273	675	510	1,260

(Table A.1 continued on next page.)

(Table A.1 continued)

Cover type	Abbreviation	Project area (ha)	Project area (ac)	Simulation area (ha)	Simulation area (ac)
Urban[a]	URB	114	282	782	1,932
Sierran Mixed Conifer with Aspen	SMC_ASP	58	143	121	299
Red Fir with Aspen	RFR_ASP	31	77	34	84
Oak Woodland	OAK	19	47	4,192	10,358
Curl-Leaf Mountain Mahogany	CMM	18	45	41	101
Agriculture[a]	AGR	16	40	5,416	13,383
Lodgepole Pine with Aspen	LPN_ASP	8	20	31	77
Yellow Pine	YPN	0	0	10,499	25,943
Big Sagebrush	SAGE	0	0	1,600	3,954
Subalpine Conifer with Aspen	SCN_ASP	0	0	6	15
Black and Low Sagebrush	LSG	0	0	5	12
Yellow Pine with Aspen	YPN_ASP	0	0	3	7
Total		181,556	448,625	408,498	1,009,399

[a] Cover types treated as nonseral.

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APPENDIX B: Cover Type Description and State-and-Transition Model for 12 Cover Types and Variants

1. Black and Low Sagebrush (LSG)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service; and (3) Michele Slaton, GIS Specialist, Inyo National Forest, USDA Forest Service.

Cover Type Classification and Crosswalks

- EVeg: Regional Dominance Type 1:
  - Low Sagebrush
  - Black Sagebrush
- Presettlement Fire Regime Type:
  - Black and Low Sagebrush
- LandFire BpS model:
  - 0610790: Great Basin Xeric Mixed Sagebrush Shrubland

Vegetation Description

The Black and Low Sagebrush cover type is a shrubland generally dominated by broad-leaved, evergreen shrubs of short stature, typically averaging about 15 percent cover. Depending on site conditions, crowns may touch. Deciduous shrubs and small trees are sometimes sparsely scattered within this type. The ground cover of grasses and forbs is typically only 5–15 percent cover (Verner 1988c). This cover type may be dominated by either *Artemisia arbuscula* or *A. nova*, often in association with *Chrysothamnus viscidiflorus*, *Purshia tridentata,* or *A. tridentata; A. nova* is also commonly associated with *Krascheninnikovia* and *Ephedra*. *Juniperus occidentalis* may be sparsely scattered in stands dominated by *A. arbuscula*, and *J. osteosperma* and *Pinus monophylla* are sometimes scattered in stands dominated by *A. nova.* A rich variety of forbs is usually present, including *Eriogonum, Erigeron, Phlox, Castilleja, Sphaeralcea,* and *Lupinus*. Common grasses include *Poa, Pseudoroegneria, Elymus, Stipa,* and *Festuca*. The abundance and distribution of associated plants is highly influenced by soils and precipitation (LandFire 2007o; Verner 1988c).

Distribution

Communities of *A. arbuscula* are generally restricted to elevated arid plains along the eastern flanks of the Sierra Nevada. *Artemisia nova* can occur in subalpine areas, at elevations above 2,400 meters (8,000 feet). Stands dominated by *A. arbuscula* range in elevation from 1,200 to 2,700 meters (4,000–9,000 feet) (Verner 1988c). Stands of *A. arbuscula* are usually found on shallow soils with impaired drainage in the transition zone between the wetter bottom and open timber on the mountainsides. This cover type also occurs on terraces with hardpan or heavy clay soils. In mosaics formed with *Purshia tridentata, A. arbuscula* occurs on harsher sites with shallow, well-drained soils, whereas *P. tridentata* occupies areas with deeper soils. Soils typically associated with stands of *A. nova* are shallow, contain a high percentage of gravel, and are rich in mineral carbonates. It is prevalent on limestone soils (Verner 1988c).

Disturbances

Wildfire

Wildfires tend to be high-mortality, stand-replacing fires that initiate a process of postfire forest succession. High-mortality fires kill large as well as small trees, and may kill many of the shrubs and herbs as well, although belowground organs of at least some individual shrubs and herbs survive and resprout. *Artemisia nova* generally supports more fire than other dwarf sagebrushes. Stand-replacing fire is rare due to relatively low fuel loads and herbaceous cover. Bare ground acts as a microbarrier to fire between low-statured shrubs. Stand-replacing fires can occur in this type when successive years of above-average precipitation are followed by an average or dry year. Stand-replacing fires predominate in the late-successional class where the herbaceous component has diminished or where trees dominate (LandFire 2007o). Although it is not included in this iteration of the model, scientists have noted that *Bromus tectorum* has invaded most of these communities, altering successional pathways and disturbance regimes. It burns readily and is an early-season postfire colonizer (Verner 1988c).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting model, but with some modifications based on expert input, as follows and as summarized in table B1.1. Due to the absence of relevant spatial data, the seral stage map corresponding to this classification for the current landscape was derived by assigning polygons with 50 percent canopy cover or more to the late-development seral stage, and polygons with less than 50 percent canopy cover to the mid-development seral stage.

Early Development (ED)

This seral stage is characterized by the dominance of herbaceous vegetation, including *Poa, Pseudoroegneria,* and *Achnatherum*. Shrub canopy is typically less than 20 percent. Fire-tolerant shrubs, such as *Chrysothamnus* species, are initial sprouters postfire (LandFire 2007o). Note that scattered residual or legacy trees from the predisturbance stand may exist, but generally occupy less than 10 percent canopy cover.

Mid-Development – Moderate Canopy Cover (MDM)

This seral stage is characterized by a mixture of herbaceous and shrub vegetation. Vegetation present is likely to include *A. nova, A. arbuscula, Poa, Achnatherum,* and *Pseudoroegneria*. Shrub cover is typically less than 25 percent (LandFire 2007o). Note that scattered residual or legacy trees from the predisturbance stand and trees established after the disturbance may exist, but generally occupy less than 10 percent canopy cover. The "moderate canopy cover" designation refers to the shrubland component of the stand and not the tree component, which is usually minor.

Late Development – Closed Canopy Cover (LDC)

This seral stage is characterized by an increased presence of conifer trees (up to 40 percent cover). The degree of tree canopy closure differs depending on whether it is an *A. arbuscula* (closure likely <15 percent) or an A. nova (closure up to 40 percent) community.

In *A. arbuscula* communities, a mixture of herbaceous and shrub vegetation with over 10 percent shrub cover would still be present. In *A. nova* communities the herbaceous and shrub component would be greatly reduced (<1 percent cover). Vegetation present includes *A. nova, A. arbuscula, Juniperus, P. monophyla,* and *Achnatherum* (LandFire 2007o). Note that the "closed canopy cover" designation is a misnomer, as neither the shrub nor tree component would compose more than 40 percent cover.

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the LSG cover type are listed in table B1.2. These rules were based on the corresponding LandFire BpS description (LandFire 2007o) and associated model created by using the Vegetation Dynamics Development Tool (VDDT). The first rule dictates that a cell in the LSG cover type which has been in the ED seral stage for 20 years will have a 100-percent chance of transitioning to MDM at the beginning of the next timestep. The second rule dictates that a cell that has been in the MDM seral stage for 120 years will have a 100-percent chance of transitioning to the LDC seral stage; thus, all stands will have transitioned to the LDC stage after 140 years since establishment.

Applying the succession rules listed in table B1.2 results in stands transitioning between seral stages in a deterministic manner, such that we know the stand age (years) for the transition to the next seral stage, as shown in table B1.3. For example, the first row in table B1.3 indicates that a cell in the LSG cover type in the ED seral stage will transition to the MDM seral stage at 20 years since the stand-replacing disturbance. The second row in table B1.3 indicates that a cell in the LSG cover type in the MDM seral stage will transition to the LDC seral stage after an additional 120 years.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B1.4). FRP for the LSG cover type was based on Van de Water and Safford (2011) and expert input from Safford and Estes.

Susceptibility: Fuels (Vegetation and Disturbance History)

The only cover type-specific factor affecting susceptibility of a cell to wildfire was fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire, which was represented as a relative probability. Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B1.4 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance

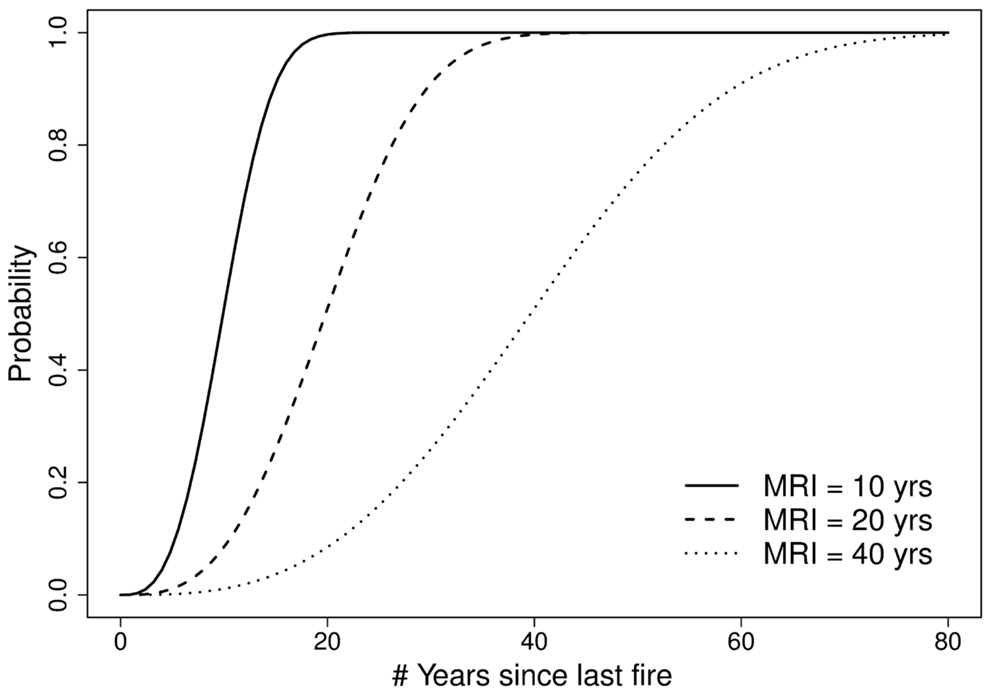

Figure B.1—Susceptibility of a cell to wildfire given as a cumulative Weibull function of the number of years since the last wildfire, shown here for different mean return intervals and a shape parameter of 3. (Source: Figure 6 in McGarigal et al. 2018).

for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire. The specified Weibull MRI parameters were based on the corresponding LandFire BpS description (LandFire 2007o) and associated VDDT model, as modified by Safford and Estes.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS description and associated VDDT model, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRP for the cover type. Thus, the MRIs assigned to each seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality: Fuels (Vegetation)

The only cover type-specific factor affecting overstory mortality following wildfire (i.e., fire severity) was fuel characteristics. Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each seral stage (table B1.4); values were based on the corresponding LandFire BpS description (LandFire 2007o) and associated VDDT model, as modified by Safford and Estes.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance were initially based on the corresponding LandFire BpS description (LandFire 2007o) and associated model created by using the VDDT, as modified by Safford and Estes. Accordingly, no rules were necessary; all low-mortality wildfires simply maintained the stand in its current seral stage. Note that rules governing transitions following high-mortality wildfire are not listed here, either, because high-mortality wildfires always result in transition to the ED seral stage.

Table B1.1—Summary of LSG seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for all seral stages refer to the residual or legacy overstory of trees from the predisturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
LSG	ED	<10 (25 cm)	<10	5	0–15
	MDM	≥10	<10	5	20–135
	LDC	≥10	<40	20	≥140

[a] ED = Early - all structures; MDM = Mid-moderate; LDC = Late-closed.

Table B1.2—Succession rules for LSG seral stages.

Cover type	From seral stage[a]	To seral stage[a]	No. of years in current successional stage	No. of years since low-mortality fire	Probability of transition
LSG	ED	MDM	20	any	1.0
	MDM	LDC	120	any	1.0

[a] ED = Early - all structures; MDM = Mid-moderate; LDC = Late-closed.

Table B1.3—Summary of LSG seral-stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage; and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
LSG	ED	MDM	20	20	20	n/a
	MDM	LDC	140	140	140	n/a

[a] ED = Early - all structures; MDM = Mid-moderate; LDC = Late-closed.

Table B1.4—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the LSG cover type.

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
LSG	n/a	76	n/a	n/a	n/a
	ED	n/a	250	3	1.00
	MDM	n/a	63	3	0.31
	LDC	n/a	149	3	1.00

[a] ED = Early - all structures; MDM = Mid-moderate; LDC = Late-closed.

2. Curl-Leaf Mountain Mahogany (CMM)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; and (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

- EVeg: Regional Dominance Type 1:
  - Curl-leaf Mountain Mahogany
- Presettlement Fire Regime Type:
  - Curl-leaf Mountain Mahogany
- LandFire BpS model:
  - 0610620: Inter-Mountain Basin Curl-leaf Mountain Mahogany Woodland and Shrubland

Vegetation Description

The Curl-leaf Mountain Mahogany cover type is a shrubland characterized by the dominance or codominance of *Cercocarpus ledifolius*. Other shrubs such as *Artemisia, Arctostaphylos, Ceanothus,* and *Ephedra* may be present. *Cercocarpus ledifolius* is both a primary early-successional colonizer rapidly invading bare mineral soils after disturbance and the dominant long-lived species. Depending on the effects of a given fire on the seedbank, it could take 10 years to recolonize in some cases. Where *C. ledifolius* has reestablished quickly after fire, *Chrysothamnus nauseosus* may codominate. Litter and shading by woody plants inhibit the establishment of *C. ledifolius*, particularly in late-seral conditions where canopy cover is high. Reproduction is often more dependent on terrain variables (e.g., slope, aspect, and elevation) than on biotic factors. *Artemisia arbuscula* and *A. nova* are infrequently associated. *Symphoricarpos, Amelanchier,* and Ribes are present on cooler, moister sites. *Pinus monophylla, Juniperus, Pseudotsuga menziesii, Abies magnifica, Abies concolor,* and *Pinus jeffreyi* may have sporadic presence at very low densities. In older stands the understory may consist largely of *Leptodactylon pungens* (Gucker 2006; LandFire 2007n).

Distribution

Cercocarpus ledifolius communities are usually found on upper slopes and ridges between 2,130 and 3,200 meters (7,000–10,500 feet), although northern stands may occur as low as 600 meters (200 feet). It is more common on northwestern and northeastern aspects. Most stands occur on rocky, shallow soils and outcrops, with mature stand cover from 10 to 55 percent. In the absence of fire, old stands may occur on somewhat deeper soils, with more than 55 percent cover (LandFire 2007n).

Disturbances

Wildfire

Wildfires tend to be high-mortality, stand-replacing fires that initiate a process of postfire forest succession. High-mortality fires kill large as well as small trees, and may also kill many of the shrubs and herbs, although belowground organs of at least some individual shrubs and herbs survive and resprout. *Cercocarpus ledifolius* is easily killed by fire and does not resprout. However, it is a primary early-successional colonizer, rapidly invading bare mineral soils after disturbance. Fires are not common in early-seral stages, when there is little fuel, except in chaparral-dominated stands. Stand-replacing fires are more common in mid-seral stands, where herbs and smaller shrubs provide ladder fuels. When surface fire is relatively common, stands will adopt a savanna-like woodland structure with an understory characterized by *Ribes, L. pungens,* and various grasses. Trees can become very old and will rarely show fire scars. In late, closed stands, the absence of herbs and small forbs makes fire uncommon; extreme winds and drought conditions are required for fire in these stands. However, stands that do burn often experience high-mortality fire (LandFire 2007n).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting model, but with some modifications based on expert input, as follows and as summarized in table B2.1. Due to the absence of relevant spatial data, the seral stage map corresponding to this classification for the current landscape was derived by randomly assigning disjunct patches of CMM to the early-, mid-, and late-development seral stages based on a 20:10:70 distribution. The proportional allocation was based on an analysis of past fire in the project area.

Early Development (ED)

This seral stage is characterized by the rapid invasion of *C. ledifolius* seedlings on bare mineral soils after fire. Litter and shading by woody plants inhibits establishment. Bunchgrasses and disturbance-tolerant forbs and resprouting shrubs, such as *Symphoricarpos*, may be present. *Ericameria* and *Artemisia* seedlings are likely to be present. Vegetation composition will affect fire behavior, especially if chaparral species such as *Arctostaphylos* or *Ceanothus* are present (LandFire 2007n). Note that scattered residual or legacy trees from the predisturbance stand may exist, but generally occupy less than 10 percent canopy cover.

Mid-Development – Moderate Canopy Cover (MDM)

This seral stage is characterized by a highly variable canopy cover of shrubs and potentially scattered residual or legacy trees from the predisturbance stand composing less than 10 percent canopy cover. Note that the "moderate canopy cover" designation refers to the shrubland component of the stand and not the residual tree component, which is usually minor.

Late Development – Closed Canopy Cover (LDC)

This seral stage is characterized by a moderate to high cover of large shrub- or tree-like *C. ledifolius* and potentially scattered residual or legacy trees from the predisturbance stand composing less than 10 percent canopy cover. When low-mortality fire is relatively frequent, late-successional *C. ledifolius* may show evidence of infrequent fire scars on older trees. Patches may consist of open savanna-like woodlands with an herbaceous-dominated understory. Other shrub species may be abundant, but decadent. When low-mortality fire is absent, very few other shrubs are present, and herbaceous cover is low. Duff may be very deep, and scattered trees may occur. *Cercocarpus ledifolius* trees reach very old age in the absence of stand-replacing fire, potentially living more than 1,000 years (LandFire 2007n). Note that the "closed canopy cover" designation refers to the shrubland component of the stand and not the residual tree component, which is usually minor.

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the CMM cover type are listed in table B2.2. These rules were initially based on the corresponding LandFire BpS description (LandFire 2007n) and associated model created by using the Vegetation Dynamics Development Tool (VDDT), but were subsequently modified based on expert input to adjust the rate of succession given the tree sizes defined for the various seral stages. For example, the first rule dictates that a cell in the CMM cover type, which has been in the ED seral stage for 20 years, will have a 100-percent chance of transitioning to MDM at the beginning of the next timestep. The next rule dictates that a cell that has been in the MDM seral stage for 120 years will have a 100-percent chance of transitioning to the LDC seral stage; thus, all stands will have transitioned to the LDC stage after 140 years since establishment.

Applying the succession rules listed in table B2.2 results in stands transitioning between seral stages in a deterministic manner, such that we know the stand age (years) for the transition to the next seral stage, as shown in table B2.3. For example, the first row in table B2.3 indicates that a cell in the CMM cover type in the ED seral stage will transition to the MDM seral stage at 20 years since the stand-replacing disturbance. The second row in table B2.3 indicates that a cell in the CMM cover type in the MDM seral stage will transition to the LDC seral stage after an additional 120 years. Note that low-mortality fires simply maintain the stand in its current seral stage.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B2.4). FRP for the CMM cover type was based on Van de Water and Safford (2011) and expert input from Safford and Estes.

Susceptibility: Fuels (Vegetation and Disturbance History)

The only cover type-specific factor affecting susceptibility of a cell to wildfire was fuel characteristics. Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B2.4 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire. The specified Weibull MRI parameters were based on the corresponding LandFire BpS description (LandFire 2007n) and associated VDDT model, as modified by Safford and Estes.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS description and associated VDDT model, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRP for the cover type. Thus, the MRIs assigned to each seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality: Fuels (Vegetation)

The only cover type-specific factor affecting overstory mortality following wildfire (i.e., fire severity) was fuel characteristics, as represented by vegetation cover type and seral stage, which was represented as a relative probability. Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each seral stage (table B2.4); values were based on the corresponding LandFire BpS description (LandFire 2007n) and associated VDDT model, as modified by Safford and Estes.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance were initially based on the corresponding LandFire BpS description (LandFire 2007n) and associated model created by using the VDDT, as modified by Safford and Estes. Accordingly, no rules were necessary; all low-mortality wildfires simply maintained the stand in its current seral stage. Note that rules governing transitions following high-mortality wildfire are not listed here, either, because high-mortality wildfires always result in transition to the ED seral stage.

Table B2.1—Summary of CMM seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for all seral stage refer to the residual or legacy overstory of trees from the predisturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
CMM	ED	<10 (25 cm)	<10	5	0–55
	MDM	≥10	<10	5	20–125
	LDC	≥10	<10	5	≥60

[a] ED = Early - all structures; MDM = Mid-moderate; LDC = Late-closed.

Table B2.2—Succession rules for CMM seral stages.

Cover type	From seral stage[a]	To seral stage	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
CMM	ED	MDM	20	any	1.0
	MDM	LDC	120	any	1.0

[a] ED = Early - all structures; MDM = Mid-moderate; LDC = Late-closed.

Table B2.3—Summary of CMM seral stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage, and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
CMM	ED	MDM	20	20	20	n/a
	MDM	LDC	140	140	140	n/a

[a] ED = Early - all structures; MDM = Mid-moderate; LDC = Late-closed.

Table B2.4—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and the number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the CMM cover type.

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
CMM	n/a	76	n/a	n/a	n/a
	ED	n/a	83	3	0.17
	MDM	n/a	17	3	0.67
	LDC	n/a	500	3	1.0

[a] ED = Early - all structures; MDM = Mid-moderate; LDC = Late-closed.

3. Lodgepole Pine (LPN)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service; and (3) Shana Gross, Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

Lodgepole Pine (LPN) Variant

- EVeg: Regional Dominance Type 1:
  - Lodgepole Pine
- Presettlement Fire Regime Type:
  - Lodgepole Pine
- LandFire BpS models:
  - 0610581: Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland – Wet
  - 0610582: Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland – Dry

Lodgepole Pine With Aspen (LPN_ASP) Variant

This type was created by overlaying the NRIS TERRA Inventory of Aspen on the EVeg layer. Where it intersected with LPN, it was assigned to LPN_ASP.

Vegetation Description

Lodgepole Pine (LPN) Variant

Pinus contorta ssp. *murrayana* is the overwhelming dominant within the Lodgepole Pine cover type, mixing occasionally with *Abies magnifica,* and with scattered *P. jeffreyi* and *P. monticola*, and *Tsuga mertensiana* at higher elevations (Fites-Kaufman et al. 2007). Mature Sierran stands often contain significant numbers of seedlings and saplings. Understory characteristics are influenced by proximity to meadow and stream margins. *Arctostaphylos* and *Ribes* are common shrubs. Stands associated with meadow edges and streams may have a rich herbaceous layer consisting of grasses, forbs, and sedges. Species associations are likely to be very location specific. Plants present may include *Cassiope, Vaccinium, Phyllodoce, Kalmia, Ceanothus, Chrysolepis, Carex,* and others. Elsewhere, the understory may be virtually absent, consisting of scattered shrubs such as *Quercus vaccinifolia*, and herbs such as *Antennaria, Arabis, Eriogonum,* and *Gayophytum*. Fast-moving streams within the cover type are generally characterized by relatively dense populations of *Salix* (Bartolome 1988; Fites-Kaufman et al. 2007; LandFire 2007k,l).

Lodgepole Pine With Aspen (LPN_ASP) Variant

This LPN variant occurs when *Populus tremuloides* co-occurs with LPN on the west side of the Sierran crest, and is typically found in smaller patches, often less than 2 hectares (5 acres) in size. Mature stands in which *P. tremuloides* are still dominant are usually relatively open. Average canopy closures range from 60 to 100 percent in young and intermediate-aged stands and from 25 to 60 percent in mature stands. The open nature of the stands results in substantial light penetration to the ground (Verner 1988a).

Distribution

Lodgepole Pine (LPN) Variant

This variant consists of open stands of *P. contorta* ssp. *murrayana*, which make up a widespread upper montane forest/woodland. This variant tolerates both rocky soils and semisaturated meadow edges, in an elevational belt within and above the *A. magnifica* zone. These forests, strongly dominated by *P. contorta* ssp. *murrayana*, generally occur at elevations of about 1,800–2,400 meters (6,000–7,800 feet) in the northern Sierra Nevada. Stands of *P. contorta* ssp. *murrayana* may reach much lower, however, with cold air drainage down glacial canyons (Anderson 1996; Fites-Kaufman et al. 2007). On infertile soils, *P. contorta* ssp. *murrayana* is often the only tree species that will grow (Lotan and Critchfield 1990).

More than any other Sierran conifer, *P. contorta* ssp. *murrayana* is relatively tolerant of poor soil aeration, and thus grows well around the margins of wet meadows and other moist areas. Many upper montane and subalpine meadows in the Sierra Nevada exhibit invasion of young *P. contorta* ssp. *murrayana* moving inward from their drier margins. It is not clear how much this process has been influenced by changes in fire frequency or grazing over the last 150 years (Fites-Kaufman et al. 2007).

Lodgepole Pine with Aspen (LPN_ASP) Variant

Sites supporting *P. tremuloides* are usually associated with added soil moisture, that is, azonal wet sites. These sites are found throughout the LPN zone, often close to streams, lakes, and meadows. Other sites include rock reservoirs, springs, and seeps. Terrain can be simple to complex.

Disturbances

Wildfire

Lodgepole Pine (LPN) Variant

Wildfires tend to be high-mortality, stand-replacing fires that initiate a process of postfire forest succession. High-mortality fires kill large as well as small trees, and may kill many of the shrubs and herbs as well, although belowground organs of at least some individual shrubs and herbs survive and resprout. Low-mortality fires tend to kill only small seedlings and depend on the herbaceous layer to carry fire.

Unlike the Rocky Mountain subspecies of *P. contorta* (ssp. *latifolia*), *P. contorta* ssp. *murrayana* does not have serotinous cones (Fites-Kaufman et al. 2007). After high-mortality fire, it initially establishes in even-aged stands, but small-scale disturbances and the ability of the subspecies to regenerate in the absence of fire promote uneven-aged structure (Cope 1993b; Shana Gross, Ecologist, USDA Forest Service, South Lake Tahoe, California, personal communication, July 2013).

High-mortality fire occurs at long intervals. Mixed-severity fire is related to fire behavior across the often moist areas where *P. contorta* ssp. *murrayana* is found. Surface fires are more common on drier sites, although in general sparse fuels limit fire ignition and spread. Most fires are small (<1 hectare [2.5 acres]), but very large fires covering hundreds of hectares do occur (LandFire 2007k,l). This is due in part to the high susceptibility to fire mortality by *P. contorta* ssp. *murrayana* because of its thin bark and shallower roots. Postfire conditions provide an ideal seedbed, and *P. contorta* ssp. *murrayana* is an early postfire colonizer (Cope 1993b).

Lodgepole Pine with Aspen (LPN_ASP) Variant

Sites supporting *P. tremuloides* are maintained by stand-replacing disturbances that allow regeneration from belowground suckers. Upland clones are impaired or suppressed by conifer ingrowth and overtopping and intensive grazing that inhibits growth. In a reference condition scenario, a few stands will advance toward conifer dominance, but in the current landscape scenario, where fire has been reduced from reference conditions, there are many more conifer-dominated mixed aspen stands (LandFire 2007m; Verner 1988a).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting models, but with some modifications (e.g., the addition of a moderate canopy cover stage in the mid- and late-seral stages) based on expert input, as follows and as summarized in table B3.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B3.2 for the LPN cover types; LPN_ASP seral stages were mapped manually by using NAIP 2010 Color IR imagery.

Lodgepole Pine (LPN) Variant

Early Development (ED)

This seral stage is characterized by bare ground, herbs, shrubs, and varying densities of tree seedlings and saplings (primarily *P. contorta* ssp. *murrayana*). This condition is characterized by the recruitment of a new cohort of early-successional, shade-intolerant tree species into an open area created by a stand-replacing disturbance. A short period of herbaceous productivity precedes closure of the tree canopy on productive sites. The prolific seed output, establishment, and seedling growth of *P. contorta* ssp. *murrayana* makes the period of herbaceous production short (Bartolome 1988). *Pinus contorta* ssp. *murrayana* regeneration density ranges from moderate to dog hair thickets (LandFire 2007k). Note that there can be residual or legacy overstory trees from the predisturbance stand making up less than 25 percent canopy cover.

Mid-Development – Open Canopy Cover (MDO)

This seral stage is characterized by a sparse ground cover of grasses, forbs, and shrubs, with a low canopy cover (<40 percent) of pole-sized (5–10 inches; 13–25 cm d.b.h.) *P. contorta* ssp. *murrayana* where surface fire or other disturbance has opened the stand (LandFire 2007k). Continued recruitment into stands produces overstocking and slow growth of the overcrowded trees. This overcrowding may make them susceptible to insects, although others have argued that the more vigorously growing trees are more likely to be attacked. Beetle infestation creates large quantities of fuel that increase the probability of wildfire (Bartolome 1988).

Mid-Development – Moderate Canopy Cover (MDM)

This seral stage is characterized by a moderate canopy cover (40–70 percent) of pole-sized *P. contorta* ssp. *murrayana* where surface fire or other disturbance has opened the stand or where there is recruitment into an MDO stand during a fire-free period. This seral stage is otherwise similar to MDO.

Mid-Development – Closed Canopy Cover (MDC)

This seral stage is characterized by a dense canopy cover (>70 percent) of pole-sized *P. contorta* ssp. *murrayana* resulting from heavy recruitment of trees following stand-replacing disturbance. Overstocking results in the slow growth of the trees and may make them susceptible to insects, although others have argued that the more vigorously growing trees are more likely to be attacked. Beetle infestation creates large quantities of fuel that increase the probability of wildfire (Bartolome 1988).

Late Development – Open Canopy Cover (LDO)

This seral stage is characterized by a sparse ground cover of grasses, forbs, and low shrubs, with a low canopy cover (<40 percent) of medium-sized (>10 inches d.b.h.) *P. contorta* ssp. *murrayana* where surface fire or other disturbance has opened the stand (LandFire 2007k). The open stand structure is maintained by low-severity fire and insect-caused tree mortality (the latter not modeled at this time).

Late Development – Moderate Canopy Cover (LDM)

This seral stage is characterized by a moderate canopy cover (40–70 percent) of medium-sized *P. contorta* ssp. *murrayana* where surface fire or other disturbance has opened the stand or where there is recruitment into an LDO stand during a fire-free period. This seral stage is otherwise similar to LDO.

Late Development – Closed Canopy Cover (LDC)

This seral stage is characterized by a high canopy cover (>70 percent) of medium-sized *P. contorta* ssp. *murrayana* where fire has had a minimal influence on the stand development. Similar to MDC, overstocking may make the trees susceptible to insects which, following an outbreak, can create large quantities of fuel that increase the probability of wildfire (Bartolome 1988).

Lodgepole Pine with Aspen (LPN_ASP) Variant

Early Development – Aspen (ED–A)

This seral stage is characterized by the recruitment of a new cohort of early-successional, shade-intolerant tree species (primarily *P. tremuloides*) into an open area created by a stand-replacing disturbance. Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover. Following disturbance, succession proceeds rapidly from an herbaceous layer to shrubs and trees, which invade together (Verner 1988a). *Populus tremuloides* suckers over 2 meters (6 feet) tall develop within about 10 years (LandFire 2007m).

Mid-Development – Aspen (MD–A)

This seral stage is characterized by *P. tremuloides* trees 5–16 inches (13–41 cm) d.b.h. Canopy cover is highly variable, and can range from 40 to 100 percent. Some understory conifers are encroaching, but *P. tremuloides* is still the dominant component of the stand (LandFire 2007m).

Mid-Development – Aspen with Conifer (MD–AC)

This seral stage is characteristic of stands that have been protected from fire since the last stand-replacing disturbance. *Populus tremuloides* trees are predominantly greater than 16 inches d.b.h. Conifers, primarily *P. contorta* ssp. *murrayana*, are present and overtopping the *P. tremuloides*. Conifers are pole-sized (5–10 inches d.b.h.) with canopy cover greater than 40 percent (LandFire 2007m).

Late Development – Conifer with Aspen (LD–CA)

If stands are sufficiently protected from fire such that conifer species, primarily *P. contorta* ssp. *murrayana*, overtop *P. tremuloides,* become larger (>10 inches d.b.h.), and make up more than 70 percent canopy cover, the conifers may be able to withstand some fire that the more sensitive *P. tremuloides* cannot. When this occurs, it creates a stand characterized by late-development conifers, primarily *P. contorta* ssp. *murrayana*, but with *P. tremuloides* present in the midstory and understory at varying densities depending on the disturbance history.

Late Development – Closed (LDC)

In this seral stage, some *P. tremuloides* continue to be present in the understory largely as a legacy, but medium- to large-sized (>10 inches d.b.h.) conifers, primarily *P. contorta* ssp. *murrayana*, are now the dominant tree species Having overtopped the *P. tremuloides,* these conifers compose more than 70 percent canopy cover. Smaller conifers are present in the midstory as well (LandFire 2007k). Note that this seral stage is analogous to the LDC condition for the LPN variant.

Model Parameterization

This section includes a listing of the model parameters that are cover type specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the LPN and LPN_ASP cover types are listed in table B3.3. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007k,l,m) and associated models created by using the Vegetation Dynamics Development Tool (VDDT), as modified by Safford and Estes. They were subsequently modified based on expert input to include probabilistic rather than deterministic seral stage transitions. Specifically, we modified the rules so that stands would gradually, instead of abruptly, transition from one seral stage to the next to reflect stochasticity in the real-world processes governing succession. For example, the first rule dictates that a cell in the LPN cover type, which has been in the ED seral stage for 10–35 years, will have a 60-percent chance of transitioning to MDC at the beginning of each timestep. Thus, stands will randomly begin transitioning to MDC stages after 10 years in the ED stage, but some stands could be delayed in the ED stage for as much as 40 years to reflect delayed tree establishment. Note that for stands currently in the ED stage and between 10 and 35 years in this stage, there is a 40-percent chance of remaining in the ED seral stage at each timestep. The second rule dictates that a cell that has been in the ED seral stage for 40 years will have a 100-percent chance of transitioning to MDC: All stands will have transitioned to the MDC seral stage after 40 years since establishment.

Applying the succession rules listed in table B3.3 results in stands transitioning between seral stages in a probabilistic rather than deterministic manner, such that we can compute the average stand age (years) for the transition to the next seral stage, as shown in table B3.4. For example, the first row in table B3.4 indicates that for a cell in the LPN cover type in the ED seral stage, the earliest stand age (i.e., number of years since the last stand-replacing disturbance) for transitioning to one of the MD seral stages is 10 years, the latest stand age is 40 years, and the average stand age at the time of the transition is 13 years. The fifth row in table B3.4 indicates that a cell in the LPN cover type in the MDO seral stage will, on average, take 16 years without a low-mortality fire disturbance to transition to the MDM seral stage (i.e., transition from an open-canopy cover, <40 percent, to a moderate-canopy cover, 40–70 percent, condition). Note that a low-mortality fire every 15 years will maintain the stand in the open-canopy condition.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B3.5). FRP for the LPN cover type was based on Mallek et al. (2013), whereas the FRP for the LPN_ASP cover type was set to be equal to that of LPN based on the corresponding LandFire BpS model (LandFire 2007m) and expert input from Safford and Estes.

Susceptibility

The cover type-specific factors affecting susceptibility of a cell to wildfire were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire. Each of these two factors is represented as a probability.

Topographic position—Topographic position, as represented by the topographic position index (TPI) described under the *Methods* section in McGarigal et al. 2018, was treated as having a static (i.e., constant over time) and universal effect on the relative susceptibility of a cell to wildfire regardless of seral stage or disturbance history. We allowed topographic position to affect susceptibility for the LPN cover type, but not LPN_ASP. Specifically, all other things being equal, for the LPN cover type, susceptibility decreased by 30 percent as the TPI decreased over its full range according to the four-parameter logistic function depicted in figure B.2. However, because the bulk of the landscape varies over a much smaller range of TPI values, the effect on susceptibility is typically much less than 30 percent.

The specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire susceptibility, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B3.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years

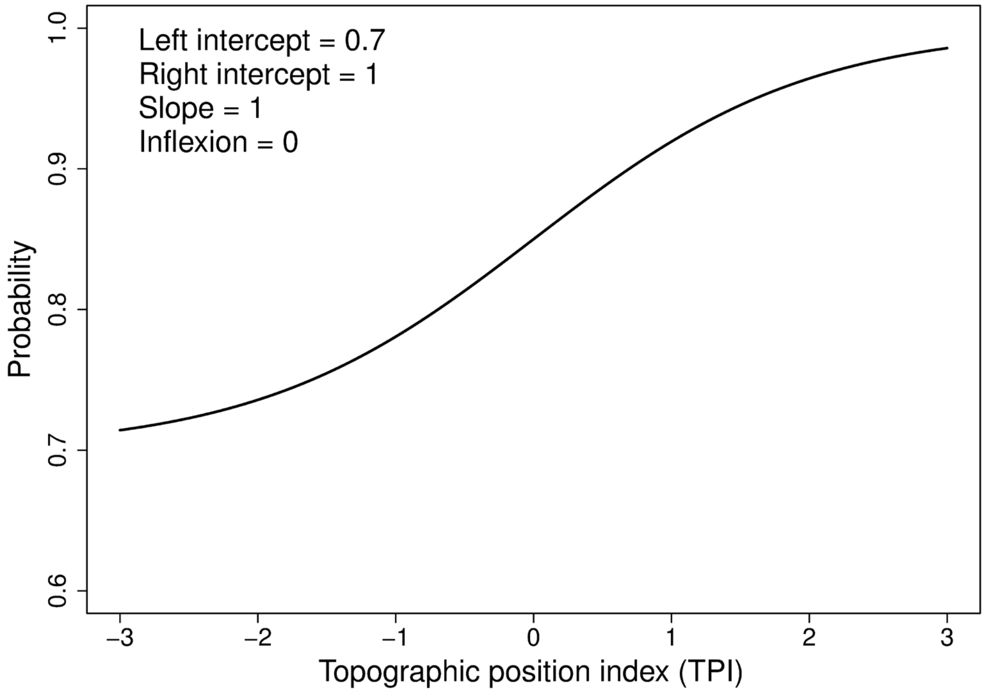

Figure B.2—Susceptibility (relative probability) of a cell to wildfire as a logistic function of topographic position (as measured by the topographic position index; see text for description) (source: Figure 5 in McGarigal et al. 2018).

since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS descriptions (LandFire 2007 k,l,m) and associated VDDT models, as modified by Safford and Estes.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS descriptions and associated VDDT models, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRPs for the cover types. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality

The cover type-specific factors affecting overstory mortality following wildfire (i.e., fire severity) were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type and seral stage. Each of these two factors is represented as a probability.

Topographic position—The effect of topographic position on mortality was treated identically to its effect on susceptibility (see previous description). Again, the specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire severity, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation)—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each cover type and seral stage (table B3.5); values were based on the corresponding LandFire BpS descriptions (LandFire 2007k,l,m) and associated VDDT models, as modified by Safford and Estes.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance for the LPN and LPN_ASP cover types are listed in table B3.6. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007k,l,m) and associated models created by using the VDDT, as modified by Safford and Estes, but were subsequently modified to include the moderate canopy cover seral stages not present in the VDDT models. Note that rules governing transitions following high-mortality wildfire are not listed in table B3.6 because high-mortality wildfires always result in transition to the ED seral stage. In addition, conditions in which low-mortality wildfire has no effect on the seral stage (i.e., does not cause a transition) are not listed. For example, the first two rules dictate that a low-mortality wildfire in a cell of LPN in the MDC seral stage has a 50-percent chance of transitioning to the MDM stage, a 50-percent chance of transitioning to the MDO stage, and (by implication) a 0-percent chance of remaining in the MDC stage. In addition, by implication (given the absence of a rule), a low-mortality wildfire in the ED, MDO, or LDO seral stage has no effect other than to maintain the cell in that seral stage.

Vegetation Treatments

Dynamic spatial constraints and priorities affecting individual cover types were described under the *Methods* section in McGarigal et al. 2018; here we describe the rules goverming seral stage transitions following each unique vegetation treatment (table B3.7). Note that these rules were created by the principals involved in this project and reflect expectations based on the common prescriptions applied today.

Table B3.1—Summary of LPN and LPN_ASP seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED/EDA seral stages refer to the residual or legacy overstory from the predisturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
LPN	ED	<5 (13 cm)	<25	10	0–35
	MDO	5–9.9 (13–25.0 cm)	<40	30	10–135
	MDM	5–9.9	40–70	55	10–125
	MDC	5–9.9	>70	85	10–115
	LDO	≥10 (25.1 cm)	<40	30	≥60
	LDM	≥10	40–70	55	≥55
	LDC	≥10	>70	85	≥50
LPN_ASP	ED-A	<5	<25	10	0–5
	MD-A	5–15.9 (13–40.5	>40	60	10–105
	MD-AC	≥16 (40.6 cm)	>50	70	60–205
	LD-CA	≥10	>70	85	160–275
	LDC	≥10	>70	85	≥230

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B3.2—Mapping rules for LPN seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories for d.b.h. are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	0–4.9 (0–12.4 cm)	any	any	any	any
MDO	5–9.9 (13–25.1 cm)	any	0–40	any	any
MDM	5–9.9	any	40–70	any	any
MDC	5–9.9	any	70–100	any	any
LDO	≥10 (25.4 cm)	any	0–40	any	any
LDM	≥10	any	40–70	any	any
LDC	≥10	any	70–100	any	any

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B3.3—Succession rules for LPN and LPN_ASP seral stages. Note that for LPN cover types, number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class, whereas for LPN_ASP it refers to the number of years in the corresponding seral stage.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
LPN	ED	MDC	10–35	any	0.6
	ED	MDC	40	any	1.0
	MDC	LDC	40–75	any	0.6
	MDC	LDC	80	any	1.0
	MDM	LDM	45–85	any	0.55
	MDM	LDM	90	any	1.0
	MDM	MDC	≥15	≥15	0.8
	MDO	LDO	50–95	any	0.5
	MDO	LDO	100	any	1.0
	MDO	MDM	≥15	≥15	0.8
	LDM	LDC	≥25	≥25	0.7
	LDO	LDM	≥25	≥25	0.7
LPN_ASP	ED-A	MD-A	10	any	1.0
	MD-A	MD-AC	50–95	any	0.6
	MD-A	MD-AC	100	any	1.0
	MD-AC	LD-CA	100	any	1.0
	LD-CA	LDC	70	any	1.0

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B3.4—Summary of LPN and LPN_ASP seral-stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage, and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average number of years without low-mortality fire to transition
LPN	ED	MD	10	40	13	n/a
	MDO	LDO	60	140	68	n/a
	MDM	LDM	55	130	62	n/a
	MDC	LDC	50	120	56	n/a
	MDO	MDM	n/a	n/a	n/a	16
	MDM	MDC	n/a	n/a	n/a	16
	LDO	LDM	n/a	n/a	n/a	27
	LDM	LDC	n/a	n/a	n/a	27
LPN_ASP	ED-A	MD-A	10	10	10	n/a
	MD-A	MD-AC	60	110	63	n/a
	MD-AC	LD-CA	160	210	163	n/a
	LC-CA	LDC	230	280	233	n/a

[a] ED = Early - all structures; MD = Mid development; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B3.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the LPN and LPN_ASP cover types.

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
LPN	n/a	52	n/a	n/a	n/a
	ED	n/a	29	3	0.03
	MDO	n/a	18	3	0.07
	MDM	n/a	27	3	0.15
	MDC	n/a	59	3	0.41
	LDO	n/a	18	3	0.07
	LDM	n/a	24	3	0.13
	LDC	n/a	37	3	0.26
LPN_ASP	n/a	52	n/a	n/a	n/a
	ED-A	n/a	29	3	0.03
	MD-A	n/a	59	3	0.41
	MD-AC	n/a	27	3	0.15
	LC-CA	n/a	24	3	0.13
	LDC	n/a	37	3	0.26

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B3.6—Disturbance rules for LPN cover types governing seral stage transitions following a low-mortality wildfire. Note that conditions in which low-mortality wildfire has no effect are not listed.

Cover type	From seral stage[a]	To seral stage[a]	Probability of transition
LPN	MDC	MDM	0.5
	MDC	MDO	0.5
	MDM	MDO	0.68
	LDC	LDM	0.5
	LDC	LDO	0.5
	LDM	LDO	0.73
LPN_ASP	LDC	LD-CA	1.0

[a] MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B3.7—Disturbance rules for the LPN and LPN_ASP cover types governing seral stage transitions following vegetation treatments. Note that treatments not affecting seral stage transitions (e.g., mastication) are not included here.

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
LPN	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: 1) matrix thin and group cut; 2) thin and burn; 3) thin, hand cut, pile, and burn; 4) thin, masticate, and burn; and 5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1
	Prescribed fire, including cells burned as part of a prescribed fire-only treatment); "cool" burn/"hot" burn transition probabilities	MDC	MDM	0.03/0.05
		MDC	MDO	0/0.03
		MDC	ED	0/0.01
		MDM	MDO	0.05/0.14
		MDM	ED	0/0.01
		LDC	LDM	0.02/0.03
		LDC	LDO	0/0.02
		LDC	ED	0/0.01
		LDM	LDO	0.04/0.11
		LDM	ED	0/0.01
	Thin and burn, including cells burned only as part of: 1) thin and burn; and 2) hand cut, pile, and burn treatments	MDC	MDM	0.03
		MDM	MDO	0.05
		LDC	LDM	0.02
		LDM	LDO	0.04
LPN_ASP	Thinning	MD-AC	MD-A	1
		LDC	MD-A	1
		LD-CA	MD-A	1
	Prescribed fire	LDC	LD-CA	1

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

4. Mixed Evergreen Forest (MEG)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service; and (3) Kyle Merriam, Sierra-Cascade Province Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

- EVeg: Regional Dominance Type 1:
  - Interior Mixed Hardwood
  - California Bay
  - Canyon Live Oak
  - Madrone
  - Bigleaf Maple
  - Interior Live Oak
  - Montane Mixed Hardwood
  - Pacific Douglas-fir
  - Tanoak
- EVeg: Regional Dominance Type 2:
  - anoak (regardless of Regional Dominance Type 1 value, and therefore inclusive of all potential Type 1 vegetation types)
  - Presettlement Fire Regime Type:
  - Mixed Evergreen Forest
- LandFire BpS model:
  - 0610430: Mediterranean California Mixed Evergreen Forest

• ***Mesic Modifier (MEG_M)***
This type was created by intersecting a binary xeric/mesic layer with the EVeg layer. MEG cells that intersected with mesic cells were assigned to the mesic modifier.

• ***Xeric Modifier (MEG_X)***
This type was created by intersecting a binary xeric/mesic layer with the EVeg layer. MEG cells that intersected with xeric cells were assigned to the xeric modifier.

• ***Ultramafic Modifier (MEG_U)***
This type was created by intersecting an ultramafic soils/geology layer with the EVeg layer. Where ultramafic cells intersected with MEG, they were assigned to the ultramafic modifier.

Vegetation Description

The Mixed Evergreen Forest cover type forms a complex mosaic of forest due to the geologic, topographic, and successional variation typical within its range. This type is characterized by a combination of coniferous and broad-leaved trees. Characteristic trees include *Pseudotsuga menziesii, Quercus chrysolepis, Notholithocarpus densiflorus* (tanoak was known as *Lithocarpus densiflorus* for over 90 years before botanists renamed it *Notholithocarpus densiflorus* in 2008 [Manos et al. 2008]; some sources and databases continue to use the old name and plant symbol), *Arbutus menziesii, Umbellularia californica,* and *Chrysolepis chrysophylla.* Species composition is primarily determined by the environmental gradients of temperature and moisture availability. *Quercus kelloggii* is found on drier sites on inland portions of the range. *Pinus lambertiana* and *P. ponderosa* can be present in this type. These stands tend to have dense or diverse shrub understories with *Ceanothus, Corylus, Gaultheria, Morella, Rhododendron, Ribes, Rubus, Toxicodendron diversilobum,* and *Vaccinium*. Grass species include *Bromus, Festuca,* and *Hierochloe*. *Polystichum munitum* and

Pteridium aquilinum var. *pubescens* sometimes grow abundantly. *Carex* species are present in some places (LandFire 2007i; McDonald 1988; Tappeiner et al. 1990).

Mesic Modifier

Deep mesic soils support aggregations that include a lower or midstory layer of dense, schlerophyllous, broad-leaved evergreen trees such as *N. densiflorus* and *A. menziesii*, with an irregular, often open, higher layer of tall needle-leaved evergreen trees, typically *P. menziesii.* A small number of pole and sapling trees occur throughout stands. On wetter sites, shrub layers are well developed, often with 100 percent cover. Cover of the herbaceous layer under the shrubs can be up to 10 percent. At higher elevations, the shrubs disappear and the herb layer is often 100 percent. Diversity of tree size typically increases with stand age, as does tree spacing. Young stands have closely spaced and uniformly distributed trees, whereas older stands have a more patchy stem distribution. Snags and downed logs, an important structural component of this cover type, increase in density or volume with stand age (Raphael 1988). Potential additional conifer associates include *Abies concolor, P. lambertiana, Calocedrus decurrens,* and *P. ponderosa* (Tappeiner et al. 1990). A large variety of shrubs, forbs, grasses, sedges, and ferns, along with *N. densiflorus* sprouts, can become aggressive on burned or cutover areas. This is especially true in areas where high-severity fires have locally eliminated conifer seed sources (Tappeiner et al. 1990).

Xeric Modifier

A pronounced hardwood tree layer is typical on xeric sites, with an infrequent and poorly developed shrub stratum, and a sparse herbaceous layer (McDonald 1988). Characteristic oaks include *Q. chrysolepis, Q. wislizeni, Q. kelloggii,* and *Q. garryana* var. *breweri*. The former two species are the most common oaks in the project area. They may individually form almost pure stands on steep canyon slopes and rocky ridgetops throughout the Sierra Nevada, or co-occur. They have tremendously variable growth forms, ranging from shrubs with multiple trunks on rocky, steep slopes, to magnificently spreading tall trees on deeper soils in moister areas. Both are evergreen with dense canopies (Allen-Diaz et al. 2007). Tree spacing is close (3–4 meters; 10–13 feet) on better sites, and wider (8–10 meters; 26–33 feet) on poor sites. In general, snags and downed woody material are sparse. Lower elevation associates are *P. sabiniana, Pinus attenuata, N. densiflorus, A. menziesii, Q. wislizeni, C. chrysophylla,* and scrubby *U. californica* (McDonald 1988).

Ultramafic Modifier

Notholithocarpus densiflorus var. *echinoides*, or dwarf tanoak, grows on ultramafic and other less productive sites. It is unclear whether the two varieties of tanoak differ genetically or whether the small stature of dwarf tanoak is due to unproductive site conditions. The scientific literature does not usually distinguish between the two infrataxa (Fryer 2007). However, its identification is pertinent to management decisions. While *N. lithocarpus* is generally protected as an oak species, the dwarf variety may be classified as a shrub and therefore subject to treatment or removal. Typically, *P. menziesii* attains less dominance and may be replaced by open stands of various conifers, such as *P. ponderosa, P. sabiniana,* or *P. jeffreyi.* Trees occur within a generally open grassland or shrubland. The shrub layer is likely to include *Q. vaccinifolia, N. densiflorus, U. californica, Q. garryana* var. *breweri*, and *Rhamnus*. Common grasses include *Stipa, Festuca,* and *Danthonia* (LandFire 2007s; McDonald 1988; O’Geen et al. 2007; Raphael 1988).

Distribution

This highly variable cover type occurs in the Sierra Nevada on all aspects at elevations of 350 meters (1,100 feet) to over 1,700 meters (5,600 feet) (LandFire 2007i). Soil depth classes range from shallow to deep. The large number of species in the type, both conifer and hardwood, allow it to occupy and persist in a wide range of environments. Good soils and poor, steep slopes and slight, frequently disturbed and pristine—all are at least adequate habitats for one or more species (McDonald 1988).

We derived a xeric-mesic gradient based on four variables: (1) aspect, (2) potential evapotranspiration, (3) topographic wetness index, and (4) soil water storage. We standardized the variables by z-scores such that higher values corresponded to more mesic environments. Thus, potential evapotranspiration was inverted to maintain this balance. We combined the four variables with equal weights into a topographic position index (TPI), which we split into xeric vs. mesic, with xeric occupying the negative end of the range up to one-fourth of the standard deviation below the mean (zero) and mesic occupying the remaining portion of the spectrum.

Mesic Modifier

This type is generally found where soils are deep, well-drained, and loamy, sandy, or gravelly. It is found in valleys, coves, and ravines, along streams, and on north-facing as well as east-facing slopes. It typically occurs in areas that are cool and on moist sites in areas where precipitation is highest, most likely in the form of rain and snow.

Xeric Modifier

This type occurs on a wide range of slopes, especially those that are moderate to steep. Soils are for the most part rocky, alluvial, coarse textured, poorly developed, and well drained. *Quercus chrysolepis* is typically more prevalent on xeric sites.

Ultramafic Modifier

Ultramafics have been mapped at various spatial densities throughout the elevational range of the MEG cover types. Low to moderate elevations in ultramafic and serpentinized areas often produce soils low in essential minerals such as calcium, potassium, and nitrogen, and have excessive accumulations of heavy metals such as nickel and chromium. These sites vary widely in the degree of serpentinization and effects on their overlying plant communities (USDA Forest Service 2008). Note that the terms “ultramafic rock” and “serpentine” are broad terms used to describe many different but related rock types: serpentinite, peridotite, dunite, pyroxenite, talc, and soapstone, among others (O’Geen et al. 2007).

Disturbances

Wildfire

Wildfires are common and frequent in the MEG cover types; vegetation mortality caused by wildfire depends on vegetation (i.e., fuel) characteristics and wildfire intensity. Low-mortality fires (≤75 percent overstory mortality) kill small trees and may consume aboveground portions of small oaks, shrubs, and herbs, but do not often kill large trees or belowground organs of most oaks, shrubs, and herbs, which promptly resprout. High-mortality fires (>75 percent overstory mortality) kill trees of all sizes and may kill many of the shrubs and herbs as well. However, high-mortality fires typically kill only the aboveground portions of the oaks, shrubs, and herbs; consequently, most oaks, shrubs and herbs promptly resprout from surviving belowground organs.

The vast majority of fires occur in late summer or early fall and are associated with lightning storms. Native American burning locally increased the frequency and may have been extensive prior to 1850. However, research also suggests that fire frequencies actually increased after European settlement (Kyle Merriam, USDA Forest Service, Quincy, California, personal communication, July 2013). Fires in the past were often large in area due to the high number of ignition points associated with fire events, and created patches of varying age and species composition (LandFire 2007i).

Hardwoods typically provide the greatest cover after fire due to root-crown sprouting. Depending on fire severity, many hardwoods may have epicormic sprouting well into the crown. Species composition, density, and interspecific competition within stands contribute to multiple pathways following disturbance. If fire has been absent from an area for a long time, some conifers may be able to establish and persist even with the return of frequent low-severity fire. But if low-severity fire is frequent after a stand-replacing fire, conifers will be more or less excluded and hardwoods will dominate (LandFire 2007i).

Fire severity in the MEG cover types is typically positively correlated with slope position, with higher mortality occurring on upper slopes and ridgetops, especially on southwest-facing aspects.

Mesic Modifier

Notholithocarpus densiflorus, which is prevalent on mesic sites, is adapted to ignite easily. In the lower montane zone of the Sierra Nevada where *N. densiflorus* occurs, the historical fire regime was characterized by dormant season fires of mostly low to moderate severity (Tappeiner et al. 1990). In stands with high *N. densiflorus* cover, *N. densiflorus* may dominate the stand for many years before conifers reestablish. Patchy, stand-replacement fires were most common on north-facing slopes and during extended droughts. Seedlings and saplings of *N. densiflorus* are typically top-killed by even low-severity surface fire. Large trees usually survive moderate-severity fire, bearing fire scars afterward. Even *N. densiflorus* with thick bark (3–10 cm; 1–4 inches) typically sustain bole damage from fire. Relative to associated conifers, mature *P. menziesii* is fairly resistant to surface fires. Crown fires cause extensive mortality (Tappeiner et al. 1990).

Xeric Modifier

Quercus chrysolepis, which is prevalent on xeric sites, has loose, dead, flaky bark that catches fire readily and burns intensely. Occasional fire often changes a stand of *Q. chrysolepis* to *Q. wislizeni*–chaparral, but without fire for sufficient time, trees again develop. Where fire is frequent, this oak becomes scarce or even drops out of the montane hardwood community (McDonald 1988).

Ultramafic Modifier

Historically, these woodland types had frequent low-severity fire. However, now there is higher susceptibility to stand-replacing fire because of fire exclusion. Overall, this type has a very limited distribution and consequently limited information for fire occurrence history.

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects, such as sudden oak death for *N. densiflorus*, which is caused by the pathogen *Phytophthora ramorum.*

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting model, but with some modifications (e.g., the addition of a moderate canopy cover stage in the mid- and late-seral stages) based on expert input, as follows and as summarized in table B4.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B4.2 for the MEG cover types.

Early Development (ED)

On mesic sites, this seral stage is characterized by abundant grasses, forbs, and low shrubs found under sparse to moderate cover of tree (primarily *P. menziesii* and *N. densiflorus*) seedlings and saplings, potentially with a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover. Seedling establishment of *P. menziesii* following fire depends on the spacing and number of surviving seed trees. Seedling establishment after large stand-replacing fires may be slow if seed trees are killed over extensive areas. Or, if there are numerous, well-spaced surviving seed trees within the burned area, a new cohort of seedlings can quickly establish (Uchytil 1991). Nearly all *N. densiflorus* burls sprout after fire, and survivorship is high. *Quercus chrysolepis*, if present, also sprouts readily, and shrubs such as *Mahonia, Gaultheria,* and *Rhododendron* may be significant. Shrub growth from seedbanks (e.g., *Ceanothus integerrimus*), can also be high (LandFire 2007i). Thus, *N. densiflorus* and other shrubs usually dominate the initial condition if *P. menziesii* is not able to seed in quickly (Raphael 1988).

On xeric sites, grasses, forbs, low shrubs, and sparse cover of tree seedlings and saplings are found often under an open canopy of residual overstory trees from the predisturbance stand. Forest openings contain a dense cover of hardwood sprouts. Sprouting shrubs such as *M. aquifolium, Gaultheria shallon*, and *Rhododendron* may be significant. Shrub growth from seedbanks (e.g., *Ceanothus integerrimus*) can also be high (LandFire 2007i). On ultramafic sites, *P. menziesii* may be stunted and slow-growing, and *N. densiflorus* var. *echinoides* may be present. Grasses such as *Festuca*, *Danthonia*, and *Acnatherum*, or else chaparral shrubs, establish. Scattered *Pinus ponderosa, P. sabiniana*, or *P. jeffreyi* may also be present (LandFire 2007s).

Mid-Development – Open Canopy Cover (MDO)

On mesic sites, this seral stage is characterized by a sparse ground cover of grasses, forbs, and shrubs, with a moderate canopy cover (<40 percent) of pole- to medium-sized (10–20 inches [25–51 cm] d.b.h.) trees (primarily *P. menziesii* and *N. densiflorus*). Other *Quercus* and *Arctostaphylos* species may also be present. In this stage, hardwoods are dominant, but *P. menziesii* and possibly other conifers are established or establishing under the predominantly *N. densiflorus* canopy (LandFire 2007i; McDonald 1988). On xeric sites, hardwoods such as *Q. chrysolepis* and *Q. kelloggii* are often prevalent, whereas conifers such as *P. menziesii* may be present at low densities in emergent status. The shrub understory is still a significant presence (LandFire 2007i). Ultramafic sites are characterized by open *P. menziesii, P. ponderosa, P. sabiniana,* or *P. jeffreyi* stands with an understory composed of *N. densiflorus* var. *echinoides* or *Q. chrysolepis* as well as grasses, forbs, and shrubs (LandFire 2007s).

Mid-Development – Moderate Canopy Cover (MDM)

This seral stage is characterized by a moderate canopy cover (40–70 percent) of pole- to medium-sized conifers, and is otherwise similar to MDO.

Mid-Development – Closed Canopy Cover (MDC)

This seral stage is characterized by a dense canopy cover (>70 percent) of pole- to medium-sized conifers, and is otherwise similar to MDO.

Late Development – Open Canopy Cover (LDO)

On mesic sites, this seral stage is characterized by an overstory of low canopy cover (<40 percent) of large trees (>20 inches d.b.h.), primarily *P. menziesii. Pinus lambertiana* also occurs. *Notholithocarpus densiflorus* is tolerant of both full sun and shade, and usually dominates the subcanopy at this stage. Codominance of the upper canopy with *P. menziesii* is uncommon but possible after extended periods without disturbance (LandFire 2007i; Uchytil 1991). There is also some evidence that the senescence of late-development *N. densiflorus* may cause openings in the canopy and allow for continued *P. menziesii* dominance. *Quercus* and *Arctostaphylos* species may also be present in the subcanopy (LandFire 2007i). On xeric sites, *P. menziesii, Q. chrysolepis,* and *Arctostaphylos mewukka* may occur. Shrubs persist in openings, but those in shade are likely to begin senescing (LandFire 2007i). On ultramafic sites, large *P. ponderosa, P. sabiniana,* or *P. jeffreyi* may be present along with *P. menziesii* and *N. densiflorus* var. *echinoides*. Grass savanna persists on sites experiencing low-intensity fire (with *Festuca, Achnatherum,* and *Danthonia*). Where fire is less frequent, chaparral shrubland develops (with *Arctostaphylos* and *Q. breweri*) (LandFire 2007s).

Late Development – Moderate Canopy Cover (LDM)

This seral stage is characterized by an overstory of large trees with canopy cover 40–70 percent, and is otherwise similar to LDO.

Late Development – Closed Canopy Cover (LDC)

This seral stage is characterized by an overstory of large trees with canopy cover greater than 70 percent, and is otherwise similar to LDO.

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the MEG cover types are listed in table B4.3. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007i,s) and associated models created by using the Vegetation Dynamics Development Tool (VDDT), as modified by Safford and Estes. They were subsequently modified based on expert input to include probabilistic rather than deterministic seral stage transitions. Specifically, we modified the rules so that stands would gradually, instead of abruptly, transition from one seral stage to the next to reflect stochasticity in the real-world processes governing succession. For example, the first rule dictates that a cell in the MEG_M cover type, which has been in the ED seral stage for 20–35 years, will have an 80-percent chance of transitioning to MDM at the beginning of each timestep. Thus, stands will randomly begin transitioning to the MDM stage after 20 years in the ED stage, but some stands could remain in the ED stage for as much as 40 years to reflect delayed tree establishment. Note that for stands currently in the ED stage and between 20 and 35 years in this stage, there is an implied 20-percent chance of remaining in the ED seral stage at each timestep. The second rule dictates that a cell that has been in the ED seral stage for 40 years will have a 100-percent chance of transitioning to the MDM seral stage; thus, all stands will have transitioned to the MDM stage after 40 years since establishment. Note that on ultramafic sites stands can be delayed in the ED stage for up to 80 years, and they always transition to MDO.

Applying the succession rules listed in table B4.3 results in stands transitioning between seral stages in a probabilistic rather than deterministic manner, such that we can compute the average stand age (years) for the transition to the next seral stage, as shown in table B4.4. For example, the first row in table B4.4 indicates that for a cell in the MEG_M cover type in the ED seral stage, the earliest stand age (i.e., number of years since the last stand-replacing disturbance) for transitioning to the MDM seral stages is 20 years, the latest stand age is 40 years, and the average stand age at the time of the transition is 21 years. Note that the average stand age at transition (21 years) is close to the specified earliest stand age (20 years) because of the relatively high rate (0.8) of transitioning beginning at the specified earliest stand age. Also, the third row in table B4.4 indicates that a cell in the MEG_M cover type in the MDM seral stage will, on average, take 16 years without a low-mortality fire disturbance to transition to the MDC seral stage (i.e., transition from a moderate-canopy cover, 40–70 percent, to a closed-canopy cover, >70 percent, condition). Note that a low-mortality fire every 15 years will maintain the stand in the open-canopy condition.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B4.5). FRPs for MEG_M and MEG_X were based on Van de Water and Safford (2011), although expert input from Safford and Estes was used to differentiate FRPs between the mesic and xeric sites; FRP for MEG_U was set to be more than double that of MEG_M, based on the corresponding LandFire BpS model (LandFire 2007s) and expert input from Safford and Estes.

Susceptibility

The cover type-specific factors affecting susceptibility of a cell to wildfire were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire. Each of these two factors is represented as a probability.

Topographic position—Topographic position, as represented by the topographic position index (TPI) described under the *Methods* section in McGarigal et al. 2018, was treated as having a static (i.e., constant over time) and universal effect on the relative susceptibility of a cell to wildfire regardless of seral stage or disturbance history. Specifically, all other things being equal, for the MEG cover types, susceptibility decreased by 30 percent as the TPI decreased over its full range according to the four-parameter logistic function depicted in figure B.2. However, because the bulk of the landscape varies over a much smaller range of TPI values, the effect on susceptibility is typically much less than 30 percent.

The specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire susceptibility, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B4.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS descriptions (LandFire 2007i,s) and associated VDDT models, as modified by Safford and Estes.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS descriptions and associated VDDT models, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRPs for the cover types. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality

The cover type-specific factors affecting overstory mortality following wildfire (i.e., fire severity) were: (1) topographic position, and (2) fuel characteristics. Each of these two factors is represented as a probability.

Topographic position—The effect of topographic position on mortality was treated identically to its effect on susceptibility (see previous description). Again, the specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire severity, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation)—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each cover type and seral stage (table B4.5); values were originally based on the corresponding LandFire BpS descriptions (LandFire 2007i,s) and associated VDDT models, but were subsequently modified based on expert input from Safford and Estes.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance for the MEG cover types are listed in table B4.6. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007i,s) and associated models created by using the VDDT, as modified by Safford and Estes. They were subsequently modified to include the moderate canopy cover seral stages not present in the VDDT models. Note that rules governing transitions following high-mortality wildfire are not listed in table B4.6 because high-mortality wildfires always result in transition to the ED seral stage. In addition, conditions in which low-mortality wildfire has no effect on the seral stage (i.e., does not cause a transition) are not listed. For example, the first two rules dictate that a low-mortality wildfire in a cell of MEG_M in the MDC seral stage has an 11-percent chance of transitioning to the MDM stage, an 11-percent chance of transitioning to the MDO stage, and (by implication) a 78-percent chance of remaining in the MDC stage. In addition, by implication (given the absence of a rule), a low-mortality wildfire in the ED, MDO, or LDO seral stage has no effect other than to maintain the cell in that seral stage.

Vegetation Treatments

Dynamic spatial constraints and priorities affecting individual cover types were described under the *Methods* section in McGarigal et al. 2018; here we describe the rules governing seral stage transitions following each unique vegetation treatment (table B4.7). Note that these rules were created by the principals involved in this project and reflect expectations based on the common prescriptions applied today.

Table B4.1—Summary of MEG seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED seral stages refer to the residual or legacy overstory from the predisturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
MEG_M	ED	<5 (13 cm)	<25	10	0–35
	MDO	5–19.9 (13–50.5	<40	30	20–75
	MDM	5–19.9	40–70	55	20–75
	MDC	5–19.9	>70	85	20–75
	LDO	≥20 (51 cm)	<40	30	≥40
	LDM	≥20	40–70	55	≥40
	LDC	≥20	>70	85	≥40
MEG_X	ED	<5	<25	10	0–35
	MDO	5–19.9	<40	30	20–85
	MDM	5–19.9	40–70	55	20–85
	MDC	5–19.9	>70	85	20–85
	LDO	≥20	<40	30	≥50
	LDM	≥20	40–70	55	≥50
	LDC	≥20	>70	85	≥50
MEG_U	ED	<5	<25%	10%	0–75
	MDO	5–19.9	<40%	30%	30–155
	MDM	5–19.9	40–70%	55%	30–155
	MDC	5–19.9	>70%	85%	30–155
	LDO	≥20	<40%	30%	≥60
	LDM	≥20	40-70%	55%	≥60
	LDC	≥20	>70%	85%	≥60

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B4.2—Mapping rules for MEG seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories for d.b.h. (inches) are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	0–4.9 (0–12.4 cm)	any	any	any	any
MDO	5–19.9 (13–50.5 cm)	any	0-40	any	any
MDM	5–19.9	any	40-70	any	any
MDC	5–19.9	any	70-100	any	any
LDO	≥20 (51 cm)	any	0-40	any	any
LDM	≥20	any	40-70	any	any
LDC	≥20	any	70-100	any	any

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B4.3—Succession rules for MEG seral stages. Note that number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
MEG_M	ED	MDM	20–35	any	0.8
	ED	MDM	40	any	1.0
	MDC	LDC	20–35	any	0.8
	MDC	LDC	40	any	1.0
	MDM	LDM	20–35	any	0.8
	MDM	LDM	40	any	1.0
	MDM	MDC	≥15	≥15	0.8
	MDO	LDO	20–35	any	0.8
	MDO	LDO	40	any	1.0
	MDO	MDM	≥15	≥15	0.8
	LDM	LDC	≥15	≥15	0.8
	LDO	LDM	≥15	≥15	0.8
MEG_X	ED	MDM	20–35	any	0.7
	ED	MDM	40	any	1.0
	MDC	LDC	30–45	any	0.7
	MDC	LDC	50	any	1.0
	MDM	LDM	30–45	any	0.7
	MDM	LDM	50	any	1.0
	MDM	MDC	≥15	≥15	0.7
	MDO	LDO	30–45	any	0.7
	MDO	LDO	50	any	1.0
	MDO	MDM	≥15	≥15	0.7
	LDM	LDC	≥15	≥15	0.7
	LDO	LDM	≥15	≥15	0.7
MEG_U	ED	MDO	30–75	any	0.4
	ED	MDO	80	any	1.0
	MDC	LDC	30–75	any	0.4
	MDC	LDC	80	any	1.0

(Table B4.3 continued on next page.)

(Table B4.3 continued)

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
	MDM	LDM	30–75	any	0.4
	MDM	LDM	80	any	1.0
	MDM	MDC	≥20	≥20	0.4
	MDO	LDO	30–75	any	0.4
	MDO	LDO	80	any	1.0
	MDO	MDM	≥20	≥20	0.4
	LDM	LDC	≥20	≥20	0.4
	LDO	LDM	≥20	≥20	0.4

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B4.4—Summary of MEG seral-stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage; and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
MEG_M	ED	MDM	20	40	21	n/a
	MD	LD	40	80	42	n/a
	MDO	MDM	n/a	n/a	n/a	16
	MDM	MDC	n/a	n/a	n/a	16
	LDO	LDM	n/a	n/a	n/a	16
	LDM	LDC	n/a	n/a	n/a	16
MEG_X	ED	MDM	20	50	23	n/a
	MD	LD	50	90	56	n/a
	MDO	MDM	n/a	n/a	n/a	18
	MDM	MDC	n/a	n/a	n/a	18
	LDO	LDM	n/a	n/a	n/a	18
	LDM	LDC	n/a	n/a	n/a	18
MEG_U	ED	MDO	30	80	37	n/a
	MD	LD	60	160	74	n/a
	MDO	MDM	n/a	n/a	n/a	27
	MDM	MDC	n/a	n/a	n/a	27
	LDO	LDM	n/a	n/a	n/a	27
	LDM	LDC	n/a	n/a	n/a	27

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B4.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the MEG cover types (original values in parentheses).

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
MEG_M	n/a	50	n/a	n/a	n/a
	ED	n/a	68	3	1.0
	MDO	n/a	18	3	0.05 (0.01)
	MDM	n/a	26	3	0.09 (0.01)
	MDC	n/a	46	3	0.20 (0.02)
	LDO	n/a	17	3	0.05 (0.005)
	LDM	n/a	25	3	0.09 (0.01)
	LDC	n/a	44	3	0.19 (0.02)
MEG_X	n/a	40	n/a	n/a	n/a
	ED	n/a	85	3	1.00
	MDO	n/a	15	3	0.03 (0.003)
	MDM	n/a	22	3	0.06 (0.01)
	MDC	n/a	39	3	0.13 (0.01)
	LDO	n/a	15	3	0.03 (0.003)
	LDM	n/a	21	3	0.06 (0.01)
	LDC	n/a	37	3	0.13 (0.01)
MEG_U	n/a	120	n/a	n/a	n/a
	ED	n/a	136	3	1.00
	MDO	n/a	35	3	0.05 (0.005)
	MDM	n/a	51	3	0.09 (0.01)
	MDC	n/a	92	3	0.20 (0.02)
	LDO	n/a	35	3	0.05 (0.005)
	LDM	n/a	50	3	0.09 (0.01)
	LDC	n/a	87	3	0.19 (0.02)

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B4.6—Disturbance rules for MEG cover types governing seral stage transitions following a low-mortality wildfire. Note that conditions in which low-mortality wildfire has no effect are not listed.

Cover type	From seral stage[a]	To seral stage[a]	Probability of transition
MEG_M	MDC	MDM	0.11
	MDC	MDO	0.11
	MDM	MDO	0.14
	LDC	LDM	0.13
	LDC	LDO	0.13
	LDM	LDO	0.17
MEG_X	MDC	MDM	0.1
	MDC	MDO	0.1
	MDM	MDO	0.13
	LDC	LDM	0.12
	LDC	LDO	0.12
	LDM	LDO	0.15
MEG_U	MDC	MDM	0.11
	MDC	MDO	0.11
	MDM	MDO	0.14
	LDC	LDM	0.13
	LDC	LDO	0.13
	LDM	LDO	0.17

[a] MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B4.7—Disturbance rules for MEG cover types governing seral stage transitions following vegetation treatments. Note that treatments not affecting seral stage transitions (e.g., mastication) are not included here.

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
MEG_M	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate, and burn; and (5) matrix thin, group cut, and burn treatments)	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1
	Prescribed fire, including cells burned as part of a prescribed fire-only treatment); "cool" burn/"hot" burn transition probabilities	MDC	MDM	0.03/0.05
		MDC	MDO	0/0.03
		MDC	ED	0/0.01
		MDM	MDO	0.05/0.14
		MDM	ED	0/0.01
		LDC	LDM	0.02/0.03
		LDC	LDO	0/0.02
		LDC	ED	0/0.01
		LDM	LDO	0.04/0.11
		LDM	ED	0/0.01
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile, and burn treatments)	MDC	MDM	0.03
		MDM	MDO	0.05
		LDC	LDM	0.02
		LDM	LDO	0.04
MEG_X; MEG_U	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate, and burn; and (5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1
	Prescribed fire, including cells burned as part of a prescribed fire-only treatment; "cool" burn/"hot" burn transition probabilities	MDC	MDM	0.05/0.15
		MDC	MDO	0.03/0.09
		MDC	ED	0.01/0.03
		MDM	MDO	0.05/0.15

(Table B4.7 continued on next page.)

(Table B4.7 continued)

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
		MDM	ED	0.01/0.03
		LDC	LDM	0.04/0.12
		LDC	LDO	0.02/0.06
		LDC	ED	0.01/0.03
		LDM	LDO	0.04/0.12
		LDM	ED	0.01/0.03
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile, and burn treatments	MDC	MDM	0.05
		MDC	MDO	0.03
		MDC	ED	0.01
		MDM	MDO	0.05
		MDM	ED	0.01
		LDC	LDM	0.04
		LDC	LDO	0.02
		LDC	ED	0.01
		LDM	LDO	0.04
		LDM	ED	0.01

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

5. Mountain Riparian (MRIP)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service; and (3) Sarah Sawyer, Assistant Pacific Southwest Regional Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

- EVeg: Regional Dominance Type 1:
    - Riparian Mixed Hardwood
    - White Alder
    - Willow
    - Black Cottonwood
    - Willow - Alder
    - Mountain Alder
    - Willow (Shrub)
- Presettlement Fire Regime Type: None
- LandFire BpS model:
    - 0611520: California Montane Riparian Systems

Vegetation Description

The Mountain Riparian cover type often occurs as a highly variable mosaic of multiple communities that are tree- or shrub-dominated. The variety of plant associations connected to this system reflect elevation, stream gradient, floodplain width, and flooding events. Usually, the montane riparian zone occurs as a narrow, often dense grove of broad-leaved, winter deciduous trees (but often shrub-form) with a sparse understory. At high elevations, there are usually more shrubs in the understory, or the type may not be well developed or may occur in the shrub stage only (Grenfell 1988; LandFire 2007q). Due to the methodology of assigning the landscape to particular cover types, the montane riparian type is limited to those sites determined to be dominated by the species assemblages listed in the preceding crosswalk section. Although we recognize that the riparian zone commonly includes areas near watercourses that are dominated by conifers and other trees, for the purposes of this model those sites have been sorted into the pertinent cover types in accordance with the dominant vegetation observed. We do not have the capacity at this time to groundtruth or map riparian zones based on understory or midstory vegetation.

Characteristic species are many, including those from the following genera: *Acer, Alnus, Cornus, Populus, Rhododendron,* and *Salix*. MRIP can occur as *Alnus* or *Salix* stringers along streams or seeps. In other situations an overstory of *Populus* or *Alnus*, or both, may be present (Grenfell 1988). Other tree species may include *Pseudotsuga menziesii, Platanus racemosa,* and *Quercus agrifolia.* At lower elevations, the riparian areas may contain *Arbutus menziesii, Notholithocarpus densiflorus, Umbellularia californica, Cornus, Acer* and *Fraxinus*. *Salix* species are common throughout, with the predominant species changing as elevation increases. Overall, the cover type most typically occurs as dense, shrub-like thickets of riparian tree and shrub species, but with scattered and variable low canopy cover of overstory trees (LandFire 2007q).

Distribution

Mountain Riparian is associated with montane lakes, ponds, seeps, bogs, and meadows, as well as rivers, streams, and springs. Water may be permanent or ephemeral. The transition between MRIP and adjacent nonriparian vegetation may be abrupt, especially where the topography is steep. Typically, this vegetation type occurs below 2,400 meters (8,000 feet) (Grenfell 1988).

Disturbances

Wildfire

Fire frequency is highly variable within the riparian zone. Multiple factors, including topography, elevation, climate, dominant vegetation, and existing vegetation all affect fire frequency and intensity. Riparian zones are heavily influenced by the fire regime of adjacent cover types and thus are still susceptible to disturbance by wildfire, even frequent and high-mortality fires. Streams also act as an inhibitor of fire spread, thus contributing to spatial and temporal diversity of landscapes beyond what their relative area would suggest (Grenfell 1988).

In some forested riparian areas, fire return intervals (FRIs) before fire suppression were very likely lower than adjacent uplands, while in others, fire frequency appears to have been comparable in riparian and upland areas. FRIs are shorter for riparian zones bordering narrow streams compared to zones around wider and deeper streams. In arid ecosystems, FRIs may be shorter than the surrounding areas in part because the increased productivity of these sites results in more fuels to carry fire. Lower elevation and adjacency to fire-tolerant vegetation also contribute to shorter FRIs for some riparian areas (Sawyer 2013).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting model, but with some modifications based on expert input, as follows and as summarized in table B5.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B5.2 for the MRIP cover type.

Early Development (ED)

This seral stage is characterized by a highly variable mixture of trees and shrubs that is largely dependent on the predisturbance vegetation composition after a stand-replacing disturbance. *Salix* and *Alnus* are most common, though overall composition is highly variable (LandFire 2007q). Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover.

Mid-Development – Open Canopy Cover (MDO)

This seral stage is characterized by a highly variable mixture of shrubs and, typically, low canopy cover (<40 percent) of medium-sized (10–20 inches d.b.h.) trees.

Late Development – Open Canopy Cover (LDO)

This seral stage is characterized by a highly variable mixture of shrubs and, typically, low canopy cover (<40 percent) of large (≥20 inches d.b.h.) trees, often dominated by *Populus* and *Alnus* (LandFire 2007q).

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the MRIP cover type are listed in table B5.3. These rules were initially based on the corresponding LandFire BpS description (LandFire 2007q) and associated model created by using the Vegetation Dynamics Development Tool (VDDT). They were subsequently modified based on expert input to adjust the rate of succession given the tree sizes defined for the various seral stages. For example, the first rule dictates that a cell in the MRIP cover type which has been in the ED seral stage for 20 years, will have a 100-percent chance of transitioning to MDO at the beginning of the next timestep. The next rule dictates that a cell that has been in the MDO seral stage for 20 years will have a 100-percent chance of transitioning to the LDO seral stage; thus, all stands will have transitioned to the LDD stage after 40 years since establishment.

Applying the succession rules listed in table B5.3 results in stands transitioning between seral stages in a deterministic manner, such that we know the stand age (years) for the transition to the next seral stage, as shown in table B5.4. For example, the first row in table B5.4 indicates that a cell in the MRIP cover type in the ED seral stage will transition to the MDO seral stage at 20 years since the stand-replacing disturbance. The second row in table B5.4 indicates that a cell in the MRIP cover type in the MDO seral stage will transition to the LDO seral stage after an additional 20 years. Note that low-mortality fires simply maintain the stand in its current seral stage.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B5.5). FRP for the MRIP cover type was based on Van de Water and Safford (2011) and expert input from Safford and Estes.

Susceptibility

The only cover type-specific factor affecting susceptibility of a cell to wildfire was fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire, which was represented as a relative probability.

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B5.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS description (LandFire 2007q) and associated VDDT model, as modified by Safford and Estes. Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS description and associated VDDT model, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRP for the cover type. Thus, the MRIs assigned to each seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality

The only cover type-specific factor affecting overstory mortality following wildfire (i.e., fire severity) was fuel characteristics, as represented by vegetation cover type and seral stage, which was represented as a relative probability.

Fuels (vegetation)—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each cover type and seral stage (table B5.5); values were based on the corresponding LandFire BpS descriptions (LandFire 2007q) and associated VDDT models, as modified by Safford and Estes.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance were initially based on the corresponding LandFire BpS description (LandFire 2007q) and associated model created by using the VDDT, as modified by Safford and Estes. Accordingly, no rules were necessary because all low-mortality wildfires simply maintained the stand in its current seral stage. Note that rules governing transitions following high-mortality wildfire are not listed here, either, because high-mortality wildfires always result in transition to the ED seral stage.

Table B5.1—Summary of MRIP seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED seral stage refer to the residual or legacy overstory from the predisturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
MRIP	ED	<10 (25 cm)	<25	10	0–55
	MDO	10–19.9 (25–50.5 cm)	<40	20	20–125
	LDO	≥20 (51 cm)	<40	30	≥60

[a] ED = Early - all structures; MDO = Mid-open; LDO = Late-open.

Table B5.2—Mapping rules for MRIP seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories for d.b.h. (inches) are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	null	any	any	any	any
ED	0–9.9 (0–25.1 cm)	any	any	any	any
MDO	10–19.9 (25.4–50.5 cm)	any	any	any	any
LDO	≥20 (51 cm)	any	any	any	any

[a] ED = Early - all structures; MDO = Mid-open; LDO = Late-open.

Table B5.3—Succession rules for MRIP seral stages. Note that number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
MRIP	ED	MDO	20	any	1.0
	MDO	LDO	20	any	1.0

[a] ED = Early - all structures; MDO = Mid-open; LDO = Late-open.

Table B5.4—Summary of MRIP seral-stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage, and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
MRIP	ED	MDO	20	20	20	n/a
	MDO	LDO	40	40	40	n/a

[a] ED = Early - all structures; MDO = Mid-open; LDO = Late-open.

Table B5.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the MRIP cover type.

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
MRIP	n/a	53	n/a	n/a	n/a
	ED	n/a	50	3	1.0
	MDO	n/a	50	3	0.5
	LDO	n/a	50	3	0.5

[a] ED = Early - all structures; MDO = Mid-open; LDO = Late-open.

6. Oak Woodland (OAK)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; and (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

- EVeg: Regional Dominance Type 1:
  - Gray Pine
  - Blue Oak
  - Valley Oak
- Presettlement Fire Regime Type:
  - Oak Woodland
- LandFire BpS model:
  - 0611140: California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna

Vegetation Description

The Oak Woodland cover type is characterized by savannas, woodlands, or forests of either monospecific or mixed stands of various oak species. *Quercus douglasii, Q. lobata, Q. wislizenii,* and *Q. garryana* var. *breweri* are the major dominants. In oak forests where mixtures of tree oak and conifer species exist, *Q. kelloggii* and *Q. chrysolepis* occur along with *Pinus sabiniana* (Allen-Diaz et al. 2007).

Both *Q. douglasii* and *Q. lobata* are endemic to California. *Quercus lobata* are among the oldest and largest oaks in North America. Tree age can exceed 500 years. *Quercus douglasii* are relatively slow-growing, long-lived trees. On *Q. douglasii-P. sabiniana* woodlands, *P. sabiniana* is taller and dominates the overstory, but is shorter-lived (at approximately 80 years) than *Q. douglasii* (150–250 years). *Quercus douglasii* is usually the more abundant of the two trees, but *P. sabiniana* contributes as much basal area as *Q. douglasii* (Allen-Diaz et al. 2007).

Typical vegetation is dominated by open oak savanna with relatively uniform mature trees at low densities (<40 percent cover), where understory vegetation structure is a function of frequent surface fire that mediates woody plant development. In some instances and in some sites, tree density will increase to 70 percent or more, forming a relatively stable hardwood forest type subject to surface fires in the hardwood litter and occasional stand-replacement fire (LandFire 2007p).

In riparian forests, associates include *Platanus racemosa, Juglans hindsii, Acer negundo, Populus fremontii, Salix,* and *Fraxinus latifolia*. In drier areas and open woodlands, shrubs usually clump together in open areas with full sun. Species may include *Aesculus californica, Ceanothus, Arctostaphylos, Rhamnus, Toxicodendron diversilobum,* and *Cercis occidentalis* (Allen-Diaz et al. 2007). The shrub layer is best developed along natural drainages, becoming insignificant in the uplands. Ground cover consists of a well-developed carpet of grasses and forbs (Ritter 1988b). Common forbs include *Daucus, Geranium, Madia,* and *Trifolium*. Most understory cover is created by annual grasses, including *Bromus, Lolium,* and *Hordeum* (Allen-Diaz et al. 2007).

Oak recruitment is poor in many areas today, due to both natural and human causes. Many stands exist as groups of medium to large trees with few or no young oaks. There is concern that these woodlands may be slowly changing into savannas and grasslands as trees die and are not replaced. Mortality of oak saplings seems to be related to competition for moisture with grasses and forbs, wild and domestic animals feeding on acorns and seedlings, fire suppression, and flood control. Most recent work suggests that recruitment is limited not by reproduction, but by the establishment and survival of saplings (Allen-Diaz et al. 2007).

Distribution

Oak Woodland has a patchy distribution embedded in a matrix of agriculture, urban development, grasslands, riparian forests, and other conifer and oak woodland types. It occurs in a band along the western Sierra Nevada foothills, generally below 800 meters (2,600 feet) in elevation, although individual species described here are capable of surviving at higher elevations. In general, tree density is highest along natural drainages with deeper soils, and lower in uplands and on steeper slopes. The transition from savanna to woodland to forest is largely driven by soil, precipitation, and elevation (Allen-Diaz et al. 2007).

Soils in this type vary significantly, with different types conducive to the establishment of differing dominant tree species. *Quercus lobata* is best developed on deep, well-drained alluvial soils, usually in valley bottoms (Ritter 1988b). *Quercus wislizeni* becomes more abundant on steeper slopes, on shallower soils, and at higher elevations. *Quercus douglasii* woodlands occur on a wide range of soils; however, they are often shallow, rocky, infertile, and well drained. The overstory ranges from sparsely scattered trees on poor sites to nearly closed canopies on good quality sites (Allen-Diaz et al. 2007; Ritter 1988a). *Quercus douglasii-P. sabiniana* woodlands are found on a variety of generally well-drained parent materials, ranging from gravelly loam through stony clay loam. They occupy steeper, drier slopes with shallower and rockier soils than pure oak woodlands (Verner 1988b).

Disturbances

Wildfire

An overstory dominated by deciduous hardwood species results in an herbaceous surface fuel complex that is the primary influence on fuels and wildfire (LandFire 2007p). Because of the long period of human habitation of oak woodlands, it is extremely difficult to define the “natural” fire regime. Lightning-caused fires certainly occurred in the past, but decades may pass between these events. Native Americans used fire in their stewardship of oak woodlands, but it is difficult to document the frequency, intensity, and extent of burning by Native Americans. Some estimate the fire return interval (FRI) of the pre-Euro-American settlement period to be around 25 years. The first European settlers continued to use fire as a management practice; burning intervals ranged from 8 to 15 years. Ranchers continued the practice through the 1950s, but since then fire suppression has emerged as the standard management policy (Allen-Diaz et al. 2007).

The fire regime that produced this cover type is thought to be frequent; mortality depends on vegetation vulnerability and wildfire intensity. Younger oaks are fire-sensitive and frequently killed by even low-severity fires. However, they typically sprout following disturbance. Older, decadent oaks are not likely to sprout after being damaged or killed by fire. Therefore, younger stands are more likely to regrow after fires, and fire exclusion can have a significant effect on stand structure. Regeneration of *P. sabiniana* is dependent on regeneration from seed, although it, too, is fire adapted. It also grows faster than *Q. douglasii* and is an important colonizer (Allen-Diaz et al. 2007).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting model, but with some modifications (e.g., the addition of a moderate canopy cover stage in the mid- and late-seral stages) based on expert input, as follows and as summarized in table B6.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B6.2 for the OAK cover type.

Early Development (ED)

This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and shrubs and the establishment of trees, including *Q. douglasii, Q. chrysolepis, Q. garryana* var. *breweri*, and *P. sabiniana*, following a stand-replacing disturbance. Reestablishment can occur from basal resprouting or sexual reproduction, depending on composition, growth form, and seed dynamics. The density of seedlings and saplings and understory shrubs can vary widely depending on site conditions. Patch sizes are likely to range from very small gap recruitment to areas of about 40 hectares (100 acres) (LandFire 2007p). Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover.

Mid-Development – Open Canopy Cover (MDO)

This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and shrubs, with a low canopy cover (<40 percent) of small (5–10 inches d.b.h.) trees. The open stand structure is maintained by low-severity surface fire (LandFire 2007p).

Mid-Development – Moderate Canopy Cover (MDM)

This seral stage is characterized by a moderate canopy cover (40–70 percent) of small trees, and is otherwise similar to MDO.

Mid-Development – Closed Canopy Cover (MDC)

This seral stage is characterized by a dense canopy cover (>70 percent) of small trees, and is otherwise similar to MDO.

Late Development – Open Canopy Cover (LDO)

This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and low shrubs, with a low canopy cover (<40 percent) of medium-sized oak and conifer trees (>10 inches d.b.h.). If *P. sabiniana* occurs, it can be very large (>20 inches d.b.h.). The open stand structure is maintained by frequent low-severity fire (LandFire 2007p).

Late Development – Moderate Canopy Cover (LDM)

This seral stage is characterized by an overstory of medium-sized oak and conifer trees with canopy cover 40–70 percent, and is otherwise similar to LDO. The moderately open stand structure is maintained by frequent low-severity fire.

Late Development – Closed Canopy Cover (LDC)

This seral stage is characterized by an overstory of medium-sized oak and conifer trees with canopy cover greater than 70 percent, and is otherwise similar to LDO. If *P. sabiniana* occurs, it can be very large (>20 inches d.b.h.) and begin to shade out the oak trees (LandFire 2007p).

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the OAK cover type are listed in table B6.3. These rules were initially based on the corresponding LandFire BpS description (LandFire 2007p) and associated model created by using the Vegetation Dynamics Development Tool (VDDT). They were subsequently modified based on expert input to include probabilistic rather than deterministic seral stage transitions. Specifically, we modified the rules so that stands would gradually, instead of abruptly, transition from one seral stage to the next to reflect stochasticity in the real-world processes governing succession. For example, the first three rules dictate that a cell in the OAK cover type which has been in the ED seral stage for 20–55 years, will have a 20-percent chance of transitioning to MDO, a 20-percent chance of transitioning to MDM, and a 20-percent chance of transitioning to MDC at the beginning of each timestep. Thus, stands will randomly begin transitioning to one of the MD stages after 20 years in the ED stage, but some stands could remain in the ED stage for as long as 60 years to reflect delayed tree establishment. Note that for stands currently in the ED stage and between 20 and 55 years in this stage, the combined chance of transitioning to MD at each timestep is 60 percent; therefore, there is a 40-percent chance of remaining in the ED seral stage at each timestep. The next three rules together dictate that a cell that has been in the ED seral stage for 60 years will have a 100-percent chance of transitioning to one of the MD seral stages; thus, all stands will have transitioned to the MD stage after 60 years since establishment.

Applying the succession rules listed in table B6.3 results in stands transitioning between seral stages in a probabilistic rather than deterministic manner, such that we can compute the average stand age (years) for the transition to the next seral stage, as shown in table B6.4. For example, the first row in table B6.4 indicates that for a cell in the OAK cover type in the ED seral stage, the earliest stand age (i.e., number of years since the last stand-replacing disturbance) for transitioning to one of the MD seral stages is 20 years, the latest stand age is 60 years, and the average stand age at the time of the transition is 23 years. Also, the third row in table B6.4 indicates that a cell in the OAK cover type in the MDO seral stage will, on average, take 17 years without a low-mortality fire disturbance to transition to the MDM seral stage (i.e., transition from an open-canopy cover, <40 percent, to a moderate-canopy cover, 40–70 percent, condition). Note that a low-mortality fire every 40 years will maintain the stand in the open-canopy condition.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B6.5). FRP for the OAK cover type was based on Mallek et al. (2013) and expert input from Safford and Estes.

Susceptibility

The cover type-specific factors affecting susceptibility of a cell to wildfire were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire. Each of these two factors is represented as a probability.

Topographic Position—Topographic position, as represented by the topographic position index (TPI) described under the *Methods* section in McGarigal et al. 2018, was treated as having a static (i.e., constant over time) and universal effect on the relative susceptibility of a cell to wildfire regardless of seral stage or disturbance history. Specifically, all other things being equal, for the OAK cover type, susceptibility decreased by 30 percent as the TPI decreased over its full range according to the four-parameter logistic function depicted in figure B.2. However, because the bulk of the landscape varies over a much smaller range of TPI values, the effect on susceptibility is typically much less than 30 percent.

The specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire susceptibility, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B6.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS description (LandFire 2007p) and associated VDDT model.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS description and associated VDDT model. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality

The cover type-specific factors affecting overstory mortality following wildfire (i.e., fire severity) were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type and seral stage. Each of these two factors is represented as a probability.

Topographic position—The effect of topographic position on mortality was treated identically to its effect on susceptibility (see previous description). Again, the specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire severity, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation)—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each seral stage (table B6.5); values were based on the corresponding LandFire BpS description (LandFire 2007p) and associated VDDT model.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance for the OAK cover type are listed in table B6.6. These rules were initially based on the corresponding LandFire BpS description (LandFire 2007p) and associated model created by using the VDDT, but were subsequently modified to include the moderate canopy cover seral stages not present in the VDDT model. Note that rules governing transitions following high-mortality wildfire are not listed in table B6.6 because high-mortality wildfires always result in transition to the ED seral stage. In addition, conditions in which low-mortality wildfire has no effect on the seral stage (i.e., does not cause a transition) are not listed. For example, the third rule dictates that a low-mortality wildfire in a cell of OAK in the MDM seral stage has a 25-percent chance of transitioning to the MDO stage and (by implication) a 75-percent chance of remaining in the MDM stage. In addition, by implication (given the absence of a rule), a low-mortality wildfire in the ED, MDO, or LDO seral stage has no effect other than to maintain the cell in that seral stage.

Vegetation Treatments

Dynamic spatial constraints and priorities affecting individual cover types were described under the *Methods* section in McGarigal et al. 2018; here we describe the rules governing seral stage transitions following each unique vegetation treatment (table B6.7). Note that these rules were created by the principals involved in this project and reflect expectations based on the common prescriptions applied today.

Table B6.1—Summary of OAK seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED seral stage refer to the residual or legacy overstory from the predisturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
OAK	ED	<5 (13 cm)	<25	10	0–55
	MDO	5–9.9 (13–25.1 cm)	<40	30	20–125
	MDM	5–9.9	40–70	55	20–125
	MDC	5–9.9	>70	75	20–125
	LDO	≥10 (25.4 cm)	<40	30	≥60
	LDM	≥10	40–70	55	≥60
	LDC	≥10	>70	75	≥60

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed;

Table B6.2—Mapping rules for OAK seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories of d.b.h. (inches) are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	0–4.9 (0–12.4 cm)	any	any	any	any
MDO	5–9.9 (13–25.1 cm)	any	0–40	any	any
MDM	5–9.9	any	40–70	any	any
MDC	5–9.9	any	70–100	any	any
LDO	≥10 (25.4 cm)	any	0–40	any	any
LDO	≥10	any	null	0–40	0–40
LDM	≥10	any	40–70	any	any
LDM	≥10	any	null	40–70	40–70
LDM	≥10	any	null	0–70	40–70
LDC	≥10	any	70–100	any	any
LDC	≥10	any	null	70–100	any
LDC	≥10	any	null	any	70–100

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B6.3—Succession rules for OAK seral stages. Note that number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
OAK	ED	MDO	20–55	any	0.2
	ED	MDM	20–55	any	0.2
	ED	MDC	20–55	any	0.2
	ED	MDO	60	any	0.3
	ED	MDM	60	any	0.4
	ED	MDC	60	any	0.3
	MDC	LDC	40–65	any	0.7
	MDC	LDC	70	any	1.0
	MDM	LDM	40–65	any	0.7
	MDM	LDM	70	any	1.0
	MDM	MDC	≥15	≥15	0.7
	MDO	LDO	40–65	any	0.7
	MDO	LDO	70	any	1.0
	MDO	MDM	≥15	≥15	0.7
	LDM	LDC	≥15	≥15	0.7
	LDO	LDM	≥15	≥15	0.7

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B6.4—Summary of OAK seral stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage; and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
OAK	ED	MD	20	60	23	n/a
	MD	LD	60	130	65	n/a
	MDO	MDM	n/a	n/a	n/a	17
	MDM	MDC	n/a	n/a	n/a	17
	LDO	LDM	n/a	n/a	n/a	17
	LDM	LDC	n/a	n/a	n/a	17

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B6.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the OAK cover type.

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
OAK	n/a	26	n/a	n/a	n/a
	ED	n/a	10	3	0.01
	MDO	n/a	10	3	0.05
	MDM	n/a	10	3	0.06
	MDC	n/a	12	3	0.07
	LDO	n/a	8	3	0.08
	LDM	n/a	12	3	0.18
	LDC	n/a	25	3	0.50

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B6.6—Disturbance rules for OAK cover type governing seral stage transitions following a low-mortality wildfire. Note that conditions in which low-mortality wildfire has no effect are not listed.

Cover type	From seral stage[a]	To seral stage	Probability of transition
OAK	MDC	MDM	0.5
	MDC	MDO	0.5
	MDM	MDO	0.25
	LDC	LDM	0.5
	LDC	LDO	0.5
	LDM	LDO	0.14

[a] MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed;

Table B6.7—Disturbance rules for OAK cover type governing seral stage transitions following vegetation treatments. Note that treatments not affecting seral stage transitions (e.g., mastication) are not included here.

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
OAK	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate, and burn; and (5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1
	Prescribed fire, including cells burned as part of a prescribed fire-only treatment); "cool" burn/"hot" burn transition probabilities	MDC	MDM	0.09/0.15
		MDC	MDO	0/0.09
		MDC	ED	0/0.03
		MDM	MDO	0.06/0.15
		MDM	ED	0/0.03
		LDC	LDM	0.02/0.03
		LDC	LDO	0/0.02
		LDC	ED	0/0.01
		LDM	LDO	0.04/0.11
		LDM	ED	0/0.01
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile, and burn treatments	LDC	LDM	0.02
		LDM	LDO	0.04

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

7. Oak-Conifer Forest and Woodland (OCFW)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service; and (3) Kyle Merriam, Sierra-Cascade Province Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

- EVeg: East of the Sierra Crest:
  Regional Dominance Type 1:
  - Black Oak
  - Eastside Pine
  - Jeffrey Pine
  - Ponderosa Pine

  AND
  Regional Dominance Type 2:
  - Black Oak
  - Canyon Live Oak
  - Madrone
  - Montane Mixed Hardwood
  - Scrub Oak
  - EVeg: West of the Sierra Crest: Regional Dominance Type 1:
  - Black Oak
  - Eastside Pine
  - Jeffrey Pine
  - Ponderosa Pine
- Presettlement Fire Regime Type:
  - Yellow Pine
- LandFire BpS model:
  - 0610300: Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland

- ***Ultramafic Modifier (OCFW_U)***
  This type was created by intersecting an ultramafic soils/geology layer with the EVeg layer. Where ultramafic cells intersected with OCFW, they were assigned to the ultramafic modifier.

Vegetation Description

The Oak-Conifer Forest and Woodland cover type is characterized by woodlands or forests of *Pinus ponderosa* or *P. jeffreyi* with one or more oaks, such as *Quercus kelloggii, Q. garryana* var. *breweri, Q. wislizeni,* or *Q. chrysolepis. Pseudotsuga menziesii* and other conifer species are uncommon but may co-occur, especially after long-term fire suppression (LandFire 2007e). *Pinus jeffreyi* tends to dominate on ultramafic sites (Fitzhugh 1988b). In some areas, sites are dominated initially by oaks, which form a dense subcanopy. Eventually, and especially on locally mesic sites, conifers will form a persistent emergent canopy over the oak as a bilayered canopy (LandFire 2007e). In other cases, characteristic species occur in a mosaic-like pattern with small pure stands of conifers interspersed with small stands of broad-leaved trees. Most of the broad-leaved trees are schlerophyllous evergreen species, but winter-deciduous species also occur (Anderson 1988). The understory is composed of shrubs such as *Arctostaphylos, Ceanothus, Chamaebatia, Cornus, Eriodictyon, Garrya, Prunus,* *Rhamnus, Ribes,* and *Toxicodendron diversilobum.* Grasses and forbs are diverse and include *Bromus, Melica, Poa, Elymus, Carex, Collinsia, Saltugilia, Iris, Lupinus, Streptanthus, Viola,* and *Pteridium aquilnum* (Fitzhugh 1988b; LandFire 2007e).

- ***Ultramafic Modifier***

Woodlands of *P. ponderosa* or *P. jeffreyi* occur mainly on low-elevation ultramafics. They grow on strongly serpentinized soil, and are typically adjacent to the non-ultramafic form of the cover type. Although *P. ponderosa* or *P. jeffreyi* dominates, it may be associated with *Calocedrus decurrens, P. attentuata, P. lambertiana, P. sabiniana,* and *Q. chysolepis* (O'Geen et al. 2007). *Quercus kelloggii* occurs occasionally on ultramafic soils (Fryer 2007). The shrub layer is dominated by *Arctostaphylos, Ceanothus, Eriodictyon, Heteromeles,* and *Pickeringia*. The herb layer is a mix of sparse perennials and many annual grasses and forbs (O'Geen et al. 2007).

Distribution

OCFW occurs in the valleys and lower slopes of mountainous terrain, on deep, well-developed soils derived from a variety of parent materials including granitics and metamorphic and Franciscan metasedimentary parent material, although rocky soils are also possible. Slopes are generally steep and all aspects are included. In the northern Sierra Nevada, the elevational range is 240 to 1,800 meters (780 to 5,900 feet) (Anderson 1988; LandFire 2007e).

- ***Ultramafic Modifier***

Ultramafics have been mapped at various spatial densities throughout the elevational range of the OCFW cover type. Low to moderate elevations in ultramafic and serpentinized areas often produce soils low in essential minerals such as calcium, potassium, and nitrogen, and have excessive accumulations of heavy metals such as nickel and chromium. These sites vary widely in the degree of serpentinization and effects on their overlying plant communities (USDA Forest Service 2008). Note that the terms "ultramafic rock" and "serpentine" are broad terms used to describe many different but related rock types: serpentinite, peridotite, dunite, pyroxenite, talc and soapstone, among others (O'Geen et al. 2007).

Disturbances

Wildfire

Wildfires are common and frequent in OCFW; vegetation mortality caused by wildfire depends on vegetation (i.e., fuel) characteristics and wildfire intensity. Low-mortality fires (≤75 percent overstory mortality) kill small trees and may consume aboveground portions of small oaks, shrubs, and herbs, but do not often kill large trees or belowground organs of most oaks, shrubs, and herbs, which promptly resprout. High-mortality fires (>75 percent overstory mortality) kill trees of all sizes and may kill many of the shrubs and herbs as well. However, high-mortality fires typically kill only the aboveground portions of the oaks, shrubs, and herbs; consequently, most oaks, shrubs, and herbs promptly resprout from surviving belowground organs.

OCFW sites are fire adapted and had frequent, low-severity surface fires prior to fire exclusion in the late 19th century. Historically, fire return intervals (FRIs) in *P. ponderosa-Q. kelloggii* forests increased with increasing elevation in the Sierra Nevada, with a tendency toward shorter mean FRIs (5–15 years) on dry, west- and south-facing slopes and longer FRIs (15–25 years) on mesic, east- and north-facing slopes. Mid-elevation forests typically had mixed-severity fires that created patchy mosaics (Fryer 2007).

Fire severity in OCFW is typically positively correlated with slope position, with higher mortality occurring on upper slopes and ridgetops, especially on southwest-facing aspects.

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting model, but with some modifications (e.g., the addition of a moderate canopy cover stage in the mid- and late-seral stages) based on expert input, as follows and as summarized in table B7.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B7.2 for the OCFW cover type.

Early Development (ED)

This seral stage is characterized by coppicing oak sprouts (predominantly *Q. kelloggii,* but potentially also *Q. chrysolepis*). *Toxicodendron diversilobum* may be abundant as well. Bunchgrasses and associated forbs dominate the understory. Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover. Localized native herbivory may maintain oak sprouts in “shrub” form for an extended period. Vegetation may also include conifer seedlings and saplings (LandFire 2007e). On sites or areas that are dry or of low quality, significant pine regeneration may depend on concurrent disturbance of shrub species and a good pine seed crop with favorable weather. Thus, it may require 50–100 years for significant pine regeneration in the absence of intervention. Dense brush is typical in young stands, and an herbaceous layer may develop on some sites. On drier sites, there is less tendency for succession toward shade-adapted species. As young, dense stands age and attain a closed canopy, they exclude most undergrowth. When other adapted conifers occur in moist pine stands of medium to high site quality, they may form a significant understory in about 20 years in the absence of fire (Fitzhugh 1988b).

Mid-Development – Open Canopy Cover (MDO)

This seral stage is characterized by a low canopy cover (<40 percent) of pole- to large-sized (5–30 inches [13–76 centimeters] d.b.h.) trees, with hardwoods dominating the canopy and sporadic conifer presence at low coverage levels. Bunchgrasses and shade-intolerant shrubs, most notably, will be prominent on most sites (LandFire 2007e).

Mid-Development – Moderate Canopy Cover (MDM)

This seral stage is characterized by a moderate canopy cover (40–70 percent) of pole- to large-sized trees, and may represent a drier, hardwood-dominated site that has gone without fire for an extended period, or a mesic site supporting both oak and yellow pine species that has been opened up by fire. Occasional *P. menziesii* may also occur. Sod-forming grasses and shade-tolerant shrubs will be prominent on most sites (LandFire 2007e).

Mid-Development – Closed Canopy Cover (MDC)

This seral stage is characterized by a dense canopy cover (>70 percent) of pole- to large-sized conifers, and is representative of the more mesic end of the environmental gradient. Stands support a dense canopy of oak and *P. ponderosa* or *P. jeffreyi,* or both pine species. Occasional *P. menziesii* may also occur. Sod-forming grasses and shade-tolerant shrubs will be prominent on most sites (LandFire 2007e).

Late Development – Open Canopy Cover (LDO)

This seral stage is characterized by a low canopy cover (<40 percent) of very large trees

(>30 inches d.b.h.). Trees may be very large, but overall size classes vary with a patchy distribution and open canopy, and the oaks are overtopped by conifers. Thus, in this stage, oaks make up a smaller proportion of the stand. This seral stage develops when low-mortality disturbance is fairly frequent; it persists as long as low-mortality fires continue to occur periodically (LandFire 2007e).

Late Development – Moderate Canopy Cover (LDM)

This seral stage is characterized by an overstory of very large trees with canopy cover 40–70 percent, and may represent a drier, hardwood-dominated site that has gone without fire for an extended period, or a mesic site supporting both oak and yellow pine species that has been opened up by fire. The oaks are overtopped by conifers and thus compose a smaller proportion of the stand. Shade-tolerant conifers such as P. menziesii may also occur and even dominate the oaks and pines (LandFire 2007e).

Late Development – Closed Canopy Cover (LDC)

This seral stage is characterized by an overstory of very large trees with canopy cover greater than 70 percent, and is representative of the more mesic end of the environmental gradient when fire has been excluded from the stand for an extended period. The oaks are overtopped by conifers and thus make up a smaller proportion of the stand. Shade-tolerant conifers such as *P. menziesii* may also occur and even dominate the oaks and pines (LandFire 2007e).

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the OCFW and OCFW_ASP cover types are listed in table B7.3. These rules were initially based on the corresponding LandFire BpS description (LandFire 2007e) and associated model created by using the Vegetation Dynamics Development Tool (VDDT), as modified by Safford and Estes. They were subsequently modified based on expert input to include probabilistic rather than deterministic seral stage transitions. Specifically, we modified the rules so that stands would gradually, instead of abruptly, transition from one seral stage to the next to reflect stochasticity in the real-world processes governing succession. For example, the first three rules dictate that a cell in the OCFW cover type, which has been in the ED seral stage for 20–35 years, will have a 40-percent chance of transitioning to MDC, a 20-percent chance of transitioning to MDM, and a 10-percent chance of transitioning to MDO at the beginning of each timestep. Thus, stands will randomly begin transitioning to one of the MD stages after 20 years in the ED stage, but some stands could remain in the ED stage for as much as 40 years to reflect delayed tree establishment. Note that for stands currently in the ED stage and between 20 and 35 years in this stage, the combined chance of transitioning to MD at each timestep is 70 percent; therefore, there is a 30-percent chance of remaining in the ED seral stage at each timestep. The next three rules together dictate that a cell that has been in the ED seral stage for 40 years will have a 100-percent chance of transitioning to one of the MD seral stages; thus, all stands will have transitioned to the MD stage after 40 years since establishment. Note that on ultramafic sites stands can be delayed in the ED stage for up to 100 years, and they always transition to MDO.

Applying the succession rules listed in table B7.3 results in stands transitioning between seral stages in a probabilistic rather than deterministic manner, such that we can compute the average stand age (years) for the transition to the next seral stage, as shown in table B7.4. For example, the first row in table B7.4 indicates that for a cell in the OCFW cover type in the ED seral stage, the earliest stand age (i.e., number of years since the last stand-replacing disturbance) for transitioning to one of the MD seral stages is 20 years, the latest stand age is 40 years, and the average stand age at the time of the transition is 22 years. Note that the average stand age at transition (22 years) is close to the specified earliest stand age (20 years) because of the relatively high rate (0.7) of transitioning beginning at the specified earliest stand age. Also, the third row in table B7.4 indicates that a cell in the OCFW cover type in the MDO seral stage will, on average, take 17 years without a low-mortality fire disturbance to transition to the MDM seral stage (i.e., transition from an open-canopy cover, <40 percent, to a moderate-canopy cover, 40–70 percent, condition). Note that a low-mortality fire every 15 years will maintain the stand in the open-canopy condition.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B7.5). FRP for the OCFW cover type was based on values reported by Mallek et al. (2013), whereas the FRP for the OCFW_U cover type was set to twice that of OCFW based on the corresponding LandFire BpS model (LandFire 2007b) and expert input from Safford and Estes.

Susceptibility

The cover type-specific factors affecting susceptibility of a cell to wildfire were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire. Each of these two factors is represented as a probability.

Topographic position—Topographic position, as represented by the topographic position index (TPI) described under the *Methods* section in McGarigal et al. 2018, was treated as having a static (i.e., constant over time) and universal effect on the relative susceptibility of a cell to wildfire regardless of seral stage or disturbance history. Specifically, all other things being equal, susceptibility decreased by 30 percent as the TPI decreased over its full range according to the four-parameter logistic function depicted in figure B.2. However, because the bulk of the landscape varies over a much smaller range of TPI values, the effect on susceptibility is typically much less than 30 percent.

The specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire susceptibility, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B7.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS description (LandFire 2007e) and associated VDDT model, as modified by Safford and Estes.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS description and associated VDDT model, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRPs for the cover types. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

<u>Mortality</u>

The cover type-specific factors affecting overstory mortality following wildfire (i.e., fire severity) were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type and seral stage. Each of these two factors was represented as a probability.

<u>Topographic position</u>—The effect of topographic position on mortality was treated identically to its effect on susceptibility (see previous description). Again, the specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire severity, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

<u>Fuels (vegetation)</u>—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each cover type and seral stage (table B7.5); values were based on the corresponding LandFire BpS descriptions (LandFire 2007e) and associated VDDT model, although the values for the ED seral stage were modified from their original value of 1.0 to 0.8 based on expert input from Safford and Estes.

<u>Disturbance Transitions</u>

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance for the OCFW cover types are listed in table B7.6. These rules were initially based on the corresponding LandFire BpS description (LandFire 2007e) and associated model created by using the VDDT as modified by Safford and Estes, but were subsequently modified to include the moderate canopy cover seral stages not present in the VDDT models. Note that rules governing transitions following high-mortality wildfire are not listed in table B7.6 because high-mortality wildfires always result in transition to the ED seral stage. In addition, conditions in which low-mortality wildfire has no effect on the seral stage (i.e., does not cause a transition) are not listed. For example, the first two rules dictate that a low-mortality wildfire in a cell of OCFW in the MDC seral stage has a 30-percent chance of transitioning to the MDM stage, a 30-percent chance of transitioning to the MDO stage, and (by implication) a 40-percent chance of remaining in the MDC stage. In addition, by implication (given the absence of a rule), a low-mortality wildfire in the ED, MDO, or LDO seral stage has no effect other than to maintain the cell in that seral stage.

Vegetation Treatments

Dynamic spatial constraints and priorities affecting individual cover types were described under the *Methods* section in McGarigal et al. 2018; here we describe the rules governing seral stage transitions following each unique vegetation treatment (table B7.7). Note that these rules were created by the principals involved in this project and reflect expectations based on the common prescriptions applied today.

Table B7.1—Summary of OCFW seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED seral stages refer to the residual or legacy overstory from the predisturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
OCFW/ OCFW_U	ED	<5 (13 cm)	<25	10	0–35
	MDO	5–29.9 (13–75.9 cm)	<40	30	20–195
	MDM	5–29.9	40–70	55	20–195
	MDC	5–29.9	>70	85	20–195
	LDO	≥30 (76 cm)	<40	30	≥100
	LDM	≥30	40–70	55	≥100
	LDC	≥30	>70	85	≥100

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B7.2.—Mapping rules for OCFW seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories for d.b.h. (inches) are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row in this table should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	null	null	any	any	any
ED	0–4.9 (0–12.4 cm)	0–4.9	any	any	any
ED	0–4.9	null	any	any	any
MDO	0–4.9	5–29.9	0–40	any	any
MDO	5–29.9 (12.7–75.9 cm)	null	0–40	any	any
MDO	5–29.9	null	null	0–40	null
MDO	5–29.9	null	null	null	0–40
MDO	5–29.9	null	null	0–40	0–40
MDO	5–29.9	0–29.9	0–40	any	any
MDO	5–29.9	0–29.9	null	0–40	0–40
MDM	0–4.9	5–29.9	40–70	any	any
MDM	5–29.9	null	40–70	any	any
MDM	5–29.9	null	null	40–70	null
MDM	5–29.9	null	null	null	40–70
MDM	5–29.9	null	null	40–70	0–70
MDM	5–29.9	null	null	0–70	40–70
MDM	5–29.9	0-29.9	40–70	any	any
MDM	5–29.9	0–29.9	null	40–70	0–70
MDM	5–29.9	0–29.9	null	0–70	40–70
MDC	0–4.9	5–29.9	70–100	any	any
MDC	5–29.9	null	70-100	any	any
MDC	5–29.9	null	null	70–100	any
MDC	5–29.9	null	null	any	70–100
MDC	5–29.9	0–29.9	70–100	any	any
MDC	5–29.9	0–29.9	null	70-100	any
MDC	5–29.9	0–29.9	null	any	70–100
LDO	≥30 (76.2 cm)	any	0–40	any	any
LDO	≥30	any	null	0–40	null
LDO	≥30	any	null	null	0–40

(Table B7.2 continued on next page.)

(Table B7.2 continued)

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
LDO	≥30	any	null	0–40	0–40
LDO	any	≥30	0–40	any	any
LDO	any	≥30	null	0–40	null
LDO	any	≥30	null	null	0–40
LDO	any	≥30	null	0–40	0–40
LDM	≥30	any	40–70	any	any
LDM	≥30	any	null	40–70	null
LDM	≥30	any	null	null	40–70
LDM	≥30	any	null	40–70	0–70
LDM	≥30	any	null	0–70	40–70
LDM	any	≥30	40–70	any	any
LDM	any	≥30	null	40–70	null
LDM	any	≥30	null	null	40–70
LDM	any	≥30	null	40–70	0–70
LDM	any	≥30	null	0–70	40–70
LDC	≥30	any	70–100	any	any
LDC	≥30	any	null	70–100	any
LDC	≥30	any	null	any	70–100
LDC	any	≥30	70–100	any	any
LDC	any	≥30	null	70–100	any
LDC	any	≥30	null	any	70–100

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B7.3—Succession rules for OCFW seral stages. Note that number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
OCFW	ED	MDC	20–35	any	0.4
	ED	MDM	20–35	any	0.2
	ED	MDO	20–35	any	0.1
	ED	MDC	40	any	0.5
	ED	MDM	40	any	0.3
	ED	MDO	40	any	0.2
	MDC	LDC	80–155	any	0.3
	MDC	LDC	160	any	1.0
	MDM	LDM	80–155	any	0.3
	MDM	LDM	160	any	1.0
	MDM	MDC	≥15	≥15	0.7
	MDO	LDO	80–155	any	0.3
	MDO	LDO	160	any	1.0
	MDO	MDM	≥15	≥15	0.7
	LDM	LDC	≥15	≥15	0.7
	LDO	LDM	≥15	≥15	0.7
OCFW_U	ED	MDO	50–95	any	0.2
	ED	MDO	100	any	1.0
	MDC	LDC	120–245	any	0.2
	MDC	LDC	250	any	1.0
	MDM	LDM	120–245	any	0.2
	MDM	LDM	250	any	1.0
	MDM	MDC	≥30	≥30	0.1
	MDO	LDO	120–245	any	0.2
	MDO	LDO	250	any	1.0
	MDO	MDM	≥30	≥30	0.1
	LDM	LDC	≥30	≥30	0.1
	LDO	LDM	≥30	≥30	0.1

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B7.4—Summary of OCFW seral stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage; and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
OCFW	ED	MD	20	40	22	n/a
	MD	LD	100	200	114	n/a
	MDO	MDM	n/a	n/a	n/a	17
	MDM	MDC	n/a	n/a	n/a	17
	LDO	LDM	n/a	n/a	n/a	17
	LDM	LDC	n/a	n/a	n/a	17
OCFW_U	ED	MD	60	120	68	n/a
	MD	LD	180	340	208	n/a
	MDO	MDM	n/a	n/a	n/a	70
	MDM	MDC	n/a	n/a	n/a	70
	LDO	LDM	n/a	n/a	n/a	70
	LDM	LDC	n/a	n/a	n/a	70

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B7.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the OCFW cover types (original values in parentheses).

Cover type	Seral stage[a]	Target fire rotation period (years)	Weibull parameters		Probability of high-mortality fire
			Mean return interval (years)	Shape	
OCFW	n/a	21	n/a	n/a	n/a
	ED	n/a	30	3	0.80 (1.0)
	MDO	n/a	8	3	0.05
	MDM	n/a	9	3	0.14
	MDC	n/a	11	3	0.26
	LDO	n/a	8	3	0.01
	LDM	n/a	10	3	0.08
	LDC	n/a	15	3	0.20
OCFW U	n/a	42	n/a	n/a	n/a
	ED	n/a	61	3	0.80 (1.0)
	MDO	n/a	16	3	0.05
	MDM	n/a	18	3	0.14
	MDC	n/a	22	3	0.26
	LDO	n/a	16	3	0.01
	LDM	n/a	21	3	0.08
	LDC	n/a	31	3	0.20

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B7.6—Disturbance rules for OCFW cover types governing seral stage transitions following a low-mortality wildfire. Note that conditions in which low-mortality wildfire has no effect are not listed.

Cover type	From seral stage[a]	To seral stage[a]	Probability of transition
OCFW	MDC	MDM	0.30
	MDC	MDO	0.30
	MDM	MDO	0.32
	LDC	LDM	0.29
	LDC	LDO	0.29
	LDM	LDO	0.18
OCFW_U	MDC	MDM	0.30
	MDC	MDO	0.30
	MDM	MDO	0.32
	LDC	LDM	0.29
	LDC	LDO	0.29
	LDM	LDO	0.18

[a] MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B7.7—Disturbance rules for OCFW cover types governing seral stage transitions following vegetation treatments. Note that treatments not affecting seral stage transitions (e.g., mastication) are not included here.

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
OCFW	Clearcut and group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate, and burn; and (5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1
	Prescribed fire, including cells burned as part of a prescribed fire-only treatment; "cool" burn/"hot" burn transition probabilities	MDC	MDM	0.03/0.05
		MDC	MDO	0/0.03
		MDC	ED	0/0.01
		MDM	MDO	0.05/0.14
		MDM	ED	0/0.01
		LDC	LDM	0.02/0.03
		LDC	LDO	0/0.02
		LDC	ED	0/0.01
		LDM	LDO	0.04/0.11
		LDM	ED	0/0.01
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile, and burn treatments	MDC	MDM	0.03
		MDM	MDO	0.05
		LDC	LDM	0.02
		LDM	LDO	0.04
OCFW_U	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate, and burn; and (5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1

(Table B7.7 continued on next page.)

(Table B7.7 continued)

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
	Prescribed fire, including cells burned as part of a prescribed fire-only treatment; "cool" burn/"hot" burn transition probabilities	MDC	MDM	0.05/0.15
		MDC	MDO	0.03/0.09
		MDC	ED	0.01/0.03
		MDM	MDO	0.05/0.15
		MDM	ED	0.01/0.03
		LDC	LDM	0.04/0.12
		LDC	LDO	0.02/0.06
		LDC	ED	0.01/0.03
		LDM	LDO	0.04/0.12
		LDM	ED	0.01/0.03
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile, and burn treatments	MDC	MDM	0.05
		MDC	MDO	0.03
		MDC	ED	0.01
		MDM	MDO	0.05
		MDM	ED	0.01
		LDC	LDM	0.04
		LDC	LDO	0.02
		LDC	ED	0.01
		LDM	LDO	0.04
		LDM	ED	0.01

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

8. Red Fir (RFR)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service; and (3) Marc Meyer, Southern Sierra Province Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

Red Fir (RFR) Variant

- ▪ EVeg: Regional Dominance Type 1:
  - ◦ Red Fir
- ***Mesic Modifier (RFR_M)***
  - ▪ Presettlement Fire Regime Type:
    - ◦ Red Fir
  - ▪ LandFire BpS model:
    - ◦ 0610322: Mediterranean California Red Fir Forest – Southern Sierra
      This type was created by intersecting a binary xeric/mesic layer with the EVeg layer. RFR cells that intersected with mesic cells were assigned to the mesic modifier.
- ***Xeric Modifier (RFR_X)***
  - ▪ Presettlement Fire Regime Type:
    - ◦ Red Fir
- LandFire BpS model:
  - ◦ 0610322 Mediterranean California Red Fir Forest – Southern Sierra
    This type was created by intersecting a binary xeric/mesic layer with the EVeg layer. RFR cells that intersected with xeric cells were assigned to the xeric modifier.
- ***Ultramafic Modifier (RFR_U)***
  - ▪ LandFire BpS model:
    - ◦ 0710220 Klamath-Siskiyou Upper Montane Serpentine Mixed Conifer Woodland
      This type was created by intersecting an ultramafic soils/geology layer with the EVeg layer. Where ultramafic cells intersected with RFR, they were assigned to the ultramafic modifier.

Red Fir with Aspen (RFR_ASP) Variant

This type was created by overlaying the NRIS TERRA Inventory of Aspen on the EVeg layer. Where it intersected with RFR, it was assigned to RFR_ASP.

Vegetation Description

Red Fir (RFR) Variant

The Red Fir cover type is characterized by the presence of *Abies magnifica*. Other conifer species such as *Pinus monticola, Pinus contorta* ssp. *murrayana*, *Tsuga mertensiana, Abies concolor,* and *Pinus jeffreyi* occur at varying densities (LandFire 2007g,h). Mature *A. magnifica* stands are frequently monotypic, with very few other plant species in any layer. Heavy shade and a thick layer of duff tend to inhibit understory vegetation, especially in dense stands (Barrett 1988). However, there are many open or patchy stands on less productive soils that are not monotypic, but rather codominant with other tree species. These sites may have substantial shrub cover (Marc Meyer, USDA Forest Service, Clovis, California, personal communication, June 2013).

Stand-replacing disturbances such as lightning-caused fires, windthrows, insect outbreaks, and disease kill groups of trees (Barrett 1988). Stand structure is complex. Most current (fire-suppressed) *A. magnifica* stands that were logged in the 19th century have an even-aged structure. In contrast, current unlogged and fire-suppressed stands have an uneven-aged or irregular age structure. Last, presettlement stands with an active fire regime had a relatively flat age-class structure that did not fit a classic even- or uneven-aged distribution (Marc Meyer, USDA Forest Service, personal communication, June 2013). That is, frequent small-scale disturbance led to small patches of even-aged trees within the average "stand," and most age classes in a given stand are represented by some of these small patches (Taylor and Halpern 1991). After fire, *A. magnifica* seedlings may establish in canopy gaps, especially if they are small to moderate in size. *Pinus contorta* ssp. *murrayana*, as well as *P. jeffreyi* and *P. monticola,* may also function as postfire pioneer species (Chappell and Agee 1996; Marc Meyer, USDA Forest Service, personal communication, June 2013). On sites where these pioneering types occur under an *A. magnifica* canopy, the *A. magnifica* will dominate over the long term (Cope 1993a).

In openings resulting from tree mortality or logging, and under open stands on poor sites, many species may occur. Large shrubfields can dominate areas after severe fire, although conifers eventually will reclaim these sites. In some cases, particularly on xeric sites with significant shrub cover, reforestation can be effectively delayed for decades. *Ribes, Arctostaphylos,* and *Ceanothus* are the most commonly found shrubs (Laacke 1990). Other associated shrubs include *Symphoricarpos rotundifolius, Lonicera conjugialis,* and *Quercus vaccinifolia* (Marc Meyer, USDA Forest Service, personal communication, June 2013). Associated herbaceous genera include *Carex, Lupinus, Xerophyllum, Eucephalus, Pedicularis, Gayophytum, Pyrola,* and *Monardella* (Cope 1993a).

- ***Mesic Modifier***
  In addition to *A. magnifica*, mesic regions within the RFR cover type are associated with the presence of *P. monticola* and *P. contorta* ssp. *murrayana*. *Tsuga mertensiana* may occur on north-facing aspects. *Abies concolor* is uncommon, except at lower elevations (LandFire 2007h).
- ***Xeric Modifier***
  These sites often include and are occasionally codominated by *A. concolor, P. jeffreyi,* and *P. contorta* ssp. *murrayana*, although other conifer species (e.g., *P. lambertiana*) can also be present in lesser amounts at lower elevations. *Abies concolor* is more prevalent at lower elevations. *Pinus jeffreyi* is more common on shallow soils or when disturbance is frequent. Shrubs and herbs generally contribute less than 30 percent cover each. If shrub cover is higher, the shrubs are short or prostrate (LandFire 2007g).
- ***Ultramafic Modifier***
  Ultramafic soils support a number of endemic plant species. Slowly growing and often stunted *P. contorta* ssp. murrayana and *P. jeffreyi* occur in combinations or in nearly pure open stands. *Abies magnifica* may be less dominant. Hardwoods are usually sparse, but shrubs such as *Arctostaphylos, Quercus, Rhamnus, Lithocarpus, Rhododendron,* and *Ceanothus* may occur on these sites (LandFire 2007r; USDA Forest Service 2008).

Red Fir With Aspen (RFR_ASP) Variant

When *Populus tremuloides* co-occurs with RFR on the west side of the Sierran crest, it is typically found in smaller patches, often less than 2 hectares in size. This variant is not subject to the modifiers described earlier because it is found only on mesic sites with deeper soils. Mature stands in which *P. tremuloides* are still dominant are usually relatively open. Average canopy closures range from 35 to 95 percent. The open nature of the stands results in substantial light penetration to the ground (Marc Meyer, USDA Forest Service, personal communication, June 2013; Verner 1988b).

Distribution

Red Fir (RFR) Variant

RFR generally forms a vegetation band ranging from 1,900 to 2,800 meters (6,200–9,000 feet). It is bounded and intergrades with Sierran Mixed Conifer at lower elevations. Geology is quite variable (Barrett 1988).

We derived a xeric-mesic gradient based on four variables: (1) aspect, (2) potential evapotranspiration, (3) topographic wetness index, and (4) soil water storage. We standardized the variables by z-scores such that higher values corresponded to more mesic environments. Thus, potential evapotranspiration was inverted to maintain this balance. We combined the four variables with equal weights into a topographic position index (TPI), which we split into xeric vs. mesic, with xeric occupying the negative end of the range up to one-fourth of a standard deviation below the mean (zero) and mesic occupying the remaining portion of the spectrum.

- ***Mesic Modifier***
  These sites generally receive more moisture, either from precipitation or by virtue of being positioned on middle or lower slopes or drainage bottoms, or both. They may be adjacent to meadows or riparian areas. They are found at the highest elevations and north-facing aspects.
- ***Xeric Modifier***
  These sites are typically drier and tend to occupy the lower portion of the RFR zone. They are also more likely to exist on south-facing aspects and steeper slopes.
- ***Ultramafic Modifier***
  Ultramafics have been mapped at various spatial densities throughout the elevational range of the RFR cover type. Low to moderate elevations in ultramafic and serpentinized areas often produce soils low in essential minerals such as calcium, potassium, and nitrogen, and have excessive accumulations of heavy metals such as nickel and chromium. These sites vary widely in the degree of serpentinization and effects on their overlying plant communities (USDA Forest Service 2008). Note that the terms "ultramafic rock" and "serpentine" are broad terms used to describe many different but related rock types: serpentinite, peridotite, dunite, pyroxenite, talc, and soapstone, among others (O'Geen et al. 2007).

Red Fir With Aspen (RFR_ASP) Variant

Sites supporting *P. tremuloides* are usually associated with added soil moisture, that is, azonal wet sites. These sites are found throughout the RFR zone, often close to streams and lakes. Other sites include meadow edges, rock reservoirs, springs, and seeps. Terrain can be simple to complex. At lower elevations, topographic conditions for this type tend toward positions resulting in relatively colder, wetter conditions within the prevailing climate (e.g., ravines, north slopes, wet depressions) (LandFire 2007m). In general, these sites lie on lower slope positions, and are associated with slopes under 25 percent (Potter 1998).

Disturbances

Wildfire

Red Fir (RFR) Variant

Wildfires in high-elevation A. magnifica forests are generally not as intense as those in the Rocky Mountains and are typically less intense than those at lower elevations. Lesser annual fuel accumulation, less severe fire weather conditions, and compact and patchy fuels are all factors (Marc Meyer, USDA Forest Service, personal communication, June 2013). Still, fire has an important role in maintaining species diversity within these forests. Fire creates canopy openings by killing mature trees. Vegetation mortality caused by wildfire depends on vegetation (i.e., fuel) characteristics and wildfire intensity. Low-mortality fires (≤75 percent overstory mortality) kill small trees and may consume aboveground portions of shrubs and herbs, but do not often kill large trees or belowground organs of most shrubs and herbs, which promptly resprout. High-mortality fires (>75 percent overstory mortality) kill trees of all sizes and may kill many of the shrubs and herbs as well. However, high-mortality fires typically kill only the aboveground portions of the shrubs and herbs; consequently, most shrubs and herbs promptly resprout from surviving belowground organs.

Fire severity in RFR is typically positively correlated with slope position, with higher mortality occurring on upper slopes and ridgetops, especially on southwest-facing aspects.

- ***Mesic Modifier***
  Fire (of any mortality level) is relatively less common on mesic sites than xeric sites, resulting in a relatively longer fire rotation period.
- ***Xeric Modifier***
  Fire (of any mortality level) is relatively more common on xeric sites than mesic sites, resulting in a relatively shorter fire rotation period.
- ***Ultramafic Modifier***
  This type has a very limited distribution and consequently limited information for fire occurrence history.

Red Fir With Aspen (RFR_ASP) Variant

Sites supporting *P. tremuloides* are maintained by both low- and high-mortality wildfire that promote regeneration of *P. tremuloides* from belowground suckers. Upland clones are impaired or suppressed by conifer ingrowth and overtopping and intensive grazing that inhibits growth. In a reference condition scenario, a few stands will advance toward conifer dominance, but in most stands fire disturbance is frequent enough to maintain *P. tremuloides* as a dominant or codominant component of the stand. In the current landscape, where fire has been reduced from reference conditions, there are many more conifer-dominated mixed aspen stands than was typical of the reference period conditions (LandFire 2007m; Verner 1988a).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting models, but with some modifications (e.g., the addition of a moderate canopy cover stage in the mid- and late-seral stages) based on expert input, as follows and as summarized in table B8.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B8.2 for the RFR cover types; RFR_ASP seral stages were mapped manually by using NAIP 2010 Color IR imagery.

Red Fir (RFR) Variant

- ***Early Development (ED)***

This seral stage is characterized by the recruitment of a new cohort of early-successional tree species into an open area created by a stand-replacing disturbance. Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover. Conifer associates regenerate from seed. Occasionally, large brush fields may develop after hot wildfires and are dominated by *Ceanothus, Arctostaphylos, Chrysolepis,* or other shrub species for many years (Barrett 1988). On mesic sites, *A. magnifica, P. monticola* and *P. contorta* ssp. *murrayana* regenerate from seed. Shrub cover is an important component; herb cover varies (LandFire 2007h). On xeric sites, there is regeneration of *A. magnifica* and *A. concolor,* and perhaps *P. jeffreyi* or *P. lambertiana* from seed. Shrub and herb cover varies (LandFire 2007g). Ultramafic sites will have similar species composition, especially at edges, but *P. jeffreyi* are relatively more common. Shrubs and herbs are sparse (O'Geen et al. 2007). Tree seedlings and saplings typical of the cover type can occur in either low or high density (i.e., 0–100 percent understory cover) depending on local environmental conditions and climate conditions following the disturbance. In some cases (e.g., favorable climate conditions after the stand-replacing disturbance, coupled with a good seed source), tree seedlings may develop a nearly continuous canopy and succeed relatively quickly to mid-development seral stages. In other cases, and more commonly on xeric or ultramafic sites, chaparral conditions may dominate and persist for long periods of time (LandFire 2007g,h).

- ***Mid-Development – Open Canopy Cover (MDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and shrubs, with a low canopy cover (<40 percent) of pole- to medium-sized (5–20 inches d.b.h.) conifers (LandFire 2007g). *A. magnifica* is or is transitioning to become the dominant tree species. On mesic sites, *P. monticola* and *P. contorta* ssp. *murrayana* are present in varying amounts. Grasses, forbs, and shrubs are declining, although chaparral-type shrubs, such as *Arctostaphylos* or *Chrysolepis* can contribute to a dense understory. On xeric sites, *A. concolor* and *P. jeffreyi* are present in varying amounts, and shrub cover varies (LandFire 2007g,h). Ultramafic sites will have similar species composition, especially at edges, but *P. jeffreyi* is relatively more common (O'Geen et al. 2007).
- ***Mid-Development – Moderate Canopy Cover (MDM)***
  This seral stage is characterized by a moderate canopy cover (40–70 percent) of pole- to medium-sized conifers, and is otherwise similar to MDO.
- ***Mid-Development – Closed Canopy Cover (MDC)***
  This seral stage is characterized by a dense canopy cover (>70 percent) of pole- to medium-sized conifers, and is otherwise similar to MDO.
- ***Late Development – Open Canopy Cover (LDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and low shrubs, with a low canopy cover (<40 percent) of large trees (>20 inches d.b.h.). Subdominant trees die and add to a growing layer of duff and downed woody material, and dominant trees continue to grow for several hundred years. *Abies magnifica* is the most common tree species. The understory of mature stands may be limited to less than 5 percent cover (e.g., *Chimaphila menziesii, Pyrola picta*). Upper canopy trees may be very large, but overall size classes vary with a patchy distribution and open canopy. This seral stage develops when low-mortality disturbance is fairly frequent; it persists as long as low-mortality fires continue to occur periodically. *Ceanothus* and *Arctostaphylos* populate disturbance-generated gaps (LandFire 2007g,h). On mesic sites, *P. monticola* and *P. contorta* ssp. *murrayana* may each compose up to 20 percent of tree cover. On xeric sites, *A. concolor* and *P. jeffreyi* are common associates of *A. magnifica* (Barrett 1988; LandFire 2007g,h). Ultramafic sites will have similar species composition, especially at edges, but *P. jeffreyi* is relatively more common (O'Geen et al. 2007).

- ***Late Development – Moderate Canopy Cover (LDM)***
  This seral stage is characterized by an overstory of large trees with canopy cover 40–70 percent, and is otherwise similar to LDO.
- ***Late Development – Closed Canopy Cover (LDC)***
  This seral stage is characterized by an overstory of large trees with canopy cover greater than 70 percent, and is otherwise similar to LDO.

Red Fir with Aspen (RFR_ASP) Variant

- ***Early Development – Aspen (ED–A)***
  This seral stage is characterized by the recruitment of a new cohort of early-successional, shade-intolerant tree species (primarily *P. tremuloides*) into an open area created by a stand-replacing disturbance. Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover. Following disturbance, succession proceeds rapidly from an herbaceous layer to shrubs and trees, which invade together (Barrett 1988). *Populus tremuloides* suckers more than 2 meters (6 feet) tall develop within about 10 years (LandFire 2007m).
- ***Mid-Development – Aspen (MD–A)***
  This seral stage is characterized by *P. tremuloides* trees 5–16 inches d.b.h. Canopy cover is highly variable, and can range from 40 to 100 percent. Some understory conifers are encroaching, but *P. tremuloides* is still the dominant component of the stand (LandFire 2007m).
- ***Mid-Development – Aspen with Conifer (MD–AC)***
  This seral stage is characteristic of stands that have been protected from fire since the last stand-replacing disturbance. *Populus tremuloides* trees are predominantly greater than 16 inches d.b.h. Conifers are present and overtopping the *P. tremuloides*. *Abies magnifica* is a typical conifer that is successional to *P. tremuloides*, but other conifers including *P. monticola* and *P. contorta* ssp. *murrayana* are also possible. Conifers are pole- to medium-sized (5–20 inches d.b.h.) with canopy cover greater than 40 percent (LandFire 2007m).
- ***Late Development – Conifer with Aspen (LD–CA)***
  If stands are sufficiently protected from fire such that conifer species overtop *P. tremuloides,* become large (>20 inches d.b.h.), and compose more than 70 percent canopy cover, these conifers may be able to withstand some fire that the more sensitive *P. tremuloides* cannot. When this occurs, it creates a stand characterized by late-development conifers dominated by *A. magnifica.* The stand may potentially also include *P. monticola* and *P. contorta* ssp. *murrayana*, but with *P. tremuloides* present in the midstory and understory at varying densities depending on the disturbance history.
- ***Late Development – Closed (LDC)***
  In this seral stage, some *P. tremuloides* continue to be present in the understory largely as a legacy, but large (>20 inches d.b.h.) conifers are now the dominant tree species, having overtopped the *P. tremuloides*, and compose more than 70 percent canopy cover. Smaller conifers are present in the midstory as well. Conifer species likely present include A. magnifica, *A. monticola,* and *P. contorta* spp. *murrayana* (LandFire 2007g,h,m,r). Note that this seral stage is analogous to the LDC condition for the RFR variant.

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the RFR and RFR_ASP varianats are listed in table B8.3. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007g,h,m,r) and associated models created by using the Vegetation Dynamics Development Tool (VDDT), as modified by Safford and Estes. They were subsequently modified based on expert input to include probabilistic rather than deterministic seral stage transitions. Specifically, we modified the rules so that stands would gradually, instead of abruptly, transition from one seral stage to the next to reflect stochasticity in the real-world processes governing succession. For example, the first rule dictates that a cell in the RFR_M cover type, which has been in the ED seral stage for 20–45 years, will have a 60-percent chance of transitioning to MDC, and thus a 40-percent chance of remaining in the ED stage, at the beginning of each timestep. Thus, stands will randomly begin transitioning to MDC after 20 years in the ED stage, but some stands could remain in the ED stage for as much as 50 years to reflect delayed tree establishment. The second rule dictates that a cell that has been in the ED seral stage for 50 years will have a 100-percent chance of transitioning to the MDC seral stage; thus, all stands will have transitioned to the MDC stage after 50 years since establishment. Note that on xeric and ultramafic sites stands can be delayed in the ED stage for up to 90 or 120 years, respectively, and they transition to MDO instead of MDC.

Applying the succession rules listed in table B8.3 results in stands transitioning between seral stages in a probabilistic rather than deterministic manner, such that we can compute the average stand age (years) for the transition to the next seral stage, as shown in table B8.4. For example, the first row in table B8.4 indicates that for a cell in the RFR_M cover type in the ED seral stage, the earliest stand age (i.e., number of years since the last stand-replacing disturbance) for transitioning to one of the MD seral stages is 20 years, the latest stand age is 50 years, and the average stand age at the time of the transition is 23 years. Note that the average stand age at transition (23 years) is close to the specified earliest stand age (20 years) because of the relatively high rate (0.6) of transitioning beginning at the specified earliest stand age. Also, the third row in table B8.4 indicates that a cell in the RFR_M cover type in the MDO seral stage will, on average, take 27 years without a low-mortality fire disturbance to transition to the MDM seral stage (i.e., transition from an open-canopy cover, <40 percent, to a moderate-canopy cover, 40–70 percent, condition). Note that a low-mortality fire every 15 years will maintain the stand in the open-canopy condition.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B8.5). FRPs for RFR_M and RFR_X were based on Mallek et al. (2013), although expert input from Safford and Estes was used to differentiate FRPs between the mesic and xeric sites. FRP for RFR_U was set to be double that of RFR_M, and FRP for RFR_ASP was set to be equal to RFR_M, based on the corresponding LandFire BpS models (LandFire 2007m,r) and expert input from Safford and Estes.

Susceptibility

The cover type-specific factors affecting susceptibility of a cell to wildfire were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire. Each of these two factors is represented as a probability.

Topographic position—Topographic position, as represented by the topographic position index (TPI) described under the *Methods* section in McGarigal et al. 2018, was treated as having a static (i.e., constant over time) and universal effect on the relative susceptibility of a cell to wildfire regardless of seral stage or disturbance history. We allowed topographic position to affect susceptibility for the RFR cover types (RFR_M, RFR_X, and RFR_U), but not RFR_ASP. Specifically, all other things being equal, for the RFR variants, susceptibility decreased by 30 percent as the TPI decreased over its full range according to the four-parameter logistic function depicted in figure B.2. However, because the bulk of the landscape varies over a much smaller range of TPI values, the effect on susceptibility is typically much less than 30 percent.

The specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire susceptibility, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B8.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS descriptions (LandFire 2007g,h,m,r) and associated VDDT models, as modified by Safford and Estes.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS descriptions and associated VDDT models, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRPs for the cover types. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality

The cover type-specific factors affecting overstory mortality following wildfire (i.e., fire severity) were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type and seral stage. Each of these two factors is represented as a probability.

Topographic position—The effect of topographic position on mortality was treated identically to its effect on susceptibility (see previous description). Again, the specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire severity, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation)—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each cover type and seral stage (table B8.5); values were originally based on the corresponding LandFire BpS descriptions (LandFire 2007g,h,m,r) and associated VDDT models, but were subsequently modified based on expert input from Safford and Estes.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance for the RFR and RFR_ASP cover types are listed in table B8.6. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007g,h,m,r) and associated models created by using the VDDT, as modified by Safford and Estes, but were subsequently modified to include the moderate canopy cover seral stages not present in the VDDT models. Note that rules governing transitions following high-mortality wildfire are not listed in table B8.6 because high-mortality wildfires always result in transition to the ED seral stage. In addition, conditions in which low-mortality wildfire has no effect on the seral stage (i.e., does not cause a transition) are not listed. For example, the first two rules dictate that a low-mortality wildfire in a cell of RFR_M in the MDC seral stage has a 9-percent chance of transitioning to the MDM stage, a 9-percent chance of transitioning to the MDO stage, and (by implication) an 82-percent chance of remaining in the MDC stage. In addition, by implication (given the absence of a rule), a low-mortality wildfire in the ED, MDO, or LDO seral stage has no effect other than to maintain the cell in that seral stage.

Vegetation Treatments

Dynamic spatial constraints and priorities affecting individual cover types were described under the *Methods* section in McGarigal et al. 2018; here we describe the rules governing seral stage transitions following each unique vegetation treatment (table B8.7). Note that these rules were created by the principals involved in this project and reflect expectations based on the common prescriptions applied today.

Table B8.1—Summary of RFR and RFR_ASP seral stage characteristics average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED/EDA seral stages refer to the residual or legacy overstory from the predisturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
RFR_M	ED	<5 (13 cm)	<25	10	0–45
	MDO	5–19.9 (13-50.5	<40	30	20–185
	MDM	5–19.9	40–70	55	20–185
	MDC	5–19.9	>70	85	20–185
	LDO	≥20 (51 cm)	<40	30	≥80
	LDM	≥20	40–70	55%	≥80
	LDC	≥20	>70	85%	≥80
RFR_X	ED	<5	<25	10	0–85
	MDO	5–19.9	<40	30	40–265
	MDM	5–19.9	40–70	55	40–265
	MDC	5–19.9	>70	85	40–265
	LDO	≥20	<40	30	≥130
	LDM	≥20	40-70	55	≥130
	LDC	≥20	>70	85	≥130
RFR_U	ED	<5	<25	10	0–115
	MDO	5–19.9	<40	30	60–335
	MDM	5–19.9	40–70	55	60–335
	MDC	5–19.9	>70	85	60–335
	LDO	≥20	<40	30	≥180
	LDM	≥20	40–70	55	≥180
	LDC	≥20	>70	85	≥180
RFR_ASP	ED-A	<5	<25	10	0–5
	MD-A	5–15.9	>40	60	10–105
	MD-AC	5–19.9	>40	70	60–205
	LD-CA	≥20	>70	85	160–275
	LDC	≥20	>70	85	≥230

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B8.2—Mapping rules for RFR seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories for d.b.h. (inches) are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	null	any	any	any	any
ED	0–4.9 (0–12.4 cm)	any	any	any	any
MDO	5–19.9 (13–50.5 cm)	any	null	null	null
MDO	5–19.9	any	0–40	any	any
MDO	5–19.9	any	null	0–40	null
MDM	5–19.9	any	40–70	any	any
MDM	5–19.9	any	null	40–70	null
MDC	5–19.9	any	70–100	any	any
MDC	5–19.9	any	null	70–100	any
LDO	≥20 (51 cm)	any	null	null	null
LDO	≥20	any	0–40	any	any
LDO	≥20	any	null	0–40	null
LDM	≥20	any	40–70	any	any
LDM	≥20	any	null	40–70	null
LDC	≥20	any	70–100	any	any
LDC	≥20	any	null	70–100	any

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B8.3—Succession rules for RFR and RFR_ASP seral stages. Note that for RFR cover types, number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class, whereas for RFR_ASP it refers to the number of years in the corresponding seral stage.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
RFR_M	ED	MDC	20–45	any	0.6
	ED	MDC	50	any	1.0
	MDC	LDC	60–135	any	0.4
	MDC	LDC	140	any	1.0
	MDM	LDM	60–135	any	0.4
	MDM	LDM	140	any	1.0
	MDM	MDC	≥15	≥15	0.3
	MDO	LDO	60–135	any	0.4
	MDO	LDO	140	any	1.0
	MDO	MDM	≥15	≥15	0.3
	LDM	LDC	≥15	≥15	0.3
	LDO	LDM	≥15	≥15	0.3
RFR_X	ED	MDO	40–85	any	0.4
	ED	MDO	90	any	1.0
	MDC	LDC	90–175	any	0.3
	MDC	LDC	180	any	1.0
	MDM	LDM	90–175	any	0.3
	MDM	LDM	180	any	1.0
	MDM	MDC	≥20	≥20	0.2
	MDO	LDO	90–175	any	0.3
	MDO	LDO	180	any	1.0
	MDO	MDM	≥20	≥20	0.2
	LDM	LDC	≥20	≥20	0.2
	LDO	LDM	≥20	≥20	0.2
RFR_U	ED	MDO	60–115	any	0.2
	ED	MDO	120	any	1.0

(Table B8.3 continued on next page.)

(Table B8.3 continued)

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
	MDC	LDC	120–215	any	0.2
	MDC	LDC	220	any	1.0
	MDM	LDM	120–215	any	0.2
	MDM	LDM	220	any	1.0
	MDM	MDC	≥30	≥30	0.1
	MDO	LDO	120–215	any	0.2
	MDO	LDO	220	any	1.0
	MDO	MDM	≥30	≥30	0.1
	LDM	LDC	≥30	≥30	0.1
	LDO	LDM	≥30	≥30	0.1
RFR_ASP	ED-A	MD-A	10	any	1.0
	MD-A	MD-AC	50–95	any	0.6
	MD-A	MD-AC	100	any	1.0
	MD-AC	LD-CA	100	any	1.0
	LD-CA	LDC	70	any	1.0

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B8.4—Summary of RFR and RFR_ASP seral stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage, and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
RFR_M	ED	MDC	20	50	23	n/a
	MD	LD	80	190	90	n/a
	MDO	MDM	n/a	n/a	n/a	27
	MDM	MDC	n/a	n/a	n/a	27
	LDO	LDM	n/a	n/a	n/a	27
	LDM	LDC	n/a	n/a	n/a	27
RFR_X	ED	MDO	40	90	47	n/a
	MD	LD	130	270	149	n/a
	MDO	MDM	n/a	n/a	n/a	40
	MDM	MDC	n/a	n/a	n/a	40
	LDO	LDM	n/a	n/a	n/a	40
	LDM	LDC	n/a	n/a	n/a	40
RFR_U	ED	MDO	60	120	79	n/a
	MD	LD	180	340	219	n/a
	MDO	MDM	n/a	n/a	n/a	70
	MDM	MDC	n/a	n/a	n/a	70
	LDO	LDM	n/a	n/a	n/a	70
	LDM	LDC	n/a	n/a	n/a	70
RFR_ASP	ED-A	MD-A	10	10	10	n/a
	MD-A	MD-AC	60	110	63	n/a
	MD-AC	LD-CA	160	210	163	n/a
	LD-CA	LDC	230	280	233	n/a

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B8.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the RFR and RFR_ASP cover types (original values in parentheses).

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
RFR_M	n/a	60	n/a	n/a	n/a
	ED	n/a	58	3	1.00
	MDO	n/a	25	3	0.10 (0.09)
	MDM	n/a	34	3	0.15 (0.17)
	MDC	n/a	55	3	0.25 (0.35)
	LDO	n/a	23	3	0.08 (0.05)
	LDM	n/a	32	3	0.15 (0.16)
	LDC	n/a	52	3	0.25 (0.41)
RFR_X	n/a	40	n/a	n/a	n/a
	ED	n/a	50	3	1.00
	MDO	n/a	50	3	0.10 (0.13)
	MDM	n/a	65	3	0.15 (0.25)
	MDC	n/a	94	3	0.25 (0.50)
	LDO	n/a	43	3	0.08 (0.09)
	LDM	n/a	55	3	0.15 (0.19)
	LDC	n/a	74	3	0.25 (0.38)
RFR_U	n/a	120	n/a	n/a	n/a
	ED	n/a	117	3	1.00
	MDO	n/a	50	3	0.10 (0.09)
	MDM	n/a	69	3	0.15 (0.17)
	MDC	n/a	110	3	0.25 (0.35)
	LDO	n/a	46	3	0.08 (0.05)
	LDM	n/a	63	3	0.15 (0.16)
	LDC	n/a	104	3	0.25 (0.41)

(Table B8.5 continued on next page.)

(Table B8.5 continued)

Cover type	Seral stage[a]	Target fire rotation period (years)	Weibull parameters		Probability of high-mortality fire
			Mean return interval (years)	Shape	
RFR_AS	n/a	60	n/a	n/a	n/a
	ED-A	n/a	58	3	1
	MD-A	n/a	55	3	0.35
	MD-AC	n/a	34	3	0.17
	LD-CA	n/a	32	3	0.16
	LDC	n/a	52	3	0.41

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B8.6—Disturbance rules for RFR and RFR_ASP cover types governing seral stage transitions following a low-mortality wildfire. Note that conditions in which low-mortality wildfire has no effect are not listed.

Cover type	From seral stage[a]	To seral stage[a]	Probability of transition
RFR_M	MDC	MDM	0.09
	MDC	MDO	0.09
	MDM	MDO	0.13
	LDC	LDM	0.08
	LDC	LDO	0.08
	LDM	LDO	0.10
RFR_X	MDC	MDM	0.09
	MDC	MDO	0.09
	MDM	MDO	0.13
	LDC	LDM	0.08
	LDC	LDO	0.08
	LDM	LDO	0.10
RFR_U	MDC	MDM	0.09
	MDC	MDO	0.09
	MDM	MDO	0.13
	LDC	LDM	0.08
	LDC	LDO	0.08
	LDM	LDO	0.10
RFR_ASP	LDC	LD-CA	0.15

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; LD-CA = Late - Conifer and Aspen.

Table B8.7—Disturbance rules for RFR and RFR_ASP cover types governing seral stage transitions following vegetation treatments. Note that treatments not affecting seral stage transitions (e.g., mastication) are not included here.

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
RFR_M	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate, and burn; and (5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1
	Prescribed fire, including cells burned as part of a prescribed fire-only treatment; "cool" burn/"hot" burn transition probabilities	MDC	MDM	0.03/0.05
		MDC	MDO	0/0.03
		MDC	ED	0/0.01
		MDM	MDO	0.05/0.14
		MDM	ED	0/0.01
		LDC	LDM	0.02/0.03
		LDC	LDO	0/0.02
		LDC	ED	0/0.01
		LDM	LDO	0.04/0.11
		LDM	ED	0/0.01
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile and burn treatments	MDC	MDM	0.03
		MDM	MDO	0.05
		LDC	LDM	0.02
		LDM	LDO	0.04
RFR_X;	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate, and burn; and (5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1

(Table B8.7 continued on next page.)

(Table B8.7 continued)

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
	Prescribed fire, including cells burned as part of a prescribed fire-only treatment) "cool" burn/"hot" burn transition probabilities	MDC	MDM	0.05/0.15
		MDC	MDO	0.03/0.09
		MDC	ED	0.01/0.03
		MDM	MDO	0.05/0.15
		MDM	ED	0.01/0.03
		LDC	LDM	0.04/0.12
		LDC	LDO	0.02/0.06
		LDC	ED	0.01/0.03
		LDM	LDO	0.04/0.12
		LDM	ED	0.01/0.03
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile, and burn treatments	MDC	MDM	0.05
		MDC	MDO	0.03
		MDC	ED	0.01
		MDM	MDO	0.05
		MDM	ED	0.01
		LDC	LDM	0.04
		LDC	LDO	0.02
		LDC	ED	0.01
		LDM	LDO	0.04
		LDM	ED	0.01
RFR_ASP	Thinning	MD_AC	MD_A	1
		LDC	MD_A	1
		LD_CA	MD_A	1
	Prescribed fire	LDC	LD_CA	0.1

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

9. Sierran Mixed Conifer (SMC)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; and (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

Sierran Mixed Conifer (SMC) Variant

- EVeg: Regional Dominance Type 1:
  - Mixed Conifer – Fir
  - Mixed Conifer – Pine
- ***Mesic Modifier (SMC_M)***
  - Presettlement Fire Regime Type:
    - Moist Mixed Conifer
  - LandFire BpS model:
    - 0610280: Mediterranean California Mesic Mixed Conifer Forest and Woodland
      This type was created by intersecting a binary xeric/mesic layer with the EVeg layer. SMC cells that intersected with mesic cells were assigned to the mesic modifier.
- ***Xeric Modifier (SMC_X)***
  - Presettlement Fire Regime Type:
    - Dry Mixed Conifer
  - LandFire BpS model:
    - 0610270 Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland
      This type was created by intersecting a binary xeric/mesic layer with the EVeg layer. SMC cells that intersected with xeric cells were assigned to the xeric modifier.
- ***Ultramafic Modifier (SMC_U)***
  - LandFire BpS model:
    - 0710220 Klamath-Siskiyou Upper Montane Serpentine Mixed Conifer Woodland
      This type was created by intersecting an ultramafic soils/geology layer with the EVeg layer. Where ultramafic cells intersected with SMC, they were assigned to the ultramafic modifier.

Sierran Mixed Conifer with Aspen (SMC_ASP) Variant

This type was created by overlaying the NRIS TERRA Inventory of Aspen on the EVeg layer. Where it intersected with SMC, it was assigned to SMC_ASP.

Vegetation Description

Sierran Mixed Conifer (SMC) Variant

The Sierran Mixed Conifer cover type is typically composed of three or more conifer species, sometimes mixed with hardwoods. In forests experiencing the natural fire regime, stand and landscape structure are both highly heterogeneous and age structure is usually uneven. Past management (e.g., logging and fire suppression) and its effects on forest succession have resulted in greater structural homogeneity and a dramatic increase in the presence of shade-tolerant and fire-intolerant tree species. Old-growth stands where fire has been excluded are often multistoried, with the overstory composed of various species (often dominated by pines) and the understory dominated by *Abies concolor* and *Calocedrus decurrens*. In the absence of fire, forested stands can form closed, multilayered canopies with over 100 percent overlapping cover. Such dense stands were probably relatively uncommon before settlement and found in moist microsites, on north slopes, and at higher elevations. When openings occur, shrubs are common in the understory. Before Euro-American settlement, this cover type was dominated by open stand conditions and old forest, but today closed canopy conditions dominated by middle-aged trees are more common, and even-aged stands are widespread (Allen 2005).

Five conifers and one hardwood typify this cover type: *A. concolor, Pseudotsuga menziesii, Pinus ponderosa, Pinus lambertiana, C. decurrens,* and *Quercus kelloggii. Abies concolor* tends to be the most ubiquitous species because it is the competitive dominant in this cover type. It tolerates shade, reproduces prolifically in the absence of fire, and has the ability to survive long periods of overtopping in brush fields. *Pseudotsuga menziesii* replaces *A. concolor* as the competitive dominant at lower elevations. *Pinus ponderosa,* which was historically the dominant species in SMC forest, still dominates at lower elevations and on south slopes, but like *P. lambertiana,* its densities have been much reduced by logging. *Pinus jeffreyi* commonly replaces *P. ponderosa* at higher elevations, on cold sites, or on ultramafic soils. *Abies magnifica* is a minor associate at the highest elevations, as are *Pinus monticola* and *Pinus contorta* ssp. *murrayana*. *Pinus lambertiana* is found throughout the cover type, but its densities have been much reduced by selective logging and white pine blister rust *(Cronartium ribicola). Quercus kelloggii* is a common component in stands on warm, dry sites. This species sprouts prolifically after fire, and although it does best on open sites, it is maintained under adverse conditions, such as overtopping by conifers and thin soils (Allen 2005). In some locations, *Populus tremuloides* is also a component of the stand and, when present, typically dominates during the early seral stages after disturbance (see following).

Ceanothus, Arctostaphylos, Chrysolepis, Prunus, Ribes, Rosa, and *Chamaebatia* are common shrub genera in the understory (Allen 2005). Grasses and forbs are diverse but rarely contribute much cover, except where the stand structure is open.

- ***Mesic Modifier***
  The primary species associated with mesic sites are *A. concolor, P. menziesii, C. decurrens,* and *P. lambertiana. Pinus contorta* ssp. *murrayana* may also be associated with mesic forests at higher elevations. As elevations begin to increase, *A. magnifica* becomes more prominent. *Notholithocarpus densiflora* is an indicator of lower elevation sites with high water availability, either from meteoric or surface water. Understory diversity is often low on these sites as high canopy cover and tree density reduce solar incidence at the soil surface. Very often the ground is covered in thick litter and duff. Some shade-tolerant shrub and herb species occur.
- ***Xeric Modifier***
  Xeric sites are characterized by the presence of shade-intolerant and fire-tolerant conifer species such as *P. ponderosa, P. jeffreyi,* and *P. lambertiana,* as well as varying amounts of more shade-tolerant species such as *A. concolor* and *C. decurrens. Quercus kelloggii* is locally common. The pines normally are prominent on south- and west-facing slopes, *A. concolor* and sometimes *P. menziesii* are prominent on north- and east-facing slopes, and *C. decurrens* is present as a secondary component on all slopes. At lower elevations, *Pinus sabiniana,* and *Q. chrysolepis* may become common associates. Understory shrubs include *Ceanothus, Arctostaphylos,* and *Chamaebatia*, and *Artemisia* and *Purshia* on dry, eastern sites.
- ***Ultramafic Modifier***
  Ultramafic soils support many endemic plant species. Slow-growing and often stunted *P. contorta* ssp. *murrayana* and *P. jeffreyi* occur in combinations or in nearly pure open stands. Other tree associates on ultramafic soils include *P. menziesii, C. decurrens,* and

Pinus attenuata. Hardwoods are usually sparse, but shrubs such as *Arctostaphylos, Quercus, Rhamnus, Notholithocarpus, Rhododendron,* and *Ceanothus* may occur on these sites. Often a dramatic landscape shift occurs across abrupt discontinuities between ultramafics and other rock types. For example, regional stands of dense conifer forests are replaced by stunted and open stands of other conifers, by chaparral, or even by barrens on which woody vegetation is absent (USDA Forest Service 2008).

Sierran Mixed Conifer with Aspen (SMC_ASP) Variant

When *P. tremuloides* co-occurs with SMC on the west side of the Sierran crest, it is typically found in smaller patches, often less than 2 hectares in size. This variant is not subject to the modifiers described earlier because it is found only on mesic sites. Mature stands in which *P. tremuloides* are still dominant are usually relatively open. Average canopy closures of stands in eastern California range from 60 to 100 percent in young and intermediate-aged stands and from 25 to 60 percent in mature stands. The open nature of the stands results in substantial light penetration to the ground (Verner 1988a).

Distribution

Sierran Mixed Conifer (SMC) Variant

SMC generally forms a vegetation band ranging from 500 to 2,000 meters (1,500–6,500 feet). It dominates the western mid-elevation slopes of the Sierra Nevada. Soils supporting SMC are varied in depth and composition, and are derived primarily from Mesozoic granitic, Paleozoic metamorphic rocks, and Cenozoic volcanic rocks (Allen 2005).

We derived a xeric-mesic gradient based on four variables: (1) aspect, (2) potential evapotranspiration, (3) topographic wetness index, and (4) soil water storage. We standardized the variables by z-scores such that higher values corresponded to more mesic environments. Thus, potential evapotranspiration was inverted to maintain this balance. We combined the four variables with equal weights into a topographic position index (TPI), which we split into xeric vs. mesic, with xeric occupying the negative end of the range up to one-fourth of a standard deviation below the mean (zero) and mesic occupying the remaining portion of the spectrum.

- ***Mesic Modifier***
  This type is generally found on favorable slopes, primarily north and east aspects throughout the geographic range, as well as along streams in drier areas. It is more common at higher elevations compared to the xeric type (USDA Forest Service 2008).
- ***Xeric Modifier***
  This type occurs on south- and west-facing aspects (LandFire 2007c). At lower elevations patches may be found on north slopes. At higher elevations this cover type typically occurs on south-, east-, and west-facing aspects.
- ***Ultramafic Modifier***
  Ultramafics have been mapped at various spatial densities throughout the elevational range of the SMC cover type. Low to moderate elevations in ultramafic and serpentinized areas often produce soils low in essential minerals such as calcium, potassium, and nitrogen, and have excessive accumulations of heavy metals such as nickel and chromium. These sites vary widely in the degree of serpentinization and effects on their overlying plant communities (USDA Forest Service 2008). Note that the terms "ultramafic rock" and "serpentine" are broad terms used to describe a number of different but related rock types: serpentinite, peridotite, dunite, pyroxenite, talc, and soapstone, among others (O'Geen et al. 2007).

Sierran Mixed Conifer with Aspen (SMC_ASP) Variant

Sites supporting *P. tremuloides* are usually associated with added soil moisture, that is, azonal wet sites. These sites are found throughout the SMC zone, often close to streams and lakes. Other sites include meadow edges, rock reservoirs, springs, and seeps. Terrain can be simple to complex. At lower elevations, topographic conditions for this type tend toward positions resulting in relatively colder, wetter conditions within the prevailing climate (e.g., ravines, north slopes, wet depressions) (LandFire 2007m).

Disturbances

Wildfire

<u>*Sierran Mixed Conifer (SMC) Variant*</u>

Wildfires are common and frequent in SMC; vegetation mortality caused by wildfire depends on vegetation (i.e., fuel) characteristics and wildfire intensity. Low-mortality fires (≤75 percent overstory mortality) kill small trees and may consume aboveground portions of small oaks, shrubs, and herbs, but do not often kill large trees or belowground organs of most oaks, shrubs, and herbs, which promptly resprout. High-mortality fires (>75 percent overstory mortality) kill trees of all sizes and may kill many of the shrubs and herbs as well. However, high-mortality fires typically kill only the aboveground portions of the oaks, shrubs, and herbs; consequently, most oaks, shrubs, and herbs promptly resprout from surviving belowground organs.

Fire severity in SMC is typically positively correlated with slope position, with higher mortality occurring on upper slopes and ridgetops, especially on southwest-facing aspects.

- ***Mesic Modifier***
  Fire is relatively less common on mesic sites than xeric sites, resulting in a relatively longer fire rotation period; however, when fires do occur they tend to result in higher severity.
- ***Xeric Modifier***
  Fire (of any mortality level) is relatively more common on xeric sites than mesic sites, resulting in a relatively shorter fire rotation period.
- ***Ultramafic Modifier***
  This type has a very limited distribution and consequently limited information for fire occurrence history.

Sierran Mixed Conifer with Aspen (SMC_ASP) Variant

Sites supporting *P. tremuloides* are maintained by both low- and high-mortality wildfire that promote regeneration of *P. tremuloides* from belowground suckers. Upland clones are impaired or suppressed by conifer ingrowth and overtopping and intensive grazing that inhibits growth. In a reference condition scenario, a few stands will advance toward conifer dominance, but in most stands fire disturbance is frequent enough to maintain *P. tremuloides* as a dominant or codominant component of the stand. In the current landscape, where fire has been reduced from reference conditions, there are many more conifer-dominated mixed aspen stands than was typical of the reference period conditions (LandFire 2007m; Verner 1988a).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting models, but with some modifications (e.g., the addition of a moderate canopy cover stage in the mid- and late-seral stages) based on expert input, as follows and as summarized in table B9.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B9.2 for the SMC cover types; SMC_ASP seral stages were mapped manually by using NAIP 2010 Color IR imagery.

Sierran Mixed Conifer (SMC) Variant

- ***Early Development (ED)***
  This seral stage is characterized by the recruitment of a new cohort of early-successional tree species into an open area created by a stand-replacing disturbance. Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover. After disturbance, succession proceeds from an ephemeral herb to a perennial grass-herb community. This grass-herb condition generally lasts only a few years before shifting to a shrub-seedling-sapling condition dominated by any of the following genera: *Arctostaphylos, Ceanothus, Prunus, Ribes,* and *Chamaebatia*, as well as *Q. vaccinifolia.* Tree seedlings and saplings typical of the cover type can occur in either low or high density (i.e., 0–100 percent understory cover) depending on local environmental conditions and climate conditions following the disturbance. In some cases (e.g., favorable climate conditions after the stand-replacing disturbance, coupled with a good seed source), tree seedlings may develop a nearly continuous canopy and succeed relatively quickly to mid-development seral stages. In other cases, and more commonly on xeric or ultramafic sites, chaparral conditions may dominate and persist for long periods of time (LandFire 2007c,d).
- ***Mid-Development – Open Canopy Cover (MDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and shrubs, with a low canopy cover (<40 percent) of pole- to medium-sized (5–20 inches d.b.h.) conifers (LandFire 2007d). Conifer species likely to be present include *A. concolor, C. decurrens, P. ponderosa, P. menziesii,* and *P. lambertiana.* Pines predominate on xeric sites, and firs predominate on mesic sites. *Quercus kelloggii* may occur as well, mostly on warmer slopes and where soils are less productive (LandFire 2007c,d). Ultramafic sites will have similar species composition, especially at edges, but *P. jeffreyi* and *C. decurrens* are relatively more common (O'Geen et al. 2007).
- ***Mid-Development – Moderate Canopy Cover (MDM)***
  This seral stage is characterized by a moderate canopy cover (40–70 percent) of pole- to medium-sized conifers, and is otherwise similar to MDO.
- ***Mid-Development – Closed Canopy Cover (MDC)***
  This seral stage is characterized by a dense canopy cover (>70 percent) of pole- to medium-sized conifers, and is otherwise similar to MDO.
- ***Late Development – Open Canopy Cover (LDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and low shrubs, with a low canopy cover (<40 percent) of large trees (>20 inches d.b.h.). This stage often occurs in small to moderate-sized patches on south-facing aspects and ridgetops. Upper canopy trees may be very large, but overall size classes vary with a patchy distribution and open canopy. This seral stage develops when low-mortality disturbance is fairly frequent; it persists as long as low-mortality fires continue to occur periodically. Conifer species likely to be present include *A. concolor, C. decurrens, P. ponderosa, P. menziesii,* and *P. lambertiana. Quercus kelloggii* may occur as well, mostly on warmer slopes and where soils are less productive (LandFire 2007c,d). Ultramafic sites

will have similar species composition, especially at edges, but *P. jeffreyi* and *C. decurrens* are relatively more common (O'Geen et al. 2007).

- ***Late Development – Moderate Canopy Cover (LDM)***
  This seral stage is characterized by an overstory of large trees with canopy cover 40–70 percent, and is otherwise similar to LDO.
- ***Late Development – Closed Canopy Cover (LDC)***
  This seral stage is characterized by an overstory of large trees with canopy cover greater than 70 percent, and is otherwise similar to LDO.

Sierran Mixed Conifer with Aspen (SMC_ASP) Variant

- ***Early Development – Aspen (ED–A)***
  This seral stage is characterized by the recruitment of a new cohort of early-successional, shade-intolerant tree species (primarily *P. tremuloides*) into an open area created by a stand-replacing disturbance. Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover. Following disturbance, succession proceeds rapidly from an herbaceous layer to shrubs and trees, which invade together (Verner 1988a). *Populus tremuloides* suckers more than 2 meters tall develop within about 10 years (LandFire 2007m).
- ***Mid-Development – Aspen (MD–A)***
  This seral stage is characterized by *P. tremuloides* trees 5–16 inches d.b.h. Canopy cover is highly variable, and can range from 40 to 100 percent. Some understory conifers, including *P. ponderosa, P. lambertiana,* and *A. concolor* are encroaching, but *P. tremuloides* is still the dominant component of the stand (LandFire 2007m).
- ***Mid-Development – Aspen with Conifer (MD–AC)***
  This seral stage is characteristic of stands that have been protected from fire since the last stand-replacing disturbance. *Populus tremuloides* trees are predominantly more than 16 inches d.b.h. Conifers are present and overtopping the *P. tremuloides. Abies concolor* is a typical conifer that is successional to *P. tremuloides,* but other conifers including *P. ponderosa* and *P. lambertiana* are also possible. Conifers are pole- to medium-sized (5–20 inches d.b.h.) with canopy cover greater than 40 percent (LandFire 2007m).
- ***Late Development – Conifer with Aspen (LD–CA)***
  If stands are sufficiently protected from fire such that conifer species overtop *P. tremuloides,* become large (>20 inches d.b.h.) and compose more than 70 percent canopy cover, they may be able to withstand some fire that more sensitive *P. tremuloides* cannot. When this occurs, it creates a stand characterized by late-development conifers, such as *A. concolor, P. ponderosa,* or *P. lambertiana,* but with *P. tremuloides* present in the midstory and understory at varying densities depending on the disturbance history.
- ***Late Development – Closed (LDC)***
  In this seral stage, some P. tremuloides continue to be present in the understory largely as a legacy, but large (>20 inches d.b.h.) conifers are now the dominant tree species, having overtopped the *P. tremuloides,* and compose more than 70 percent canopy cover. Smaller conifers are present in the midstory as well. Conifer species likely to be present include *A. concolor, C. decurrens, P. ponderosa, P. menziesii,* and *P. lambertiana* (LandFire 2007c,d,m,r). Note that this seral stage is analogous to the LDC condition for the SMC variant.

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the SMC and SMC_ASP cover types are listed in table B9.3. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007c,d,m,r) and associated models created by using the Vegetation Dynamics Development Tool (VDDT), as modified by Safford and Estes. They were subsequently modified based on expert input to include probabilistic rather than deterministic seral stage transitions. Specifically, we modified the rules so that stands would gradually, instead of abruptly, transition from one seral stage to the next to reflect stochasticity in the real-world processes governing succession. For example, the first three rules dictate that a cell in the SMC_M cover type, which has been in the ED seral stage for 15–35 years, will have a 40-percent chance of transitioning to MDC, a 25-percent chance of transitioning to MDM, and a 15-percent chance of transitioning to MDO at the beginning of each timestep. Thus, stands will randomly begin transitioning to one of the MD stages after 15 years in the ED stage, but some stands could remain in the ED stage for as much as 40 years to reflect delayed tree establishment. Note that for stands currently in the ED stage and between 15 and 35 years in this stage, the combined chance of transitioning to MD at each timestep is 80 percent; therefore, there is a 20-percent chance of remaining in the ED seral stage at each timestep. The next three rules together dictate that a cell that has been in the ED seral stage for 40 years will have a 100-percent chance of transitioning to one of the MD seral stages; thus, all stands will have transitioned to the MD stage after 40 years since establishment. Note that on xeric and ultramafic sites stands can be delayed in the ED stage for up to 70 or 120 years, respectively, and they always transition to MDO.

Applying the succession rules listed in table B9.3 results in stands transitioning between seral stages in a probabilistic rather than deterministic manner, such that we can compute the average stand age (years) for the transition to the next seral stage, as shown in table B9.4. For example, the first row in table B9.4 indicates that for a cell in the SMC_M cover type in the ED seral stage, the earliest stand age (i.e., number of years since the last stand-replacing disturbance) for transitioning to one of the MD seral stages is 15 years, the latest stand age is 40 years, and the average stand age at the time of the transition is 16 years. Note that the average stand age at transition (16 years) is close to the specified earliest stand age (15 years) because of the relatively high rate (0.8) of transitioning beginning at the specified earliest stand age. Also, the third row in table B9.4 indicates that a cell in the SMC_M cover type in the MDO seral stage will, on average, take 16 years without a low-mortality fire disturbance to transition to the MDM seral stage (i.e., transition from an open-canopy cover, <40 percent, to a moderate-canopy cover, 40–70 percent, condition). Note that a low-mortality fire every 15 years will maintain the stand in the open-canopy condition.

Wildfire Disturbance

<u>*Rotation Period*</u>

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B9.5). FRPs for SMC_M and SMC_X were based on Mallek et al. (2013). FRP for SMC_U was set to be double that of SMC_M, and FRP for SMC_ASP was set to be equal to SMC_M, based on the corresponding LandFire BpS models (LandFire 2007m,r) and expert input from Safford and Estes.

Susceptibility

The cover type-specific factors affecting susceptibility of a cell to wildfire were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire. Each of these two factors is represented as a probability.

Topographic position—Topographic position, as represented by the topographic position index (TPI) described under the *Methods* section in McGarigal et al. 2018, was treated as having a static (i.e., constant over time) and universal effect on the relative susceptibility of a cell to wildfire regardless of seral stage or disturbance history. We allowed topographic position to affect susceptibility for the SMC cover types (SMC_M, S MC_X, and SMC_U), but not SMC_ASP. Specifically, all other things being equal, for the SMC cover types, susceptibility decreased by 30 percent as the TPI decreased over its full range according to the four-parameter logistic function depicted in figure B.2. However, because the bulk of the landscape varies over a much smaller range of TPI values, the effect on susceptibility is typically much less than 30 percent.

The specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire susceptibility, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B9.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS descriptions (LandFire 2007c,d,m,r) and associated VDDT models, as modified by Safford and Estes.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS descriptions and associated VDDT models, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRPs for the cover types. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality

The cover type-specific factors affecting overstory mortality following wildfire (i.e., fire severity) were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type and seral stage. Each of these two factors is represented as a probability.

Topographic position—The effect of topographic position on mortality was treated identically to its effect on susceptibility (see previous description). Again, the specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire severity, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation)—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each cover type and seral stage (table B9.5); values were originally based on the corresponding LandFire BpS descriptions (LandFire 2007c,d,m,r) and associated VDDT models, but were subsequently modified based on expert input from Safford and Estes.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance for the SMC and SMC_ASP cover types are listed in table B9.6. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007c,d,m,r) and associated models created by using the Vegetation Dynamics Development Tool (VDDT), as modified by Safford and Estes, but were subsequently modified to include the moderate canopy cover seral stages not present in the VDDT models. Note that rules governing transitions following high-mortality wildfire are not listed in table B9.6 because high-mortality wildfires always result in transition to the ED seral stage. In addition, conditions in which low-mortality wildfire has no effect on the seral stage (i.e., does not cause a transition) are not listed. For example, the first two rules dictate that a low-mortality wildfire in a cell of SMC_M in the MDC seral stage has a 9-percent chance of transitioning to the MDM stage, a 9-percent chance of transitioning to the MDO stage, and (by implication) an 82-percent chance of remaining in the MDC stage. In addition, by implication (given the absence of a rule), a low-mortality wildfire in the ED, MDO, or LDO seral stage has no effect other than to maintain the cell in that seral stage.

Vegetation Treatments

Dynamic spatial constraints and priorities affecting individual cover types were described under the *Methods* section in McGarigal et al. 2018; here we describe the rules governing seral stage transitions following each unique vegetation treatment (table B9.7). Note that these rules were created by the principals involved in this project and reflect expectations based on the common prescriptions applied today.

Table B9.1—Summary of SMC and SMC_ASP seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED/ED-A seral stages refers to the residual or legacy overstory from the pre-disturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
SMC_M	ED	<5 (13 cm)	<25	10	0–35
	MDO	5–19.9 (13–50.5 cm)	<40	30	15–175
	MDM	5–19.9	40–70	55	15–175
	MDC	5–19.9	>70	85	15–175
	LDO	≥20 (51 cm)	<40	30	≥75
	LDM	≥20	40–70	55	≥75
	LDC	≥20	>70	85	≥75
SMC_X	ED	<5	<25	10	0–65
	MDO	5–19.9	<40	30	30–245
	MDM	5–19.9	40–70	55	30–245
	MDC	5–19.9	>70	85	30–245
	LDO	≥20"	<40	30	≥120
	LDM	≥20	40–70	55	≥120
	LDC	≥20	>70	85	≥120
SMC_U	ED	<5	<25	10	0–115
	MDO	5–19.9	<40	30	60–335
	MDM	5–19.9	40–70	55	60–335
	MDC	5–19.9	>70	85	60–335
	LDO	≥20	<40	30	≥180
	LDM	≥20	40–70	55	≥180
	LDC	≥20	>70	85	≥180
SMC_ASP	ED-A	<5	<25	10	0–5
	MD-A	5–15.9	>40	60	10–105
	MD-AC	5–19.9	>40	70	60–205
	LD-CA	≥20	>70	85	160–275
	LDC	≥20	>70	85	≥230

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B9.2—Mapping rules for SMC seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories for d.b.h. are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	null	any	any	any	any
ED	0–4.9 (0–12.4 cm)	any	any	any	any
MDO	5–19.9 (13–50.5 cm)	any	null	null	null
MDO	5–19.9	any	0–40	any	any
MDO	5–19.9	any	null	0–40	null
MDM	5–19.9	any	40–70	any	any
MDM	5–19.9	any	null	40–70	null
MDC	5–19.9	any	70–100	any	any
MDC	5–19.9	any	null	70–100	any
LDO	≥20 (51 cm)	any	null	null	null
LDO	≥20	any	0–40	any	any
LDO	≥20	any	null	0–40	null
LDM	≥20	any	40–70	any	any
LDM	≥20	any	null	40–70	any
LDC	≥20	any	70–100	any	any
LDC	≥20	any	null	70–100	any

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B9.3—Succession rules for SMC and SMC_ASP seral stages. Note that for SMC cover types, number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class, whereas for SMC_ASP it refers to the number of years in the corresponding seral stage.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
SMC_M	ED	MDC	15–35	any	0.4
	ED	MDM	15–35	any	0.25
	ED	MDO	15–35	any	0.15
	ED	MDC	40	any	0.5
	ED	MDM	40	any	0.3
	ED	MDO	40	any	0.2
	MDC	LDC	60–135	any	0.4
	MDC	LDC	140	any	1.0
	MDM	LDM	60–135	any	0.4
	MDM	LDM	140	any	1.0
	MDM	MDC	≥15	≥15	0.9
	MDO	LDO	60–135	any	0.4
	MDO	LDO	140	any	1.0
	MDO	MDM	≥15	≥15	0.9
	LDM	LDC	≥15	≥15	0.9
	LDO	LDM	≥15	≥15	0.9
SMC_X	ED	MDO	30–65	any	0.4
	ED	MDO	70	any	1.0
	MDC	LDC	90–175	any	0.3
	MDC	LDC	180	any	1.0
	MDM	LDM	90–175	any	0.3
	MDM	LDM	180	any	1.0
	MDM	MDC	≥20	≥20	0.3
	MDO	LDO	90–175	any	0.3
	MDO	LDO	180	any	1.0
	MDO	MDM	≥20	≥20	0.3
	LDM	LDC	≥20	≥20	0.3
	LDO	LDM	≥20	≥20	0.3

(Table B9.3 continued on next page.)

(Table B9.3 continued)

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
SMC_U	ED	MDO	60–115	any	0.2
	ED	MDO	120	any	1.0
	MDC	LDC	120–215	any	0.2
	MDC	LDC	220	any	1.0
	MDM	LDM	120–215	any	0.2
	MDM	LDM	220	any	1.0
	MDM	MDC	≥30	≥30	0.1
	MDO	LDO	120–215	any	0.2
	MDO	LDO	220	any	1.0
	MDO	MDM	≥30	≥30	0.1
	LDM	LDC	≥30	≥30	0.1
	LDO	LDM	≥30	≥30	0.1
SMC_ASP	ED-A	MD-A	10	any	1.0
	MD-A	MD-AC	50–95	any	0.6
	MD-A	MD-AC	100	any	1.0
	MD-AC	LD-CA	100	any	1.0
	LD-CA	LDC	70	any	1.0

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B9.4—Summary of SMC and SMC_ASP seral stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage; and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
SMC_M	ED	MD	15	40	16	n/a
	MD	LD	75	180	83	n/a
	MDO	MDM	n/a	n/a	n/a	16
	MDM	MDC	n/a	n/a	n/a	16
	LDO	LDM	n/a	n/a	n/a	16
	LDM	LDC	n/a	n/a	n/a	16
SMC_X	ED	MD	30	70	37	n/a
	MD	LD	120	250	139	n/a
	MDO	MDM	n/a	n/a	n/a	32
	MDM	MDC	n/a	n/a	n/a	32
	LDO	LDM	n/a	n/a	n/a	32
	LDM	LDC	n/a	n/a	n/a	32
SMC_U	ED	MD	60	120	79	n/a
	MD	LD	180	340	219	n/a
	MDO	MDM	n/a	n/a	n/a	70
	MDM	MDC	n/a	n/a	n/a	70
	LDO	LDM	n/a	n/a	n/a	70
	LDM	LDC	n/a	n/a	n/a	70
SMC_ASP	ED-A	MD-A	10	10	10	n/a
	MD-A	MD-AC	60	110	63	n/a
	MD-AC	LD-CA	160	210	163	n/a
	LD-CA	LDC	230	280	233	n/a

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B9.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the SMC and SMC_ASP cover types (original values in parentheses).

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
SMC_M	n/a	29	n/a	n/a	n/a
	ED	n/a	44	3	0.67 (1.00)
	MDO	n/a	10	3	0.06 (0.14)
	MDM	n/a	13	3	0.09 (0.17)
	MDC	n/a	19	3	0.16 (0.23)
	LDO	n/a	8	3	0.03 (0.08)
	LDM	n/a	13	3	0.06 (0.14)
	LDC	n/a	34	3	0.19 (0.37)
SMC_X	n/a	22	n/a	n/a	n/a
	ED	n/a	32	3	0.80 (1.00)
	MDO	n/a	9	3	0.03 (0.09)
	MDM	n/a	10	3	0.06 (0.26)
	MDC	n/a	11	3	0.15 (0.48)
	LDO	n/a	8	3	0.01 (0.05)
	LDM	n/a	10	3	0.03 (0.11)
	LDC	n/a	16	3	0.10 (0.25)
SMC_U	n/a	60	n/a	n/a	n/a
	ED	n/a	89	3	0.67 (1.00)
	MDO	n/a	21	3	0.06 (0.14)
	MDM	n/a	27	3	0.09 (0.17)
	MDC	n/a	39	3	0.16 (0.23)
	LDO	n/a	16	3	0.03 (0.08)
	LDM	n/a	27	3	0.06 (0.14)
	LDC	n/a	69	3	0.19 (0.37)
SMC_ASP	n/a	29	n/a	n/a	n/a
	ED-A	n/a	44	3	1

(Table B9.5 continued on next page.)

(Table B9.5 continued)

Cover type	Seral stage[a]	Target fire rotation period (years)	Weibull parameters		Probability of high-mortality fire
			Mean return interval (years)	Shape	
	MD-A	n/a	19	3	0.26
	MD-AC	n/a	13	3	0.18
	LD-CA	n/a	13	3	0.14
	LDC	n/a	34	3	0.37

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B9.6—Disturbance rules for SMC and SMC_ASP cover types governing seral stage transitions following a low-mortality wildfire. Note that conditions in which low-mortality wildfire has no effect are not listed.

Cover type	From seral stage[a]	To seral stage[a]	Probability of transition
SMC_M	MDC	MDM	0.09
	MDC	MDO	0.09
	MDM	MDO	0.24
	LDC	LDM	0.27
	LDC	LDO	0.27
	LDM	LDO	0.24
SMC_X	MDC	MDM	0.21
	MDC	MDO	0.21
	MDM	MDO	0.32
	LDC	LDM	0.28
	LDC	LDO	0.28
	LDM	LDO	0.30
SMC_U	MDC	MDM	0.09
	MDC	MDO	0.09
	MDM	MDO	0.24
	LDC	LDM	0.27
	LDC	LDO	0.27
	LDM	LDO	0.24
SMC_ASP	LDC	LD-CA	0.54

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; LD-CA = Late - Conifer and Aspen.

Table B9.7—Disturbance rules for SMC and SMC_ASP cover types governing seral stage transitions following vegetation treatments. Note that treatments not affecting seral-stage transitions (e.g., mastication) are not included here.

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
SMC_M	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate, and burn; and (5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1
	Prescribed fire (including cells burned as part of a prescribed fire-only treatment); "cool" burns/"hot" burn transition probabilities	MDC	MDM	0.03/0.05
		MDC	MDO	0/0.03
		MDC	ED	0/0.01
		MDM	MDO	0.05/0.14
		MDM	ED	0/0.01
		LDC	LDM	0.02/0.03
		LDC	LDO	0/0.02
		LDC	ED	0/0.01
		LDM	LDO	0.04/0.11
		LDM	ED	0/0.01
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile, and burn treatments	MDC	MDM	0.03
		MDM	MDO	0.05
		LDC	LDM	0.02
		LDM	LDO	0.04
SMC_X;	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate, and burn; and (5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1

(Table B9.7 continued on next page.)

(Table B9.7 continued)

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
	Prescribed fire (including cells burned as part of a prescribed fire-only treatment) "cool" burns/"hot" burn transition probabilities	MDC	MDM	0.05/0.15
		MDC	MDO	0.03/0.09
		MDC	ED	0.01/0.03
		MDM	MDO	0.05/0.15
		MDM	ED	0.01/0.03
		LDC	LDM	0.04/0.12
		LDC	LDO	0.02/0.06
		LDC	ED	0.01/0.03
		LDM	LDO	0.04/0.12
		LDM	ED	0.01/0.03
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile, and burn treatments	MDC	MDM	0.05
		MDC	MDO	0.03
		MDC	ED	0.01
		MDM	MDO	0.05
		MDM	ED	0.01
		LDC	LDM	0.04
		LDC	LDO	0.02
		LDC	ED	0.01
		LDM	LDO	0.04
		LDM	ED	0.01
SMC_ASP	Thinning	MD_AC	MD_A	1
		LDC	MD_A	1
		LD_CA	MD_A	1
	Prescribed fire	LDC	LD_CA	0.54

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

10. Subalpine Conifer (SCN)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service; and (3) Marc Meyer, Southern Sierra Province Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

Subalpine Conifer (SCN) Variant

- EVeg: Regional Dominance Type 1:
  - Alpine Mixed Scrub
  - Mountain Hemlock
  - Subalpine Conifers
  - Whitebark Pine
- Presettlement Fire Regime Type:
  - Subalpine Conifer
- LandFire BpS models:
  - 0610330: Mediterranean California Subalpine Woodland
  - 0610440: Northern California Mesic Subalpine Woodland
  - 0610710: Sierra Nevada Alpine Dwarf-Shrubland

Subalpine Conifer with Aspen (SCN_ASP) Variant

This type was created by overlaying the NRIS TERRA Inventory of Aspen on top of the EVeg layer. Where it intersected with SCN, it was assigned to SCN_ASP.

Vegetation Description

Subalpine Conifer (SCN) Variant

The Subalpine Conifer landscape is composed of a mosaic of subalpine forests and woodlands, meadows, rock outcrops, and scrub vegetation types. These forests are open stands of conifers occurring on generally sandy soils or rocky slopes at elevations above the upper montane forest stands of *Abies magnifica.* Stand densities are low. Many, but not all, species form shrubby krummholz forms of growth near their upper elevational limits (Fites-Kaufman et al. 2007).

Tsuga mertensiana is often the most common tree species and mixes with *P. contorta* ssp. *murrayana, A. magnifica, Pinus monticola,* and *P. albicaulis.* In some areas, *P. contorta* ssp. *murrayana* dominates postdisturbance stands. *Tsuga mertensiana* seedlings are relatively shade-tolerant compared to other subalpine conifers and do well under closed-canopy conditions. *Pinus albicaulis* presence increases in the southern portion of the project area (Fites-Kaufman et al. 2007; LandFire 2007j).

Treeline growth of multistemmed trees and shrubby krummholz growth of conifers varies with latitude in the Sierra Nevada. Treeline in the northern Sierra Nevada is dominated by *P. albicaulis,* which frequently occurs with a krummholz form of growth near its upper limit. Several other species may also form krummholz growth forms, including Sierra juniper, *T. mertensiana, P. contorta* ssp. *murrayana*, and occasionally *P. jeffreyi* (Fites-Kaufman et al. 2007).

Although typically of minor importance, a shrub understory may include *Arctostaphylos, Ribes, Phyllodoce,* and *Vaccinium*, and *Kalmia* can occur on moist sites. Herbs present may include *Lupinus, Hieracium, Arabis, Aster,* and *Erigeron*. *Carex* and various grasses are also common (LandFire 2007j; Verner and Purcell 1988).

Subalpine Conifer With Aspen (SCN_ASP) Variant

This SCN variant occurs when these upland forests and woodlands are dominated by *Populus tremuloides* without a significant conifer component. Conifers may be present in these systems; however, these patches of *P. tremuloides* are not typically successional to conifers. The understory structure may be complex with multiple shrub and herbaceous layers, or simple with just an herbaceous layer. The herbaceous layer may be dense or sparse, dominated by graminoids or forbs. Common shrubs include *Acer, Amelanchier, Artemisia, Juniperus, Prunus, Rosa, Shepherdia, Symphoricarpos,* and the dwarf-shrubs *Mahonia* and *Vaccinium*. Common graminoids may include *Bromus, Calamagrostis, Carex, Elymus, Festuca,* and *Hesperostipa*. Associated forbs may be *Achillea, Eucephalus, Delphinium, Geranium, Heracleum, Ligusticum, Lupinus, Osmorhiza, Pteridium, Rudbeckia, Thalictrum, Valeriana, Wyethia,* and many others (LandFire 2007m).

Distribution

Subalpine Conifer (SCN) Variant

The elevational distribution of subalpine forest communities varies with latitude. In the northern Sierra Nevada, such stands begin around 2,450 meters (8,000 feet) and extend up to treeline at 2,750–3,100 meters (9,000–11,000 feet). Both upper and lower limits of subalpine species distributions are driven by a variety of factors, including soil resources, water availability, and climatic limiting factors (Fites-Kaufman et al. 2007).

These forests are characterized by a relatively short growing season with cool temperatures. With the exception of occasional summer thunderstorms, most precipitation falls as snow. Wet years with abundant snowfall can limit growth as these may produce late-lying snowfields that reduce the length of the growing season. Winds can be severe, particularly around exposed ridges. Such wind conditions may produce snow-free winter areas that lower soil temperatures and increase plant water stress (Fites-Kaufman et al. 2007). Because of the solid granite parent material, areas with deeper soil accumulation can become waterlogged for much of the year. For these reasons, the length of the growing season is a function of not only early-season limitation due to low temperatures and snowfields, but also late-season limitations due to drought. Studies of the dynamics of alterations of treeline elevation over the past several millennia have reinforced the significance of complex interactions of both temperature and seasonal water availability in determining such changes (Fites-Kaufman et al. 2007).

Subalpine Conifer with Aspen (SCN_ASP) Variant

Sites supporting *P. tremuloides* are usually associated with added soil moisture, that is, azonal wet sites. These sites are found throughout the SCN zone, often close to streams, lakes, and meadows. Other sites include rock reservoirs, springs, and seeps. Terrain can be simple to complex. At lower elevations, topographic conditions for this type tend toward positions resulting in relatively colder, wetter conditions within the prevailing climate (e.g., ravines, north slopes, wet depressions) (LandFire 2007m). *Populus tremuloides* stands may also be associated with lateral or terminal moraine boulder material, talus-colluvium, rock falls, or lava flows. In addition, pure stands may be found in topographic positions where snow accumulates, mostly at higher north-facing elevations, where snow presence means the growing season is too short to support conifers (Shepperd et al. 2006).

Disturbances

Wildfire

Subalpine Conifer (SCN) Variant

Most of the subalpine areas of the Sierra Nevada were subjected to repeated glaciation during the Pleistocene, and thus have thin and poorly developed soils with little organic matter. The small amounts of litter accumulation and open stand structure of subalpine forests mean that fire is rare (Fites-Kaufman et al. 2007). It is, however, the major disturbance event of this type (LandFire 2007j). Meyer's (2013) review suggests that historical and current fire regimes in subalpine forests are normally climate-limited and dominated by surface fires with crown fires occurring occasionally.

Subalpine Conifer with Aspen (SCN_ASP) Variant

Sites supporting *P. tremuloides* are maintained by stand-replacing disturbances that allow regeneration from belowground suckers. Replacement fire and ground fire are thought to have been common in stable *P. tremuloides* stands historically. Because *P. tremuloides* is associated with mesic conditions, it rarely burns during the normal lightning season. However, during years with little precipitation, stands may be more susceptible to burning. Evidence from fire scars and historical studies show that past fires occurred mostly during the spring and fall. These are typically self-perpetuating stands (LandFire 2007b).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting models, but with some modifications (e.g., the addition of a moderate canopy cover stage in the mid- and late-seral stages) based on expert input, as follows and as summarized in table B10.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B10.2 for the SCN cover types; SCN_ASP seral stages were mapped manually by using NAIP 2010 Color IR imagery.

Subalpine Conifer (SCN) Variant

- ***Early Development (ED)***
  This seral stage is characterized by bare ground, herbs, shrubs, and varying densities of tree seedlings (presumably dependent on seed sources). Dominant species include coniferous tree seedlings, resprouting grasses and shrubs, and invading herbs. Shrubs include *Ribes* species. Herbs and grasses include *Aster*, *Pedicularis*, *Hieracium*, *Arabis*, *Erigeron*, *Carex*, *Luzula*, and *Poa* (LandFire 2007j). Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover.
- ***Mid-Development – Open Canopy Cover (MDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and shrubs, with a low canopy cover (<40 percent) of pole- to medium-sized (5–20 inches d.b.h.) conifers. This seral stage results from delayed tree regeneration and long-term

domination by shrubs and herbs. Shrubs include *Ribes* species. Forbs and grasses include *Aster, Pedicularis, Hieracium, Arabis, Erigeron, Carex, Luzula,* and *Poa*. Trees are represented by seedlings and saplings of *P. contorta* ssp. *murrayana, T. mertensiana, A. magnifica,* and *P. monticola* (LandFire 2007j).

- ***Mid-Development – Moderate Canopy Cover (MDM)***
  This seral stage is characterized by a moderate canopy cover (40–70 percent) of pole- to medium-sized conifers, resulting from rapid regeneration of conifers following stand-replacing disturbance, and is otherwise similar to MDO.
- ***Mid-Development – Closed Canopy Cover (MDC)***
  This seral stage is characterized by a dense canopy cover (>70 percent) of pole- to medium-sized conifers, resulting from rapid regeneration of conifers following stand-replacing disturbance, and is otherwise similar to MDO.
- ***Late Development – Open Canopy Cover (LDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and low shrubs, with a low canopy cover (<40 percent) of large trees (>20 inches d.b.h.). The open stand structure is maintained by mixed-severity fire and insect-caused tree mortality (the latter not modeled at this time). Shrubs include *Ribes* species. Forbs and grasses include *Aster, Pedicularis, Hieracium, Arabis, Erigeron, Carex, Luzula,* and *Poa* (LandFire 2007j).
- ***Late Development – Moderate Canopy Cover (LDM)***
  This seral stage is characterized by an overstory of large trees with canopy cover 40–70 percent, and is otherwise similar to LDO.
- ***Late Development – Closed Canopy Cover (LDC)***
  This seral stage is characterized by an overstory of large trees with canopy cover greater than 70 percent, and is otherwise similar to LDO.

Subalpine Conifer with Aspen (SCN_ASP) Variant

- ***Early Development – Aspen (ED–A)***
  This seral stage is characterized by the recruitment of a new cohort of early-successional, shade-intolerant tree species (primarily *P. tremuloides*) into an open area created by a stand-replacing disturbance. Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover. Following disturbance, succession proceeds rapidly from an herbaceous layer to shrubs and trees, which invade together (Verner 1988a). *Populus tremuloides* suckers over 2 meters tall develop within about 10 years (LandFire 2007b).
- ***Mid-Development – Aspen (MD–A)***
  This seral stage is characterized by *P. tremuloides* trees 5–16 inches d.b.h. Canopy cover is highly variable, and can range from 40 to 100 percent. Some understory conifers are encroaching, but *P. tremuloides* is still the dominant component of the stand (LandFire 2007b).
- ***Late Development – Conifer with Aspen (LD–CA)***
  If stands are sufficiently protected from fire such that conifer species encroach, they may eventually overtop the *P. tremuloides,* which are predominantly larger than 16 inches d.b.h. Total canopy cover is high variable, but generally more than 50 percent. The conifers in this stage may be able to withstand some fire that the more sensitive *P. tremuloides* cannot. When this occurs, it creates a stand characterized by late-development conifers, but with *P. tremuloides* present in the midstory and understory at varying densities depending on the disturbance history.

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the SCN and SCN_ASP cover types are listed in table B10.3. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007j,m) and associated models created by using the Vegetation Dynamics Development Tool (VDDT), as modified by Safford and Estes. They were subsequently modified based on expert input to include probabilistic rather than deterministic seral stage transitions. Specifically, we modified the rules so that stands would gradually, instead of abruptly, transition from one seral stage to the next to reflect stochasticity in the real-world processes governing succession. For example, the first three rules dictate that a cell in the SCN cover type, which has been in the ED seral stage for 20–75 years, will have a 20-percent chance of transitioning to MDC, a 15-percent chance of transitioning to MDM, and a 5-percent chance of transitioning to MDO at the beginning of each timestep. Thus, stands will randomly begin transitioning to one of the MD stages after 20 years in the ED stage, but some stands could remain in the ED stage for as much as 80 years to reflect delayed tree establishment. Note that for stands currently in the ED stage and between 20 and 75 years in this stage, the combined chance of transitioning to MD at each timestep is 40 percent; therefore, there is a 60-percent chance of remaining in the ED seral stage at each timestep. The next three rules together dictate that a cell that has been in the ED seral stage for 80 years will have a 100-percent chance of transitioning to one of the MD seral stages; thus, all stands will have transitioned to the MD stage after 80 years since establishment.

Applying the succession rules listed in table B10.3 results in stands transitioning between seral stages in a probabilistic rather than deterministic manner, such that we can compute the average stand age (years) for the transition to the next seral stage, as shown in table B10.4. For example, the first row in table B10.4 indicates that for a cell in the SCN cover type in the ED seral stage, the earliest stand age (i.e., number of years since the last stand-replacing disturbance) for transitioning to one of the MD seral stages is 20 years, the latest stand age is 80 years, and the average stand age at the time of the transition is 27 years. Also, the third row in table B10.4 indicates that a cell in the SCN cover type in the MDO seral stage will, on average, take 52 years without a low-mortality fire disturbance to transition to the MDM seral stage (i.e., transition from an open-canopy cover, <40 percent, to a moderate-canopy cover, 40–70 percent, condition). Note that a low-mortality fire every 40 years will maintain the stand in the open-canopy condition.

Wildfire Disturbance

<u>Rotation Period</u>

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B10.5). FRP for the SCN cover type was based on Mallek et al. (2013), whereas the FRP for the SCN_ASP cover type was based on the corresponding LandFire BpS model (LandFire 2007m) and expert input from Safford and Estes.

<u>*Susceptibility*</u>—The only cover type-specific factor affecting susceptibility of a cell to wildfire was fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire, which was represented as a relative probability.

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B10.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS descriptions (LandFire 2007j,m) and associated VDDT models, as modified by Safford and Estes.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS descriptions and associated VDDT models, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRPs for the cover types. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality

The only cover type-specific factor affecting overstory mortality following wildfire (i.e., fire severity) was fuel characteristics, as represented by vegetation cover type and seral stage, which was represented as a relative probability.

Fuels (vegetation)—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each cover type and seral stage (table B10.5); values were based on the corresponding LandFire BpS descriptions (LandFire 2007j,m) and associated VDDT models, as modified by Safford and Estes.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance for the SCN cover type are listed in table B10.6. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007j) and associated models created by using the Vegetation Dynamics Development Tool (VDDT), as modified by Safford and Estes, but were subsequently modified to include the moderate canopy cover seral stages not present in the VDDT models. Note that rules governing transitions following high-mortality wildfire are not listed in table B10.6 because high-mortality wildfires always result in transition to the ED seral stage. In addition, conditions in which low-mortality wildfire has no effect on the seral stage (i.e., does not cause a transition) are not listed. For example, the first two rules dictate that a low-mortality wildfire in a cell of SCN in the MDC seral stage has a 50-percent chance of transitioning to the MDM stage, a 50-percent chance of transitioning to the MDO stage, and (by implication) a 0-percent chance of remaining in the MDC stage.

In addition, by implication (given the absence of a rule), a low-mortality wildfire in the ED, MDO, or LDO seral stage has no effect other than to maintain the cell in that seral stage. Similarly, for cells in the SCN_ASP cover type, all low-mortality wildfires maintain the stand in the current seral stage and thus are not listed.

Table B10.1—Summary of SCN and SCN_ASP seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED/ED-A seral stages refer to the residual or legacy overstory from the pre-disturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
SCN	ED	<5 (13 cm)	<25	10	0–75
	MDO	5–19.9 (13–50.5	<40	30	20–215
	MDM	5–19.9	40–70	55	20–215
	MDC	5–19.9	>70	85	20–215
	LDO	≥20 (51 cm)	<40	30	≥80
	LDM	≥20	40–70	55	≥80
	LDC	≥20	>70	85	≥80
SCN_ASP	ED-A	<5	<25	10	0–5
	MD-A	5–15.9 (13–40.4	>40	60	10–205
	LD-CA	≥16 (40.6 cm)	>50	70	≥90

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; LD-CA = Late - Conifer and Aspen.

Table B10.2—Mapping rules for SCN seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories for d.b.h. are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	null	any	any	any	any
ED	0–4.9 (0–12.4 cm)	any	any	any	any
MDO	5–19.9 (13–50.5	any	null	null	null
MDO	5–19.9	any	0–40	any	any
MDO	5–19.9	any	null	0–40	null
MDM	5–19.9	any	40–70	any	any
MDM	5–19.9	any	null	40–70	null
MDC	5–19.9	any	70–100	any	any
MDC	5–19.9	any	null	70–100	any
LDO	≥20 (51 cm)	any	null	null	null
LDO	≥20	any	0–40	any	any
LDO	≥20	any	null	0–40	null
LDM	≥20	any	40–70	any	any
LDM	≥20	any	null	40–70	any
LDC	≥20	any	70–100	any	any
LDC	≥20	any	null	70–100	any

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B10.3—Succession rules for SCN and SCN_ASP seral stages. Note that for SCN cover types, number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class, whereas for SCN_ASP it refers to the number of years in the corresponding seral stage.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
SCN	ED	MDC	20-75	any	0.2
	ED	MDM	20-75	any	0.15
	ED	MDO	20-75	any	0.05
	ED	MDC	80	any	0.6
	ED	MDM	80	any	0.3
	ED	MDO	80	any	0.1
	MDC	LDC	60-135	any	0.4
	MDC	LDC	140	any	1.0
	MDM	LDM	60-135	any	0.4
	MDM	LDM	140	any	1.0
	MDM	MDC	≥40	≥40	0.3
	MDO	LDO	60-135	any	0.4
	MDO	LDO	140	any	1.0
	MDO	MDM	≥40	≥40	0.3
	LDM	LDC	≥40	≥40	0.3
	LDO	LDM	≥40	≥40	0.3
SCN_ASP	ED-A	MD-A	10	any	1.0
	MD-A	LD-CA	80-195	any	0.3
	MD-A	LD-CA	200	any	1.0

[a] ED = Early - all structures; MDC = Mid-closed; MDM = Mid-moderate; MDO = Mid-open; LDC = Late-closed; LDM = Late-moderate; LDO = Late-open; ED-A = Early – Aspen; MD-A = Mid – Aspen; LD-CA = Late - Conifer and Aspen.

Table B10.4— Summary of SCN and SCN_ASP seral stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage; and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. ofyears without low-mortality fire to transition
SCN	ED	MD	20	80	27	n/a
	MD	LD	80	220	94	n/a
	MDO	MDM	n/a	n/a	n/a	52
	MDM	MDC	n/a	n/a	n/a	52
	LDO	LDM	n/a	n/a	n/a	52
	LDM	LDC	n/a	n/a	n/a	52
SCN_ASP	ED-A	MD-A	10	10	10	n/a
	MD-A	LD-CA	90	210	102	n/a

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; LD-CA = Late - Conifer and Aspen.

Table B10.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the SCN and SCN_ASP cover types.

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
SCN	n/a	296	n/a	n/a	n/a
	ED	n/a	500	3	1.00
	MDO	n/a	303	3	0.61
	MDM	n/a	317	3	0.63
	MDC	n/a	333	3	0.67
	LDO	n/a	303	3	0.61
	LDM	n/a	317	3	0.63
	LDC	n/a	333	3	0.67
SCN_ASP	n/a	296	n/a	n/a	n/a
	ED-A	n/a	200	3	1
	MD-A	n/a	333	3	0.67
	LD-CA	n/a	317	3	0.63

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; LD-CA = Late - Conifer and Aspen.

Table B10.6—Disturbance rules for SCN cover types governing seral stage transitions following a low-mortality wildfire. Note that conditions in which low-mortality wildfire has no effect are not listed.

Cover type	From seral stage[a]	To seral stage[a]	Probability of transition
SCN	MDC	MDM	0.5
	MDC	MDO	0.5
	MDM	MDO	1.0
	LDC	LDM	0.5
	LDC	LDO	0.5
	LDM	LDO	1.0

[a] MDC = Mid-closed; MDM = Mid-moderate; MDO = Mid-open; LDC = Late-closed; LDM = Late-moderate; LDO = Late-open.

11. Western White Pine (WWP)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; and (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

- EVeg: Regional Dominance Type 1:
  - Western White Pines
- Presettlement Fire Regime Type:
  - Western White Pine
- LandFire BpS model:
  - 0711720: Sierran-Intermontane Desert Western White Pine-White Fir Woodland

Vegetation Description

Pinus monticola is locally abundant in subalpine habitats along the west slope of the Sierra Nevada, where it may occur in small pure stands. More commonly, it mixes with *P. contorta* ssp. *murrayana*, *P. jeffreyi, Tsuga mertensiana,* and *Abies magnifica* (particularly on the west side of the Sierra crest) and *A. concolor* or *P. ponderosa* (particularly on the east side) (Fites-Kaufman et al. 2007; LandFire 2007t).

This system tends to be more woodland than forest in character, and the undergrowth is more open and drier, with little shrub or herbaceous cover. Tree regeneration is less prolific than in other mixed-montane conifer systems of the Cascades, Sierras, and California Coast Ranges (LandFire 2007t). *Pinus monticola* generally maintains a tree form of growth up nearly to treeline, where it is commonly replaced by other subalpine species on rocky ridges (Fites-Kaufman et al. 2007).

Understories are typically open, with moderately low shrub cover and diversity, and include *Arctostaphylos, Chrysolepis, Ceanothus*, and *Ribes*. Common herbaceous taxa include *Arnica, Festuca, Poa, Carex, Pyrola,* and *Hieracium*. In openings, *Wyethia* can be abundant (LandFire 2007t).

Distribution

In the northern Sierra Nevada, these forests and woodlands are found in the upper montane to subalpine zones, at elevations generally over 2,000 meters (6,600 feet). This cover type is found on all slopes and aspects, although it occurs more frequently on drier areas. This cover type generally occurs on basalts, andesite, glacial till, basaltic rubble, colluvium, or volcanic ash-derived soils. These soils have characteristic features of good aeration and drainage, coarse textures, circumneutral to slightly acidic pH, an abundance of mineral material, rockiness, and periods of drought during the growing season. This system occurs somewhat in the rainshadow of the Sierras and has a more continental climate, similar to the northern Great Basin (LandFire 2007t).

Disturbances

Wildfire

Most fires in this cover type are low-mortality fires that allow large areas of the landscape to develop mature characteristics. Occasional severe fires are driven by weather extremes (LandFire 2007t). Young trees are very susceptible to mortality from fire, but mature *P. monticola* is moderately fire resistant. After a stand-replacing fire, *P. monticola* will seed in from adjacent areas. After a cool to moderate fire that leaves a mosaic of mineral soil and duff, it will reoccupy the site from seed stored in the seedbank. Overall, *P. monticola* is a fire-dependent, seral species. Fire suppression has resulted in decreased stocking levels, mostly due to the increase in white pine blister rust *(Cronartium ribicola)*. Periodic, stand-replacing fire or other disturbance is needed to remove competing conifers and allow *P. monticola* to develop (Griffith 1992).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting model, but with some modifications (e.g., the addition of a moderate canopy cover stage in the mid- and late-seral stages) based on expert input, as follows and as summarized in table B11.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B11.2 for the WWP cover type.

- ***Early Development (ED)***
  This seral stage is characterized by an open stand of *P. monticola* and *A. magnifica,* as well as other tree seedlings, mixed with grasses and shrubs. Early-seral dominant species include *Ceanothus* and various grasses. A portion of these stands enter a shrub-dominated stage that can persist for a few decades (LandFire 2007t). Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover.
- ***Mid-Development – Open Canopy Cover (MDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and shrubs, with a low canopy cover (<40 percent) of pole- to medium-sized (5–20 inches d.b.h.) conifers. Conifer species likely to be present include *P. monticola*, *A. magnifica*, and *P. jeffreyi* (LandFire 2007t).
- ***Mid-Development – Moderate Canopy Cover (MDM)***
  This seral stage is characterized by a moderate canopy cover (40–70 percent) of pole- to medium-sized conifers, and is otherwise similar to MDO.
- ***Mid-Development – Closed Canopy Cover (MDC)***
  This seral stage is characterized by a dense canopy cover (>70 percent, although rarely, if ever, exceeding 80 percent) of pole- to medium-sized conifers, and is otherwise similar to MDO.
- ***Late Development – Open Canopy Cover (LDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and low shrubs, with a low canopy cover (<40 percent) of large trees (>20 inches d.b.h.). The open stand structure is maintained by mixed-severity fire and insect-caused tree mortality (the latter not modeled at this time) (LandFire 2007t).
- ***Late Development – Moderate Canopy Cover (LDM)***
  This seral stage is characterized by an overstory of large trees with canopy cover 40–70 percent, and is otherwise similar to LDO.
- ***Late Development – Closed Canopy Cover (LDC)***
  This seral stage is characterized by an overstory of large trees with canopy cover greater than 70 percent (although rarely, if ever, exceeding 80 percent), and is otherwise similar to LDO.

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the WWP cover type are listed in table B11.3. These rules were initially based on the corresponding LandFire BpS description (LandFire 2007t) and associated model created by using the Vegetation Dynamics Development Tool (VDDT). They were subsequently modified based on expert input to include probabilistic rather than deterministic seral stage transitions. Specifically, we modified the rules so that stands would gradually, instead of abruptly, transition from one seral stage to the next to reflect stochasticity in the real-world processes governing succession. For example, the first three rules dictate that a cell in the WWP cover type, which has been in the ED seral stage for 30–65 years, will have a 40-percent chance of transitioning to MDO, a 20-percent chance of transitioning to MDM, and a 10-percent chance of transitioning to MDC at the beginning of each timestep. Thus, stands will randomly begin transitioning to one of the MD stages after 30 years in the ED stage, but some stands could remain in the ED stage for as much as 70 years to reflect delayed tree establishment. Note that for stands currently in the ED stage and between 30 and 65 years in this stage, the combined chance of transitioning to MD at each timestep is 70 percent; therefore, there is a 30-percent chance of remaining in the ED seral stage at each timestep. The next three rules together dictate that a cell that has been in the ED seral stage for 70 years will have a 100-percent chance of transitioning to one of the MD seral stages; thus, all stands will have transitioned to the MD stage after 70 years since establishment.

Applying the succession rules listed in table B11.3 results in stands transitioning between seral stages in a probabilistic rather than deterministic manner, such that we can compute the average stand age (years) for the transition to the next seral stage, as shown in table B11.4. For example, the first row in table B11.4 indicates that for a cell in the WWP cover type in the ED seral stage, the earliest stand age (i.e., number of years since the last stand-replacing disturbance) for transitioning to one of the MD seral stages is 30 years, the latest stand age is 70 years, and the average stand age at the time of the transition is 32 years. Also, the third row in table B11.4 indicates that a cell in the WWP cover type in the MDO seral stage will, on average, take 16 years without a low-mortality fire disturbance to transition to the MDM seral stage (i.e., transition from an open-canopy cover, <40 percent, to a moderate-canopy cover, 40–70 percent, condition). Note that a low-mortality fire every 40 years will maintain the stand in the open-canopy condition.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target fire rotation periods (FRPs) were specified by cover type (table B11.5). FRP for the WWP cover type was based on Van de Water and Safford (2011) and expert input from Safford and Estes.

Susceptibility

The cover type-specific factors affecting susceptibility of a cell to wildfire were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire. Each of these two factors is represented as a probability.

Topographic position—Topographic position, as represented by the topographic position index (TPI) described under the *Methods* section in McGarigal et al. 2018, was treated as having a static (i.e., constant over time) and universal effect on the relative susceptibility of a cell to wildfire regardless of seral stage or disturbance history. Specifically, all other things being equal, for the WWP cover type, susceptibility decreased by 30 percent as the TPI index decreased over its full range according to the four-parameter logistic function depicted in figure B.2. However, because the bulk of the landscape varies over a much smaller range of TPI values, the effect on susceptibility is typically much less than 30 percent.

The specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire susceptibility, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number of years) since the last fire according to the cumulative Weibull function and the parameters listed in table B11.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS description (LandFire 2007t) and associated VDDT model.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS description and associated VDDT model; taken collectively, these values do not necessarily agree with the target FRP for the cover type. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality

The cover type-specific factors affecting overstory mortality following wildfire (i.e., fire severity) were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type and seral stage. Each of these two factors is represented as a probability.

Topographic position—The effect of topographic position on mortality was treated identically to its effect on susceptibility (see previous description). Again, the specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire severity, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation)—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each seral stage (table B11.5); values were based on the corresponding LandFire BpS description (LandFire 2007t) and associated VDDT model.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance for the WWP cover type are listed in table B11.6. These rules were initially based on the corresponding LandFire BpS description (LandFire 2007t) and associated model created by using the VDDT, but were subsequently modified to include the moderate canopy cover seral stages not present in the VDDT model. Note that rules governing transitions following high-mortality wildfire are not listed in table B11.6 because high-mortality wildfires always result in transition to the ED seral stage. In addition, conditions in which low-mortality wildfire has no effect on the seral stage (i.e., does not cause a transition) are not listed. For example, the first two rules dictate that a low-mortality wildfire in a cell of WWP in the MDC seral stage has a 40-percent chance of transitioning to the MDM stage, a 40-percent chance of transitioning to the MDO stage, and (by implication) a 20-percent chance of remaining in the MDC stage. In addition, by implication (given the absence of a rule), a low-mortality wildfire in the ED, MDO, or LDO seral stage has no effect other than to maintain the cell in that seral stage.

Vegetation Treatments

Dynamic spatial constraints and priorities affecting individual cover types were described under the *Methods* section in McGarigal et al. 2018; here we describe the rules governing seral stage transitions following each unique vegetation treatment (table B11.7). Note that these rules were created by the principals involved in this project and reflect expectations based on the common prescriptions applied today.

Table B11.1—Summary of WWP seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED seral stages refer to the residual or legacy overstory from the predisturbance stand.

Cover type	Seral stage[a]	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
WWP	ED	<5 (13 cm)	<25	10	0–65
	MDO	5–19.9 (13–50.5	<40	30	30–185
	MDM	5–19.9	40–70	55	30–185
	MDC	5–19.9	>70	75	30–185
	LDO	≥20 (51 cm)	<40	30	≥100
	LDM	≥20	40–70	55	≥100
	LDC	≥20	>70	75	≥100

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B11.2—Mapping rules for WWP seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories for d.b.h. are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	0–4.9 (0–12.4 cm)	any	any	any	any
MDO	5–19.9 (13–50.5 cm)	any	0–40	any	any
MDM	5–19.9	any	40–70	any	any
MDC	5–19.9	any	70–100	any	any
MDC	5–19.9	any	null	70–100	any
LDO	≥20 (51 cm)	any	0–40	any	any
LDM	≥20	any	40–70	any	any
LDC	≥20	any	70–100	any	any

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B11.3—Succession rules for WWP seral stages. Note that number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
WWP	ED	MDO	30–65	any	0.4
	ED	MDM	30–65	any	0.2
	ED	MDC	30–65	any	0.1
	ED	MDO	70	any	0.6
	ED	MDM	70	any	0.25
	ED	MDC	70	any	0.15
	MDC	LDC	70–115	any	0.4
	MDC	LDC	120	any	1.0
	MDM	LDM	70–115	any	0.4
	MDM	LDM	120	any	1.0
	MDM	MDC	≥15	≥15	0.8
	MDO	LDO	70–115	any	0.4
	MDO	LDO	120	any	1.0
	MDO	MDM	≥15	≥15	0.8
	LDM	LDC	≥15	≥15	0.8
	LDO	LDM	≥15	≥15	0.8

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B11.4—Summary of WWP seral stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage; and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
WWP	ED	MD	30	70	32	n/a
	MD	LD	100	190	109	n/a
	MDO	MDM	n/a	n/a	n/a	16
	MDM	MDC	n/a	n/a	n/a	16
	LDO	LDM	n/a	n/a	n/a	16
	LDM	LDC	n/a	n/a	n/a	16

[a] ED = Early - all structures; MD = mid development; LD = late development; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed;

Table B11.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the WWP cover type.

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
WWP	n/a	88	n/a	n/a	n/a
	ED	n/a	33	3	0.17
	MDO	n/a	18	3	0.09
	MDM	n/a	24	3	0.12
	MDC	n/a	33	3	0.17
	LDO	n/a	18	3	0.09
	LDM	n/a	24	3	0.12
	LDC	n/a	33	3	0.17

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B11.6—Disturbance rules for WWP cover type governing seral stage transitions following a low-mortality wildfire. Note that conditions in which low-mortality wildfire has no effect are not listed.

Cover type	From seral stage[a]	To seral stage[a]	Probability of transition
WWP	MDC	MDM	0.4
	MDC	MDO	0.4
	MDM	MDO	0.4
	LDC	LDM	0.4
	LDC	LDO	0.4
	LDM	LDO	0.4

[a] MDC = Mid-closed; MDM = Mid-moderate; MDO = Mid-open; LDC = Late-closed; LDM = Late-moderate; LDO = Late-open.

Table B11.7—Disturbance rules for the WWP cover type governing seral stage transitions following vegetation treatments. Note that treatments not affecting seral stage transitions (e.g., mastication) are not included here.

Cover type	Treatment type	From seral stage[a]	To seral stage[a]	Probability of transition
WWP	Clearcut and Group cuts	Any	ED	1
	Thinning, including cells thinned in: (1) matrix thin and group cut; (2) thin and burn; (3) thin, hand cut, pile, and burn; (4) thin, masticate and burn; and (5) matrix thin, group cut, and burn treatments	MDC	MDM	1
		MDM	MDO	1
		LDC	LDM	1
		LDM	LDO	1
	Prescribed fire, including cells burned as part of a prescribed fire-only treatment); "cool" burn/"hot" burn transition probabilities	MDC	MDM	0.03/0.05
		MDC	MDO	0/0.03
		MDC	ED	0/0.01
		MDM	MDO	0.05/0.14
		MDM	ED	0/0.01
		LDC	LDM	0.02/0.03
		LDC	LDO	0/0.02
		LDC	ED	0/0.01
		LDM	LDO	0.04/0.11
		LDM	ED	0/0.01
	Thin and burn, including cells burned only as part of: (1) thin and burn; and (2) hand cut, pile, and burn treatments	MDC	MDM	0.03
		MDM	MDO	0.05
		LDC	LDM	0.02
		LDM	LDO	0.04

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

12. Yellow Pine (YPN)

Reviewed by: (1) Hugh Safford, Regional Ecologist, USDA Forest Service; and (2) Becky Estes, Central Sierra Province Ecologist, USDA Forest Service.

Cover Type Classification and Crosswalks

Yellow Pine (YPN) Variant

- EVeg: Regional Dominance Type 1:
  - Eastside Pine
  - Jeffrey Pine
  - Ponderosa Pine
- Presettlement Fire Regime Type:
  - Yellow Pine
- LandFire BpS model:
  - 0610310: California Montane Jeffrey Pine (–Ponderosa Pine) Woodland

Yellow Pine With Aspen (YPN_ASP) Variant

This type was created by overlaying the NRIS TERRA Inventory of Aspen on the EVeg layer. Where it intersected with YPN, it was assigned to YPN_ASP.

Vegetation Description

Yellow Pine (YPN) Variant

The Yellow Pine cover type is characterized by yellow pine species such as *Pinus ponderosa* or *P. jeffreyi* that occur on the east side of the Sierra crest (LandFire 2007f). Relatively pure stands of yellow pine may occur, or they may mix with other tree species, including *Abies concolor, Juniperus occidentalis, P. contorta* ssp. *murrayana*, and *Quercus kelloggii* (Fites-Kaufman et al. 2007; Fitzhugh 1988a). The understory may include both montane forest and Great Basin shrubs, such as *Ceanothus, Arctostaphylos, Symphoricarpos, Artemisia tridentata, Purshia tridentata, Ericameria nauseosa, Cercocarpus,* and *Holodiscus.* Herbaceous plants may include *Wyethia, Balsamorhiza sagittata, Festuca, Calamagrostis,* and Elymus (Fitzhugh 1988a; LandFire 2007f).

Where fire occurs naturally, a mosaic of uneven-aged patches develops, with open spaces and dense sapling stands. *Quercus kelloggii* or *J. occidentalis* may form an understory, but pure stands of pine also are found. An open stand of low shrubs and a grassy herb layer are typical. Crowns of pines are open, allowing light, wind, and rain to penetrate, whereas other associated trees provide more dense foliage (Fitzhugh 1988a).

Yellow Pine With Aspen (YPN_ASP) Variant

This YPN variant occurs when these upland forests and woodlands are dominated by *Populus tremuloides* without a significant conifer component, and are often termed “stable aspen.” The understory structure may be complex with multiple shrub and herbaceous layers, or simple with just an herbaceous layer. The herbaceous layer may be dense or sparse, dominated by graminoids or forbs. Common shrubs include *Acer, Amelanchier, Artemisia, Juniperus, Prunus, Rosa, Shepherdia, Symphoricarpos,* and the dwarf-shrubs *Mahonia* and *Vaccinium*. Common graminoids may include *Bromus, Calamagrostis, Carex, Elymus, Festuca,* and *Hesperostipa*. Associated forbs may be *Achillea, Eucephalus, Delphinium, Geranium, Heracleum, Ligusticum, Lupinus, Osmorhiza, Pteridium, Rudbeckia, Thalictrum, Valeriana, Wyethia,* and many others (LandFire 2007a).

Distribution

Yellow Pine (YPN) Variant

This cover type occurs on all aspects from about 1,200 to 2,000 meters (4,000–6,500 feet) in elevation, east of the Sierra Nevada crest (Fitzhugh 1988a). It is usually found on volcanic and granitic substrates, in shallow soils with a frigid soil temperature regime (LandFire 2007f).

Yellow Pine With Aspen (YPN_ASP) Variant

Sites supporting *P. tremuloides* are usually associated with added soil moisture, that is, azonal wet sites. These sites are found throughout the YPN zone, often close to streams, lakes, and meadows. Other sites include rock reservoirs, springs, and seeps. Terrain can be simple to complex. At lower elevations, topographic conditions for this type tend toward positions resulting in relatively colder, wetter conditions within the prevailing climate (e.g., ravines, north slopes, wet depressions) (LandFire 2007a). *Populus tremuloides* stands may also be associated with lateral or terminal moraine boulder material, talus-colluvium, rock falls, or lava flows. In addition, pure stands may be found in topographic positions where snow accumulates, mostly at higher north-facing elevations, where snow presence means the growing season is too short to support conifers (Shepperd et al. 2006).

Disturbances

Wildfire

Yellow Pine (YPN) Variant

Wildfires are common and frequent; mortality depends on vegetation vulnerability and wildfire intensity. Low-mortality fires kill small trees and consume aboveground portions of shrubs and herbs, but do not kill large trees or belowground organs of most shrubs and herbs, which promptly resprout. High-mortality fires kill large as well as small trees, and may kill many of the shrubs and herbs as well. Fire kills the aboveground portions of the shrubs and herbs, but most shrubs and herbs resprout from surviving belowground organs.

The relatively long needles of yellow pines and relatively open structure of these stands make for dry surface and ground fuels that burn readily. Thus, fires in these stands burn more frequently than those in adjacent forests (Fites-Kaufman et al. 2007). In fact, fire is an integral part of the ecology of yellow pines. Fire has allowed yellow pines to dominate sites where they are the potential climax species, as well as sites where seral to more shade-tolerant tree species would occur otherwise. *Pinus ponderosa* and *P. jeffreyi* have evolved with thick bark and an open crown structure that allow them to survive most fires. Mature trees will self-prune, leaving a smooth bole that reduces aerial fire spread. Fire also creates favorable seedbeds for seedling establishment (Habeck 1992).

Yellow Pine With Aspen (YPN_ASP) Variant

Sites supporting *P. tremuloides* are maintained by stand-replacing disturbances that allow regeneration from belowground suckers. Replacement fire and ground fire are thought to have been common in stable *P. tremuloides* stands historically. Because *P. tremuloides* is associated with mesic conditions, it rarely burns during the normal lightning season. However, during years with little precipitation, stands may be more susceptible to burning. Evidence from fire scars and historical studies show that past fires occurred mostly during the spring and fall. These are typically self-perpetuating stands (LandFire 2007a).

Van de Water and Safford (2011) found a mean fire return interval (FRI) of 19 years, median of 20 years, mean minimum interval of 10 years, and mean maximum interval of 90 years for aspen. The LandFire model for northern Sierra Nevada "stable aspen" predicts a mean FRI of 31 years. Replacement FRI has a mean of 68 years with a range of 50–300 years, mixed-severity FRI has a mean of 57 years with a range of 20–60 years, and low-severity fire is not modeled (LandFire 2007a).

Other Disturbances

Other disturbances are not currently being modeled, but may, depending on the seral stage and mortality levels, reset patches to early development, maintain existing seral stages, or shift or accelerate succession to a more open condition. All of the tree species associated with this vegetation type are susceptible to a wide variety of pathogens and insects.

Seral Stages

The classification of seral stages originated from the corresponding LandFire biophysical setting models, but with some modifications (e.g., the addition of a moderate canopy cover stage in the mid- and late-seral stages) based on expert input, as follows and as summarized in table B12.1. The seral stage map corresponding to this classification for the current landscape was derived from the EVeg dataset and the rules in table B12.2 for the YPN cover types; YPN_ASP seral stages were mapped manually by using NAIP 2010 Color IR imagery.

Yellow Pine (YPN) Variant

- ***Early Development (ED)***
  This seral stage is characterized by the recruitment of a new cohort of early-successional, shade-intolerant tree species (primarily *P. ponderosa* or *P. jeffreyi*) into an open area created by a stand-replacing disturbance. Following such disturbance, some sites are dominated by dense shrub stands composed of *P. tridentata, Arctostaphylos,* or *Ceanothus*, or a combination thereof, depending on location. Other postfire sites are more open and dominated by dense pine seedlings, bunchgrasses, and forbs (LandFire 2007f). Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover.
- ***Mid-Development – Open Canopy Cover (MDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and shrubs, with a low canopy cover (<40 percent) of pole- to medium-sized (5–20 inches d.b.h.) conifers. This seral stage results from delayed tree regeneration or frequent burning (LandFire 2007f).
- ***Mid-Development – Moderate Canopy Cover (MDM)***
  This seral stage is characterized by a moderate canopy cover (40–70 percent) of pole- to medium-sized conifers, resulting from rapid regeneration of conifers following stand-replacing disturbance, and is otherwise similar to MDO.
- ***Mid-Development – Closed Canopy Cover (MDC)***
  This seral stage is characterized by a dense canopy cover (>70 percent) of pole- to medium-sized conifers, resulting from rapid regeneration of conifers following stand-replacing disturbance, and is otherwise similar to MDO. These stands are susceptible to stagnation and often have a marginal understory associated with limited site resources. This condition develops where fire frequency is too low to thin small trees (LandFire 2007f).
- ***Late Development – Open Canopy Cover (LDO)***
  This seral stage is characterized by a heterogeneous ground cover of grasses, forbs, and low shrubs, with a low canopy cover (<40 percent) of large trees (>20 inches d.b.h.). The open stand structure is maintained by frequent low- or mixed-severity fire and insect-

caused tree mortality (the latter not modeled at this time) (LandFire 2007f).

- ***Late Development – Moderate Canopy Cover (LDM)***
  This seral stage is characterized by an overstory of large trees with canopy cover 40–70 percent, and is otherwise similar to LDO.
- ***Late Development – Closed Canopy Cover (LDC)***
  This seral stage is characterized by an overstory of large trees with canopy cover greater than 70 percent, and is otherwise similar to LDO. There can exist substantial surface fuel accumulation and ladder fuels (LandFire 2007f).

Yellow Pine with Aspen (YPN_ASP) Variant

- ***Early Development – Aspen (ED–A)***
  This seral stage is characterized by the recruitment of a new cohort of early-successional, shade-intolerant tree species (primarily *P. tremuloides*) into an open area created by a stand-replacing disturbance. Note that there can be a residual or legacy of overstory trees from the predisturbance stand making up less than 25 percent canopy cover. Following disturbance, succession proceeds rapidly from an herbaceous layer to shrubs and trees, which invade together (Verner 1988a). *Populus tremuloides* suckers more than 2 meters tall develop within about 10 years (LandFire 2007a).
- ***Mid-Development – Aspen (MD–A)***
  This seral stage is characterized by *P. tremuloides* trees 5–16 inches d.b.h. Canopy cover is highly variable, and can range from 40 to 100 percent. Some understory conifers are encroaching, but *P. tremuloides* is still the dominant component of the stand (LandFire 2007a).
- ***Late Development – Conifer with Aspen (LD–CA)***
  If stands are sufficiently protected from fire such that conifer species encroach and eventually overtop the *P. tremuloides,* which are predominantly larger than 16 inches d.b.h., but it is unlikely that conifers will be the dominant portion of the stand. Total canopy cover is high variable, but generally greater than 50 percent.

Model Parameterization

This section includes a listing of the model parameters that are cover type-specific. Note that there are additional model parameters not specific to a cover type (e.g., climate modifier) that ultimately affect the model processes and outcomes, and these are discussed under the *Methods* section in McGarigal et al. 2018.

Succession

The rules (i.e., parameters) governing succession for the YPN and YPN_ASP cover types are listed in table B12.3. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007a,f) and associated models created by using the Vegetation Dynamics Development Tool (VDDT), as modified by Safford and Estes. They were subsequently modified based on expert input to include probabilistic rather than deterministic seral stage transitions. Specifically, we modified the rules so that stands would gradually, instead of abruptly, transition from one seral stage to the next to reflect stochasticity in the real-world processes governing succession. For example, the first three rules dictate that a cell in the YPN cover type which has been in the ED seral stage for 40–75 years, will have a 40-percent chance of transitioning to MDC, a 20-percent chance of transitioning to MDM, and a 10-percent chance of transitioning to MDO at the beginning of each timestep. Thus, stands will randomly begin transitioning to one of the MD stages after 40 years in the ED stage, but some stands could remain in the ED stage for as much as 80 years to reflect delayed tree establishment. Note that for stands currently in the ED stage and between 40 and 75 years in this stage, the combined chance of transitioning to MD at each timestep is 70 percent; therefore, there is a 30-percent chance of remaining in the ED seral stage at each timestep. The next three rules together dictate that a cell that has been in the ED seral stage for 80 years will have a 100-percent chance of transitioning to one of the MD seral stages; thus, all stands will have transitioned to the MD stage after 80 years since establishment.

Applying the succession rules listed in table B12.3 results in stands transitioning between seral stages in a probabilistic rather than deterministic manner, such that we can compute the average stand age (years) for the transition to the next seral stage, as shown in table B12.4. For example, the first row in table B12.4 indicates that for a cell in the YPN cover type in the ED seral stage, the earliest stand age (i.e., number of years since the last stand-replacing disturbance) for transitioning to one of the MD seral stages is 40 years, the latest stand age is 80 years, and the average stand age at the time of the transition is 42 years. Also, the fifth row in table B12.4 indicates that a cell in the YPN cover type in the MDO seral stage will, on average, take 21 years without a low-mortality fire disturbance to transition to the MDM seral stage (i.e., transition from an open-canopy cover, <40 percent, to a moderate-canopy cover, 40–70 percent, condition). Note that a low-mortality fire every 20 years will maintain the stand in the open-canopy condition.

Wildfire Disturbance

Rotation Period

Wildfire rotation period (equivalent to the point-specific mean return interval) is not formally a model parameter, but rather is specified as a target value to be achieved through model calibration. Target FRPs were specified by cover type (table B12.5). FRP for the YPN cover type was based on Mallek et al. (2013), whereas the FRP for the YPN_ASP cover type was based on Van de Water and Safford (2011) and expert input from Safford and Estes.

Susceptibility

The cover type-specific factors affecting susceptibility of a cell to wildfire were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type, seral stage, and time since the last wildfire. Each of these two factors is represented as a probability.

Topographic position—Topographic position, as represented by the topographic position index (TPI) described under the *Methods* section in McGarigal et al. 2018, was treated as having a static (i.e., constant over time) and universal effect on the relative susceptibility of a cell to wildfire regardless of seral stage or disturbance history. We allowed topographic position to affect susceptibility for the YPN cover type, but not YPN_ASP. Specifically, all other things being equal, for the YPN cover type, susceptibility decreased by 30 percent as the TPI index decreased over its full range according to the four-parameter logistic function depicted in figure B.2. However, because the bulk of the landscape varies over a much smaller range of TPI values, the effect on susceptibility is typically much less than 30 percent.

The specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire susceptibility, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation and disturbance history)—Fuels, as represented by vegetation cover type, seral stage, and recent disturbance history, were treated as having a dynamic (i.e., changing over time) effect on the relative susceptibility of a cell to wildfire. Specifically, susceptibility varied among cover types and seral stages in relation to the time (number years) since the last fire according to the cumulative Weibull function and the parameters listed in table B12.5 (e.g., as illustrated in figure B.1). Note that here we use the cumulative form of the Weibull distribution, which gives the cumulative probability of a disturbance for any number of years since the last disturbance. Thus, the probability increases from 0 immediately following a fire to approaching 1 after a certain number of years since the last fire, depending on the specified mean return interval (MRI) and shape parameters of the Weibull function. Holding Shape constant, and all other things being equal, as MRI increases the curve shifts to the right, resulting in a lower probability for any given number of years since the last disturbance. In this manner, varying the MRI among cover types and seral stages affects the relative susceptibility to wildfire.

The specified Weibull MRI parameters were based on the corresponding LandFire BpS descriptions (LandFire 2007a,f) and associated VDDT models, as modified by Safford and Estes.

Importantly, although susceptibility of the various seral stages is determined by MRI (holding Shape constant), these return intervals should not be interpreted literally, as the concept of a return interval does not meaningfully apply to a dynamic seral stage. Moreover, these MRIs were derived from the LandFire BpS descriptions and associated VDDT models, as modified by Safford and Estes; taken collectively, these values do not necessarily agree with the target FRPs for the cover types. Thus, the MRIs assigned to each cover type and seral stage should be interpreted as relative values that affect the relative susceptibility of the various vegetation states.

Mortality

The cover type-specific factors affecting overstory mortality following wildfire (i.e., fire severity) were: (1) topographic position, and (2) fuel characteristics, as represented by vegetation cover type and seral stage. Each of these two factors is represented as a probability.

Topographic position—The effect of topographic position on mortality was treated identically to its effect on susceptibility (see previous description). Again, the specified logistic parameters were based on consensus expert opinion about the strength and nature of the topographic influence on wildfire severity, and reflect general support for such an effect in the scientific literature (North 2012; Taylor and Skinner 2003).

Fuels (vegetation)—Fuels, as represented by vegetation cover type and seral stage, were treated as having a dynamic (i.e., changing over time) effect on the relative probability of a high-mortality response to wildfire. Specifically, we assigned a probability of high-mortality response to wildfire to each cover type and seral stage (table B12.5); values were based on the corresponding LandFire BpS descriptions (LandFire 2007a,f) and associated VDDT models, as modified by Safford and Estes.

Disturbance Transitions

The rules (i.e., parameters) governing seral stage transitions following low-mortality wildfire disturbance for the YPN and YPN_ASP cover types are listed in table B12.6. These rules were initially based on the corresponding LandFire BpS descriptions (LandFire 2007a,f) and associated models created by using the VDDT as modified by Safford and Estes, but were subsequently modified to include the moderate canopy cover seral stages not present in the VDDT models. Note that rules governing transitions following high-mortality wildfire are not listed in table B12.6 because high-mortality wildfires always result in transition to the early-development (ED) seral stage. In addition, conditions in which low-mortality wildfire has no effect on the seral stage (i.e., does not cause a transition) are not listed. For example, the first two rules dictate that a low-mortality wildfire in a cell of YPN in the MDC seral stage has a 30-percent chance of transitioning to the MDM stage, a 30-percent chance of transitioning to the MDO stage, and (by implication) a 40-percent chance of remaining in the MDC stage. In addition, by implication (given the absence of a rule), a low-mortality wildfire in the ED, MDO, or LDO seral stage has no effect other than to maintain the cell in that seral stage. Similarly, for cells in the YPN_ASP cover type, all low-mortality wildfires maintain the stand in the current seral stage and thus are not listed.

Table B12.1—Summary of YPN and YPN_ASP seral stage characteristics: average overstory tree diameter at breast height (d.b.h.) of the dominant and codominant trees, overstory tree percent cover from above (CFA), assigned average CFA value for classifying the landscape by percent canopy cover, and range of stand ages (number of years since the last stand-replacing disturbance) possible for the corresponding seral stage. Note that overstory tree d.b.h. and CFA for the ED/ED-A seral stages refer to the residual or legacy overstory from the predisturbance stand.

Cover type	Seral stage	Overstory tree d.b.h. (inches)	Overstory tree CFA (%)	Assigned average CFA (%)	Stand age range (years)
YPN	ED	<5 (13 cm)	<25	10	0–75
	MDO	5–19.9 (13–50.5 cm)	<40	30	40–305
	MDM	5–19.9	40–70	55	40–285
	MDC	5–19.9	>70	85	40–275
	LDO	≥20 (51 cm)	<40	30	≥210
	LDM	≥20	40–70	55	≥170
	LDC	≥20	>70	85	≥140
YPN_ASP	ED-A	<5	<25	10	0–5
	MD-A	5–15.9 (13–40.4 cm)	>40	60	10–135
	LD-CA	≥16 (40.6 cm)	>50	70	≥90

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B12.2—Mapping rules for YPN seral stages. Diameter at breast height (d.b.h.) and cover from above (CFA) values were taken from EVeg polygons. Categories for d.b.h. are: null, 0–0.9, 1–4.9, 5–9.9, 10–19.9, 20–29.9, ≥30. CFA categories (%) are: null, 0–10, 10–20, … , 90–100. Each row should be read with a Boolean AND across each column. Within each seral stage the rows should be read with a Boolean OR across rows.

Seral stage[a]	Overstory tree d.b.h. 1 (inches)	Overstory tree d.b.h. 2 (inches)	Total tree CFA (%)	Conifer CFA (%)	Hardwood CFA (%)
ED	0–4.9 (0–12.4 cm)	any	any	any	any
MDO	5–19.9 (13–50.5 cm)	any	0–40	any	any
MDM	5–19.9	any	40–70	any	any
MDC	5–19.9	any	70–100	any	any
LDO	≥20 (51 cm)	any	0–40	any	any
LDM	≥20	any	40–70	any	any
LDC	≥20	any	70–100	any	any

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table B12.3—Succession rules for YPN and YPN_ASP seral stages. Note that for YPN cover types, number of years in current successional stage refers to the number of years in either early-development (ED), mid-development (MD), or late-development (LD) stage independent of canopy cover class, whereas for YPN_ASP it refers to the number of years in the corresponding seral stage.

Cover type	From seral stage[a]	To seral stage[a]	Number of years in current successional stage	Number of years since low-mortality fire	Probability of transition
YPN	ED	MDC	40–75	any	0.4
	ED	MDM	40–75	any	0.2
	ED	MDO	40–75	any	0.1
	ED	MDC	80	any	0.5
	ED	MDM	80	any	0.3
	ED	MDO	80	any	0.2
	MDC	LDC	100–195	any	0.2
	MDC	LDC	200	any	1.0
	MDM	LDM	130–205	any	0.3
	MDM	LDM	210	any	1.0
	MDM	MDC	≥20	≥20	0.8
	MDO	LDO	170–225	any	0.4
	MDO	LDO	230	any	1.0
	MDO	MDM	≥20	≥20	0.8
	LDM	LDC	≥20	≥25	0.7
	LDO	LDM	≥20	≥25	0.7
YPN_ASP	ED-A	MD-A	10	any	1.0
	MD-A	LD-CA	80–125	any	0.6
	MD-A	LD-CA	130	any	1.0

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B12.4—Summary of YPN and YPN_ASP seral stage transitions: earliest, latest, and average stand age (number of years since the last stand-replacing disturbance) for the transition to the next seral stage; and average number of years without low-mortality fire to transition to the next canopy cover class.

Cover type	From seral stage[a]	To seral stage[a]	Earliest stand age (years) at transition	Latest stand age (years) at transition	Average stand age (years) at transition	Average no. of years without low-mortality fire to transition
YPN	ED	MD	40	80	42	n/a
	MDO	LDO	210	310	219	n/a
	MDM	LDM	170	290	184	n/a
	MDC	LDC	140	280	162	n/a
	MDO	MDM	n/a	n/a	n/a	21
	MDM	MDC	n/a	n/a	n/a	21
	LDO	LDM	n/a	n/a	n/a	27
	LDM	LDC	n/a	n/a	n/a	27
YPN_ASP	ED-A	MD-A	10	10	10	n/a
	MD-A	LD-CA	90	140	93	n/a

[a] ED = Early - all structures; MD = Mid development; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B12.5—Weibull function parameters associated with the susceptibility of a cell to wildfire based on fuels (i.e., vegetation cover type, seral stage, and number of years since the last fire) and the probability of a high-mortality wildfire by cover type and seral stage for the YPN and YPN_ASP cover types.

			Weibull parameters		
Cover type	Seral stage[a]	Target fire rotation period (years)	Mean return interval (years)	Shape	Probability of high-mortality fire
YPN	n/a	21	n/a	n/a	n/a
	ED	n/a	30	3	1.00
	MDO	n/a	8	3	0.05
	MDM	n/a	9	3	0.14
	MDC	n/a	11	3	0.26
	LDO	n/a	8	3	0.01
	LDM	n/a	10	3	0.08
	LDC	n/a	15	3	0.20
YPN_ASP	n/a	21	n/a	n/a	n/a
	ED-A	n/a	30	3	1
	MD-A	n/a	11	3	0.26
	LD-CA	n/a	10	3	0.08

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table B12.6—Disturbance rules for YPN and YPN_ASP cover types governing seral-stage transitions following a low-mortality wildfire. Note that conditions in which low-mortality wildfire has no effect are not listed.

Cover type	From seral stage[a]	To seral stage[a]	Probability of transition
YPN	MDC	MDM	0.3
	MDC	MDO	0.3
	MDM	MDO	0.32
	LDC	LDM	0.29
	LDC	LDO	0.29
	LDM	LDO	0.18

[a] MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed;

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APPENDIX C: Parameterization of Selected Landscape Metrics

Core Area Metrics

Tables C.1, C.2, and C.3 list the specified edge depths (meters and feet) between adjacent patches defined by developmental stage, canopy cover class, and seral stage, respectively, as used to quantify range of variability (ROV) in landscape structure in the upper Yuba River watershed. Edge depths are required for quantifying several landscape metrics pertaining to core area (DCORE_MN, DCORE_AM, CAI_MN, and CAI_AM), where "core area" is defined as the patch area excluding the area within the specified distance of the patch edge. Core area metrics require the specification of edge depths, that is, the distance from the patch perimeter, to exclude when computing the interior or core area of a patch. Although depth-of-edge effects can vary widely depending on the process or organism under consideration, here we did not have any focal process or species under consideration. Therefore, we specified edge depths based on the general magnitude of ecological differences between patch types, based loosely on the range of depth-of-edge effects reported in the literature for various biophysical attributes and focal species. Each table is read as follows. Each row refers to the focal patch and each column the adjacent patch. Thus, a patch of late-development stage adjacent to an early-development stage has a 60-meter (200-foot) edge effect penetrating into the focal patch of late development (table C.1).

The table of edge depths for the 151 unique combinations of cover type and seral stage, the most finely resolved thematic classification we considered, is too large to present here, so a brief explanation will have to suffice. For each edge between two abutting patches, we considered three ecological attributes: (1) difference in vegetation canopy cover between the two patches, with edge depths varying up to a maximum of 120 meters (400 feet) for a nonvegetated patch adjacent to a closed-canopy forest; (2) differences in vegetation vertical structure between the two patches, with edge depths varying up to a maximum of 120 meters for a nonvegetated patch adjacent to a late-development forest; and (3) an edge distance of 240 meters (800 feet) for natural cover adjacent to Developed (i.e., Urban or Agriculture). For each edge we applied the maximum edge depth from these three criteria. Thus, all patch edges involving Developed received an edge effect distance of 240 meters, whereas as all other edges between natural cover types and seral stages received edge effect distances increasing with the difference in canopy cover and developmental stage and ranging from 0 to 120 meters.

Edge Contrast Metrics

Tables C.4, C.5, and C.6 list the specified edge contrast weights (0–1) between adjacent patches defined on the basis of developmental stage, canopy cover class, and seral stage, respectively, as used to quantify ROV in landscape structure in the project area. Contrast weights the area required for quantifying the edge contrast landscape metrics (TECI, CWED), where edge contrast is defined as the magnitude of ecological differences between the adjacent patch types forming the edge, with 1 equal to the maximum contrast. Although edge contrast can vary widely depending on the process or organism under consideration, here we did not have any focal process or species under consideration. Therefore, we specified edge contrast weights based on the general magnitude of ecological differences between patch types.

The table of edge contrast weights for the 151 unique combinations of cover type and seral stage is too large to present here. Briefly, for each edge between two abutting patches, we considered four ecological attributes: (1) difference in floristic composition, with the edge contrast between conifer and mixed conifer-aspen variants of the same cover type equal to 0.1, and all other edges equal to 0.2; (2) difference in vegetation canopy cover between the two patches, with edge contrasts varying up to a maximum of 0.3 for a nonvegetated patch adjacent to a closed-canopy forest; (3) differences in vegetation vertical structure between the two patches, with edge contrasts varying up to a maximum of 0.4 for a nonvegetated patch adjacent to a late-development forest; and (4) an edge contrast of 1.0 for natural cover adjacent to Developed (i.e., Urban or Agriculture). For each edge we applied either the maximum of the sum of the edge contrasts across the first three criteria, or the fourth criterion. Thus, all patch edges involving Developed received an edge contrast weight of 1.0, whereas all other edges between natural cover types and seral stages received edge weights increasing with the difference in cover type, canopy cover, and developmental stage and ranging from 0 to 0.9.

Table C1—Edge depths (m) between adjacent patches defined by vegetation developmental stage.

Developmental stage	None	Early	Mid	Late
None	0	60 (200 ft)	90 (300 ft)	120 (400 ft)
Early	60	0	30 (100 ft)	60
Mid	90	30	0	30
Late	120	60	30	0

Table C2—Edge depths (m) between adjacent patches defined by canopy cover class.

Canopy cover class	None	Open	Moderate	Closed
None	0	30 (100 ft)	60 (200 ft)	120 (400 ft)
Open	30	0	30	60
Moderate	60	30	0	30
Closed	120	60	30	0

Table C3—Edge depths (m) between adjacent patches defined on the basis of seral stage.

Seral stage	Nonseral	Early – All Structures	Mid – Closed	Mid – Moderate	Mid – Open	Late – Closed	Late – Moderate	Late – Open
Nonseral	0	30 (100 ft)	150 (500 ft)	120 (400 ft)	90 (300 ft)	180 (600 ft)	150	120
Early – All Structures	30	0	120	90	60 (200 ft)	150	120	90
Mid – Closed	150	120	0	30	60	30	60	90
Mid – Moderate	120	90	30	0	30	60	30	60
Mid – Open	90	60	60	30	0	90	60	30
Late – Closed	180	150	30	60	90	0	30	60
Late – Moderate	150	120	60	30	60	30	0	30
Late – Open	120	90	90	60	30	60	30	0
Early – Aspen	60	30	90	60	30	120	90	60
Mid – Aspen	90	60	30	45	60	60	60	90
Mid – Aspen and Conifer	90	60	30	45	60	30	45 (150 ft)	60
Late – Conifer and Aspen	120	90	30	60	90	0	30	45

(Table C3 continued)

Seral stage	Early – Aspen	Mid – Aspen	Mid – Aspen and Conifer	Late – Conifer and Aspen
Nonseral	60	90	90	120
Early – All Structures	30	60	60	90
Mid – Closed	90	30	30	30
Mid – Moderate	60	45	45	60
Mid – Open	30	60	60	90
Late – Closed	120	60	30	0
Late – Moderate	90	60	45	30
Late – Open	60	90	60	45
Early – Aspen	0	0	60	60
Mid – Aspen	0	0	0	0
Mid – Aspen and Conifer	60	0	0	0
Late – Conifer and Aspen	60	0	0	0

Table C4—Edge contrast weights (0–1) between adjacent patches defined by vegetation developmental stage.

Developmental stage	None	Early	Mid	Late
None	0	0.33	0.66	1
Early	0.33	0	0.33	0.66
Mid	0.66	0.33	0	0.33
Late	1	0.66	0.33	0

Table C5—Edge contrast weights (0–1) between adjacent patches defined by canopy cover class.

Canopy cover class	None	Open	Moderate	Closed
None	0	0.33	0.66	1
Open	0.33	0	0.33	0.66
Moderate	0.66	0.33	0	0.33
Closed	1	0.66	0.33	0

Table C6—Edge contrast weights (0–1) between adjacent patches defined by seral stage.

Seral stage	Nonseral	Early – All Structures	Mid – Closed	Mid – Moderate	Mid– Open	Late – Closed	Late – Moderate	Late – Open
Nonseral	0	0.3	0.8	0.7	0.6	1	0.9	0.8
Early – All Structures	0.3	0	0.6	0.5	0.4	0.8	0.7	0.6
Mid – Closed	0.8	0.6	0	0.1	0.2	0.2	0.3	0.4
Mid – Moderate	0.7	0.5	0.1	0	0.1	0.3	0.2	0.3
Mid – Open	0.6	0.4	0.2	0.1	0	0.4	0.3	0.2
Late – Closed	1	0.8	0.2	0.3	0.4	0	0.1	0.2
Late – Moderate	0.9	0.7	0.3	0.2	0.3	0.1	0	0.1
Late – Open	0.8	0.6	0.4	0.3	0.2	0.2	0.1	0
Early – Aspen	0.6	0.4	0.2	0.3	0.4	0.6	0.5	0.6
Mid – Aspen	0.8	0.6	0.1	0.1	0.2	0.4	0.3	0.4
Mid – Aspen and Conifer	1	0.8	0.2	0.3	0.4	0.2	0.1	0.2
Late – Conifer and Aspen	1	0.8	0.2	0.3	0.4	0.2	0.1	0.2

(Table C6 continued)

Seral stage	Early – Aspen	Mid – Aspen	Mid – Aspen and Conifer	Late – Conifer and Aspen
Nonseral	0.6	0.8	1	1
Early – All Structures	0.4	0.6	0.8	0.8
Mid – Closed	0.2	0.1	0.2	0.2
Mid – Moderate	0.3	0.1	0.3	0.3
Mid – Open	0.4	0.2	0.4	0.4
Late – Closed	0.6	0.4	0.2	0.2
Late – Moderate	0.5	0.3	0.1	0.1
Late – Open	0.6	0.4	0.2	0.2
Early – Aspen	0	0.2	0.4	0.4
Mid – Aspen	0.2	0	0.2	0.2
Mid – Aspen and Conifer	0.4	0.2	0	0.1
Late – Conifer and Aspen	0.4	0.2	0.1	0

APPENDIX D: Detailed Supplemental Results

This appendix provides detailed supplemental results organized into several tables (tables D.1–D.10).

Table D1—Historical range of variability (HRV) in the percentage of each major cover type (i.e., those with ≥1,000 ha [2,500 ac] extent) in each vegetation developmental stage for ca. 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV.

Cover type/ Develop-mental stage	Percentile of historical range of variability							Current	
	0th	5th	25th	50th	75th	95th	100th	% eligible	% HRV
Mixed Evergreen – Mesic									
Early	1.34	2.73	4.81	6.65	9.22	13.05	19.14	8.21	65
Mid	1.17	2.67	4.28	5.89	8.32	11.95	17.88	52.66	100
Late	76.18	80.09	83.91	86.42	89.03	91.72	95.69	39.12	0
Mixed Evergreen – Xeric									
Early	2.62	3.71	5.5	7.56	9.7	13.03	15.8	10.88	85
Mid	3.32	5.38	7.33	8.71	10.66	13.82	16.99	71.06	100
Late	72.42	77.35	80.57	83.28	85.64	87.8	89.65	18.06	0
Oak-Conifer Forest and Woodland									
Early	6.03	8.91	12.25	15.04	18.24	23.32	29.64	19.97	84
Mid	24.12	28.46	32.84	35.73	38.45	42.29	47.93	76.32	100
Late	37.14	42.15	46.35	48.69	51.55	55.81	59.99	3.72	0
Oak-Conifer Forest and Woodland – Ultramafic									
Early	0.54	0.99	2.41	3.7	6.27	12.77	15.65	17.76	100
Mid	1.19	1.97	3.11	5.06	8.63	15.12	18.87	74.35	100
Late	69.73	75.97	84.09	90.67	92.66	95.37	96.84	7.89	0
Red Fir – Mesic									
Early	1.16	2.42	5.04	7.78	11.1	19.68	27.64	24.21	99
Mid	9.25	13.41	17.64	20.98	24.63	31.52	35.86	39.00	100
Late	56.2	59.06	65.85	70.41	74.3	78.71	83.45	36.79	0

(Table D1 continued on next page.)

(Table D1 continued)

Cover type/ Develop-mental stage	Percentile of historical range of variability							Current	
	0th	5th	25th	50th	75th	95th	100th	% eligible	% HRV
Red Fir – Xeric									
Early	11.54	16.13	21.32	25.57	30.87	39.46	46.21	32.39	82
Mid	14.47	17.88	22.88	27.2	31.12	36.43	42.19	39.49	98
Late	29.55	35.38	41.83	46.69	51.11	56.64	61.17	28.12	0
Sierran Mixed Conifer – Mesic									
Early	2.26	3.57	5.2	7.25	9.64	13.55	15.68	14.98	100
Mid	16.25	19.59	22.62	24.63	27.19	29.88	32.27	44.00	100
Late	58.06	62.03	65.05	67.48	70.09	73.44	76.66	41.02	0
Sierran Mixed Conifer – Ultramafic									
Early	7.32	9.07	11.12	12.61	14.47	17.09	20.71	48.70	100
Mid	8.37	9.64	12.57	14.18	16.3	18.98	20.02	15.09	62
Late	66.73	68.15	70.66	72.99	74.3	77.04	82.53	36.21	0
Sierran Mixed Conifer – Xeric									
Early	4.88	7.17	8.43	9.54	10.65	12.46	13.8	19.48	100
Mid	8.25	10.35	12.14	12.96	13.89	15.23	17.13	38.36	100
Late	74.73	75.42	76.35	77.29	78.41	79.81	80.64	42.16	0

Table D2—Historical range of variability (HRV) in the percentage of each vegetation developmental stage in each canopy cover class by major cover type (i.e., those with ≥1,000 ha [2,500 ac] extent) for ca. 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV. Note that percentages reflect the percentage of the developmental stage (mid or late) in each canopy cover class (open, moderate, or closed) for the corresponding cover type.

Cover type/ Developmental stage[a]/ Canopy cover class	Percentile of historical range of variability							Current	
	0th	5th	25th	50th	75th	95th	100th	% eligible	% HRV
Mixed Evergreen – Mesic									
MDO	0.57	1.64	3.51	5.75	8.46	13.08	17.29	12.09	93
MDM	35.23	52.13	69.52	79.2	86.55	93.09	97.05	18.54	0
MDC	0.73	2.17	7.51	14.07	24.25	42.37	60.23	69.37	100
LDO	2.12	3.43	5.44	7.28	10.64	15.04	20.35	6.39	38
LDM	6.13	8.33	10.6	13.04	15.15	18.27	22.21	18.69	97
LDC	62.73	69.18	74.91	79.44	82.99	86.47	90.68	74.92	26
Mixed Evergreen – Xeric									
MDO	1.72	3.06	4.78	6.71	9.08	12.68	19.85	18.1	100
MDM	32.74	43.33	55.66	64.11	71.78	79.35	90.23	13.22	0
MDC	5.39	13.39	20.9	28.41	37.49	50.16	60.87	68.68	100
LDO	3.8	4.85	6.83	8.79	11.53	15.73	20.07	7.64	34
LDM	8.99	10.68	12.88	14.91	16.82	20.7	23.74	21.27	97
LDC	57.94	65.29	71.68	76.48	79.84	83.39	86.64	71.08	24
Oak-Conifer Forest and Woodland									
MDO	11.13	16.83	21.35	26.69	33.9	44.27	53.39	31.9	71
MDM	21.39	24.36	27.71	30.02	32.57	36.32	43.35	19.15	0
MDC	19.14	24.53	34.88	42.89	48.9	56.46	62.74	48.95	76
LDO	8.63	10.87	14.94	19.11	25.63	33.41	42.76	30.23	89
LDM	20.38	22.78	27.27	30.74	33.89	39.17	43.99	27.37	27

(Table D2 continued on next page.)

(Table D2 continued)

Cover type/ Developmental stage[a]/ Canopy cover class	Percentile of historical range of variability							Current	
	0th	5th	25th	50th	75th	95th	100th	% eligible	% HRV
LDC	23.2	28.84	41.6	49.28	56.97	63.65	69.51	42.4	27
Oak-Conifer Forest and Woodland – Ultramafic									
MDO	23.88	59.22	79.03	87.95	93.52	97.61	99.08	45.05	3
MDM	0.86	2.19	6.15	11.32	19.3	38.06	76.12	15.52	63
MDC	0	0	0.1	0.39	1.05	4.93	10.35	39.43	100
LDO	74.34	88.29	96.25	97.88	98.71	99.06	99.29	4.31	0
LDM	0.71	0.92	1.26	1.99	3.68	10.68	17.92	27.88	100
LDC	0	0	0.01	0.04	0.15	1.02	7.74	67.81	100
Red Fir – Mesic									
MDO	1.01	1.94	3.06	4.25	6.27	10	12.75	42.82	100
MDM	1.25	2.32	3.32	4.28	5.75	7.66	9.86	47.87	100
MDC	77.39	82.68	88.1	91.44	93.56	95.65	97.75	9.31	0
LDO	2.35	3.16	4.41	5.57	6.89	10.17	12.07	11.23	100
LDM	5.8	6.95	8.29	9.38	10.65	12.35	13.62	59.69	100
LDC	74.41	78.06	82.61	85.12	87.1	89.75	91.28	29.08	0
Red Fir – Xeric									
MDO	35.33	44.56	53.58	60.11	66.97	73.71	82.22	31.85	0
MDM	14.53	19.07	25.81	31.48	36.04	43.72	50.87	47.24	99
MDC	1.99	3.93	6.26	8.43	11.27	16.45	21.19	20.91	100
LDO	7.86	10.32	12.55	14.75	18.15	21.77	26.77	11.02	10
LDM	17.3	19.4	22.24	24.34	26.77	30	33.57	51.81	100
LDC	44.6	50.59	56.03	60.18	64.83	69.41	72.47	37.17	0

(Table D2 continued on next page.)

(Table D2 continued)

Cover type/ Developmental stage[a]/ Canopy cover class	Percentile of historical range of variability							Current	
	0th	5th	25th	50th	75th	95th	100th	% eligible	% HRV
Sierran Mixed Conifer – Mesic									
MDO	13.37	16.37	20.89	26.5	32.58	40.22	48.66	37.01	88
MDM	18.89	22.38	25.9	28.05	30.7	34.76	39.36	40.84	100
MDC	25.61	31.15	38.93	44.48	50.02	57.76	65.32	22.14	0
LDO	7.59	11.32	16	21.09	26.92	35.37	44.35	8.78	1
LDM	15.89	21.91	24.64	27.45	30.99	36.6	43.63	34.58	91
LDC	22.46	32.58	43.57	51.31	57.04	63.9	72.04	56.64	73
Sierran Mixed Conifer – Ultramafic									
MDO	54.4	66.06	73.08	77.15	80.9	84.87	89.24	35.32	0
MDM	9.67	13.44	17.02	20.18	24.01	30.01	37.24	44.84	100
MDC	0.72	1.15	1.83	2.4	3.08	5.15	11.18	19.84	100
LDO	33.66	38.09	42.89	46.42	50.48	57.54	64.23	9.04	0
LDM	24.69	26.55	29.05	31.18	33.61	37.1	41.31	23.51	0
LDC	9.95	13.86	18.6	21.82	25.03	28.65	33.49	67.45	100
Sierran Mixed Conifer – Xeric									
MDO	54.58	59.76	64.73	69.78	74.73	79.94	85.03	29.93	0
MDM	12.98	17.22	20.64	24.38	28.09	32.27	36.06	38.9	100
MDC	1.7	2.55	4.05	5.32	6.97	9.67	11	31.17	100
LDO	31.7	36.73	43.63	48.98	55.07	65.3	73.83	9.79	0
LDM	20.45	25.78	31.18	33.37	35.7	39.34	44.54	31.57	30
LDC	5.72	8.61	12.81	17.09	20.96	26.77	32.37	58.63	100

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table D3—Historical range of variability (HRV) in the percentage of each major cover type (i.e., those with ≥1,000 ha [2,500 ac] extent) in each vegetation seral stage for ca. 1550–1850 in the upper Yuba River watershed. Select percentiles of the simulated HRV are given, as well as the current landscape condition and its corresponding percentile of the simulated HRV.

Cover type/ Seral stage[a]	Percentile of historical range of variability							Current	
	0th	5th	25th	50th	75th	95th	100th	% eligible	% HRV
Mixed Evergreen – Mesic									
ED	1.34	2.72	4.81	6.65	9.22	13.05	19.14	8.21	65
MDC	0.04	0.14	0.37	0.79	1.32	3.04	7.96	36.53	100
MDM	0.89	1.80	3.15	4.41	6.41	9.98	16.42	9.76	95
MDO	0.02	0.10	0.19	0.30	0.51	0.96	1.40	6.37	100
LDC	50.40	56.99	63.11	68.29	73.45	78.63	86.77	29.31	0
LDM	5.84	7.56	9.34	11.05	12.86	15.39	18.43	7.31	4
LDO	1.68	3.06	4.83	6.39	9.11	12.53	17.10	2.50	2
Mixed Evergreen – Xeric									
ED	2.62	3.71	5.50	7.56	9.70	13.03	15.80	10.88	85
MDC	0.49	0.96	1.73	2.43	3.41	5.08	8.84	48.80	100
MDM	1.67	2.80	4.41	5.48	7.16	9.57	12.89	9.39	95
MDO	0.13	0.26	0.40	0.59	0.81	1.26	1.78	12.87	100
LDC	44.43	51.06	58.6	63.39	67.84	72.35	76.86	12.84	0
LDM	7.46	9.24	10.87	12.35	13.62	16.24	18.41	3.84	0
LDO	3.23	4.2	5.78	7.48	9.45	12.47	15.39	1.38	0
Oak-Conifer Forest and Woodland									
ED	6.03	8.91	12.25	15.05	18.24	23.33	29.64	19.97	84
MDC	4.96	7.65	11.84	15.05	18.24	22.12	28.16	37.36	100
MDM	6.77	8.33	9.42	10.5	11.8	14.24	16.27	14.61	98
MDO	4.09	6.27	7.63	9.47	11.82	14.68	16.48	24.34	100
LDC	10.11	12.63	19.29	24.36	28.57	33.09	38.54	1.58	0
LDM	10.41	11.8	13.37	14.81	16.41	18.69	22.92	1.02	0
LDO	4.19	5.47	7.4	9.4	12.07	15.96	22.35	1.12	0

(Table D3 continued on next page.)

(Table D3 continued)

Cover type/ Seral stage[a]	Percentile of historical range of variability							Current	
	0th	5th	25th	50th	75th	95th	100th	% eligible	% HRV
Oak-Conifer Forest and Woodland – Ultramafic									
ED	0.54	0.99	2.41	3.7	6.27	12.78	15.65	17.76	100
MDC	0.01	0.01	0.02	0.03	0.08	0.19	0.54	29.32	100
MDM	0.05	0.12	0.31	0.56	0.96	2.51	7.16	11.54	100
MDO	0.72	1.45	2.5	4.35	7.94	14.33	17.57	33.49	100
LDC	0.01	0.01	0.02	0.06	0.15	0.79	5.49	5.35	100
LDM	0.61	0.81	1.13	1.69	3.25	8.09	12.7	2.2	61
LDO	52.7	66.87	81.64	88.27	90.11	94.01	95.58	0.34	0
Red Fir – Mesic									
ED	1.16	2.42	5.04	7.77	11.1	19.68	27.64	24.21	99
MDC	7.49	11.69	15.88	18.81	22.82	28.87	33.75	3.63	0
MDM	0.34	0.47	0.7	0.9	1.17	1.64	2.18	18.67	100
MDO	0.27	0.43	0.64	0.89	1.24	1.96	3.05	16.7	100
LDC	43.55	47.21	54.02	59.83	63.99	69.91	74.23	10.7	0
LDM	4.32	5.21	5.9	6.51	7.12	8.03	8.6	21.96	100
LDO	1.56	2.31	3.19	3.85	4.68	6.66	7.48	4.13	59
Red Fir – Xeric									
ED	11.54	16.13	21.32	25.57	30.87	39.46	46.21	32.39	82
MDC	0.39	0.94	1.62	2.23	3.06	4.79	8.94	8.26	100
MDM	2.83	4.63	6.55	8.08	10.37	13.05	17.44	18.66	100
MDO	6.56	9.67	13.01	16.08	19.51	23.44	26.51	12.58	22
LDC	14.23	18.13	23.94	27.84	32.62	38.15	42.7	10.45	0
LDM	7.32	8.82	10.2	11.21	12.48	13.9	16.12	14.57	99
LDO	3.65	4.78	6.1	6.91	7.79	9.51	11.23	3.1	0
Sierran Mixed Conifer – Mesic									
ED	2.26	3.57	5.2	7.25	9.64	13.55	15.68	14.98	100

(Table D3 continued on next page.)

(Table D3 continued)

Cover type/ Seral stage[a]	Percentile of historical range of variability							Current	
	0th	5th	25th	50th	75th	95th	100th	% eligible	% HRV
MDC	5.23	6.99	9.28	10.93	12.94	15.42	19.25	9.74	32
MDM	3.89	4.87	6.08	6.94	8	9.67	12.29	17.97	100
MDO	2.95	4.07	5.27	6.47	7.91	9.71	12.91	16.29	100
LDC	13.96	21.15	29.26	34.46	39.32	44.86	52.89	23.23	10
LDM	10.72	14.82	16.8	18.43	20.69	24.29	27.81	14.18	3
LDO	5.16	7.87	11.15	14.22	18.09	23.38	29.2	3.6	0
Sierran Mixed Conifer – Ultramafic									
ED	7.32	9.07	11.12	12.61	14.48	17.09	20.71	48.7	100
MDC	0.07	0.13	0.24	0.35	0.45	0.85	1.86	2.99	100
MDM	1.09	1.52	2.25	2.92	3.55	5.1	6.52	6.77	100
MDO	7.03	7.75	9.45	10.77	12.15	14.42	15.75	5.33	0
LDC	7.37	9.68	13.33	15.87	18.22	21.41	27.64	24.43	99
LDM	17.09	19.06	20.96	22.81	24.59	26.94	28.9	8.51	0
LDO	24.27	27.89	31.36	33.58	36.44	41.57	47.62	3.27	0
Sierran Mixed Conifer – Xeric									
ED	4.88	7.17	8.43	9.54	10.65	12.46	13.8	19.48	100
MDC	0.16	0.3	0.51	0.69	0.91	1.33	1.88	11.96	100
MDM	1.27	1.9	2.61	3.16	3.74	4.64	5.9	14.92	100
MDO	6.14	7.24	8.32	9.08	9.69	10.74	11.62	11.48	100
LDC	4.45	6.58	9.91	13.29	16.35	20.98	24.74	24.72	100
LDM	15.91	19.63	24.05	25.85	27.69	30.53	34.69	13.31	0
LDO	24.37	28.56	33.64	37.83	42.57	49.66	57.44	4.13	0

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed.

Table D4—Range of variability (ROV) in the percentage of each major cover type (i.e., those with >1,000 ha extent) in each vegetation developmental stage (early, mid, and late) for the simulated historical range of variability (circa 1550–1850) (HRV) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2-7) in the Upper Yuba River watershed. Select percentiles of the simulated ROV are given as well as the current landscape condition.

			Percentile of range of variability			
Cover type	Development stage	Scenario	5th	50th	95th	Current
Mixed Evergreen – Mesic						
	Early	HRV	2.73	6.65	13.05	8.21
		MS1	0.14	0.77	6.47	8.21
		MS2	4.54	6.96	14.34	8.21
		MS3a	4.21	6.80	9.29	8.21
		MS3b	4.50	6.52	8.42	8.21
		MS4	5.19	7.45	10.41	8.21
		MS5	6.58	7.70	10.88	8.21
		MS6	7.40	10.16	12.77	8.21
		MS7	6.58	9.29	11.69	8.21
	Mid	HRV	2.67	5.89	11.95	52.66
		MS1	0.04	0.69	3.84	52.66
		MS2	3.58	6.12	7.81	52.66
		MS3a	3.19	5.58	7.15	52.66
		MS3b	4.89	7.02	8.41	52.66
		MS4	4.17	5.94	7.16	52.66
		MS5	5.98	7.17	8.38	52.66
		MS6	6.63	8.71	10.61	52.66
		MS7	6.85	8.72	10.52	52.66
	Late	HRV	80.09	86.42	91.72	39.12
		MS1	90.35	98.08	99.81	39.12
		MS2	80.67	86.97	88.93	39.12
		MS3a	85.54	87.68	89.48	39.12
		MS3b	83.17	87.00	89.65	39.12
		MS4	83.34	86.84	88.95	39.12
		MS5	82.79	84.81	86.89	39.12

(Table D4 continued on next page.)

(Table D4 continued)

Cover type	Development stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS6	78.88	81.02	83.09	39.12
		MS7	79.62	82.80	83.70	39.12
Mixed Evergreen – Xeric						
	Early	HRV	3.71	7.56	13.03	10.88
		MS1	0.27	1.34	5.42	10.88
		MS2	3.48	5.12	10.17	10.88
		MS3a	2.96	4.32	6.26	10.88
		MS3b	3.77	4.75	6.12	10.88
		MS4	3.99	4.59	8.82	10.88
		MS5	5.07	6.10	8.60	10.88
		MS6	6.78	8.91	10.81	10.88
		MS7	6.25	7.56	9.34	10.88
	Mid	HRV	5.38	8.71	13.82	71.06
		MS1	0.16	1.11	5.06	71.06
		MS2	3.84	5.10	7.44	71.06
		MS3a	4.94	6.21	8.12	71.06
		MS3b	7.18	8.86	9.99	71.06
		MS4	3.83	5.80	7.86	71.06
		MS5	6.95	7.62	9.23	71.06
		MS6	9.55	11.21	12.21	71.06
		MS7	9.24	10.25	11.36	71.06
	Late	HRV	77.35	83.28	87.80	18.06
		MS1	90.47	96.27	99.12	18.06
		MS2	85.19	89.25	91.22	18.06
		MS3a	87.04	89.33	90.33	18.06
		MS3b	84.49	86.65	88.13	18.06
		MS4	83.70	89.25	91.91	18.06
		MS5	83.62	85.77	86.99	18.06
		MS6	78.35	80.23	81.93	18.06

(Table D4 continued on next page.)

(Table D4 continued)

Cover type	Development stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS7	79.51	82.17	83.52	18.06
Oak-Conifer Forest and Woodland						
	Early	HRV	8.91	15.04	23.32	19.97
		MS1	0.58	1.64	11.82	19.97
		MS2	5.53	8.29	17.40	19.97
		MS3a	5.44	6.76	9.62	19.97
		MS3b	5.85	6.67	9.45	19.97
		MS4	5.51	7.02	14.67	19.97
		MS5	6.92	8.16	12.94	19.97
		MS6	9.67	10.70	13.21	19.97
		MS7	7.68	9.99	11.84	19.97
	Mid	HRV	28.46	35.73	42.29	76.32
		MS1	9.12	14.32	32.11	76.32
		MS2	19.07	22.44	28.91	76.32
		MS3a	17.91	22.35	28.45	76.32
		MS3b	21.89	24.32	31.64	76.32
		MS4	19.98	22.50	28.68	76.32
		MS5	21.85	25.98	28.87	76.32
		MS6	29.96	31.58	36.07	76.32
		MS7	28.22	30.17	35.24	76.32
	Late	HRV	42.15	48.69	55.81	3.72
		MS1	60.28	81.06	88.91	3.72
		MS2	61.67	68.41	72.40	3.72
		MS3a	66.25	70.96	73.45	3.72
		MS3b	62.06	67.66	71.54	3.72
		MS4	62.00	68.41	72.69	3.72
		MS5	60.08	65.32	67.60	3.72
		MS6	53.33	57.25	59.43	3.72
		MS7	54.72	59.69	61.92	3.72

(Table D4 continued on next page.)

(Table D4 continued)

Cover type	Development stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS7	79.51	82.17	83.52	18.06
Oak-Conifer Forest and Woodland						
	Early	HRV	8.91	15.04	23.32	19.97
		MS1	0.58	1.64	11.82	19.97
		MS2	5.53	8.29	17.40	19.97
		MS3a	5.44	6.76	9.62	19.97
		MS3b	5.85	6.67	9.45	19.97
		MS4	5.51	7.02	14.67	19.97
		MS5	6.92	8.16	12.94	19.97
		MS6	9.67	10.70	13.21	19.97
		MS7	7.68	9.99	11.84	19.97
	Mid	HRV	28.46	35.73	42.29	76.32
		MS1	9.12	14.32	32.11	76.32
		MS2	19.07	22.44	28.91	76.32
		MS3a	17.91	22.35	28.45	76.32
		MS3b	21.89	24.32	31.64	76.32
		MS4	19.98	22.50	28.68	76.32
		MS5	21.85	25.98	28.87	76.32
		MS6	29.96	31.58	36.07	76.32
		MS7	28.22	30.17	35.24	76.32
	Late	HRV	42.15	48.69	55.81	3.72
		MS1	60.28	81.06	88.91	3.72
		MS2	61.67	68.41	72.40	3.72
		MS3a	66.25	70.96	73.45	3.72
		MS3b	62.06	67.66	71.54	3.72
		MS4	62.00	68.41	72.69	3.72
		MS5	60.08	65.32	67.60	3.72
		MS6	53.33	57.25	59.43	3.72
		MS7	54.72	59.69	61.92	3.72

(Table D4 continued on next page.)

(Table D4 continued)

Cover type	Development stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
Oak-Conifer Forest and Woodland – Ultramafic						
	Early	HRV	0.99	3.70	12.77	17.76
		MS1	0.88	3.38	9.79	17.76
		MS2	1.18	2.61	6.15	17.76
		MS3a	0.55	1.48	3.52	17.76
		MS3b	0.86	1.58	3.54	17.76
		MS4	0.65	2.38	7.96	17.76
		MS5	2.26	3.53	7.77	17.76
		MS6	3.36	4.59	6.77	17.76
		MS7	3.88	5.05	7.03	17.76
	Mid	HRV	1.97	5.06	15.12	74.35
		MS1	17.38	20.18	23.12	74.35
		MS2	18.34	20.80	22.90	74.35
		MS3a	19.98	22.55	26.78	74.35
		MS3b	23.40	25.48	27.48	74.35
		MS4	18.28	20.81	23.81	74.35
		MS5	18.58	22.23	24.20	74.35
		MS6	20.66	23.77	28.30	74.35
		MS7	21.63	23.66	26.04	74.35
	Late	HRV	75.97	90.67	95.37	7.89
		MS1	68.40	76.82	79.32	7.89
		MS2	73.05	76.14	80.36	7.89
		MS3a	72.39	75.56	77.97	7.89
		MS3b	70.11	72.97	74.42	7.89
		MS4	73.40	75.94	80.12	7.89
		MS5	71.75	73.92	76.52	7.89
		MS6	66.49	71.22	74.30	7.89
		MS7	68.61	71.16	73.24	7.89
Red Fir – Mesic						

(Table D4 continued on next page.)

(Table D4 continued)

Cover type	Development stage	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
	Early	HRV	2.42	7.78	19.68	24.21
		MS1	0.11	1.02	10.32	24.21
		MS2	4.90	6.93	17.36	24.21
		MS3a	4.94	5.76	7.14	24.21
		MS3b	4.65	5.43	6.74	24.21
		MS4	4.43	6.29	12.95	24.21
		MS5	7.03	7.72	12.46	24.21
		MS6	8.50	10.12	13.56	24.21
		MS7	7.75	9.29	13.42	24.21
	Mid	HRV	13.41	20.98	31.52	39.00
		MS1	1.91	5.31	12.40	39.00
		MS2	7.43	10.23	16.08	39.00
		MS3a	6.93	8.43	10.03	39.00
		MS3b	9.50	11.82	12.91	39.00
		MS4	7.58	10.36	17.18	39.00
		MS5	10.10	12.55	13.87	39.00
		MS6	17.02	18.75	20.60	39.00
		MS7	13.71	16.18	19.76	39.00
	Late	HRV	59.06	70.41	78.71	36.79
		MS1	78.01	90.70	97.41	36.79
		MS2	72.30	81.81	85.76	36.79
		MS3a	83.70	85.78	87.01	36.79
		MS3b	81.03	82.91	84.70	36.79
		MS4	73.98	83.27	86.90	36.79
		MS5	76.38	79.57	80.87	36.79
		MS6	66.90	71.33	72.75	36.79
		MS7	69.24	74.43	76.78	36.79
Red Fir – Xeric						
	Early	HRV	16.13	25.57	39.46	32.39

(Table D4 continued on next page.)

(Table D4 continued)

Cover type	Development stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS1	1.28	4.98	19.70	32.39
		MS2	3.69	6.57	30.11	32.39
		MS3a	3.73	4.88	9.25	32.39
		MS3b	4.17	5.12	7.56	32.39
		MS4	4.69	7.23	17.97	32.39
		MS5	6.54	8.41	14.16	32.39
		MS6	8.34	10.32	16.96	32.39
		MS7	8.11	10.52	21.82	32.39
	Mid	HRV	17.88	27.20	36.43	39.49
		MS1	20.34	24.53	36.48	39.49
		MS2	21.95	27.51	30.89	39.49
		MS3a	26.56	28.91	31.41	39.49
		MS3b	29.70	32.88	36.16	39.49
		MS4	24.10	29.41	34.08	39.49
		MS5	25.45	29.32	33.56	39.49
		MS6	29.51	31.95	34.34	39.49
		MS7	25.42	29.65	34.17	39.49
	Late	HRV	35.38	46.69	56.64	28.12
		MS1	59.63	65.84	73.72	28.12
		MS2	50.08	65.32	69.04	28.12
		MS3a	61.08	65.08	68.96	28.12
		MS3b	58.74	61.57	63.98	28.12
		MS4	52.49	64.06	70.44	28.12
		MS5	56.13	61.63	63.73	28.12
		MS6	51.38	56.75	60.22	28.12
		MS7	52.77	57.33	61.67	28.12
Sierran Mixed Conifer – Mesic						
	Early	HRV	3.57	7.25	13.55	14.98
		MS1	0.19	0.89	5.26	14.98

(Table D4 continued on next page.)

(Table D4 continued)

Cover type	Development stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS2	4.77	5.90	11.73	14.98
		MS3a	4.68	5.30	7.65	14.98
		MS3b	5.11	5.56	9.23	14.98
		MS4	5.16	5.78	10.37	14.98
		MS5	5.75	6.39	10.32	14.98
		MS6	7.85	8.52	9.09	14.98
		MS7	6.69	7.42	9.99	14.98
	Mid	HRV	19.59	24.63	29.88	44.00
		MS1	2.28	6.43	14.37	44.00
		MS2	15.02	18.28	24.41	44.00
		MS3a	13.92	15.77	18.90	44.00
		MS3b	16.71	18.59	23.05	44.00
		MS4	14.37	16.91	21.04	44.00
		MS5	17.40	19.45	22.09	44.00
		MS6	24.14	25.47	27.96	44.00
		MS7	22.40	24.04	27.92	44.00
	Late	HRV	62.03	67.48	73.44	41.02
		MS1	82.59	91.85	96.71	41.02
		MS2	66.18	72.71	80.22	41.02
		MS3a	75.46	78.34	80.65	41.02
		MS3b	67.88	75.59	78.03	41.02
	Late	MS4	70.76	75.92	79.96	41.02
		MS5	71.39	73.17	75.63	41.02
		MS6	63.59	66.13	67.37	41.02
		MS7	63.45	68.14	69.79	41.02
Sierran Mixed Conifer – Ultramafic						
	Early	HRV	9.07	12.61	17.09	48.70
		MS1	1.12	2.12	10.75	48.70
		MS2	2.25	4.34	5.83	48.70

(Table D4 continued on next page.)

(Table D4 continued)

Cover type	Development stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS3a	1.96	3.66	4.59	48.70
		MS3b	2.02	3.23	5.56	48.70
		MS4	2.01	2.97	6.05	48.70
		MS5	3.81	5.41	7.14	48.70
		MS6	5.43	7.00	8.03	48.70
		MS7	5.59	6.64	8.95	48.70
	Mid	HRV	9.64	14.18	18.98	15.09
		MS1	46.59	48.27	49.13	15.09
		MS2	47.62	48.92	50.57	15.09
		MS3a	49.96	51.02	52.75	15.09
		MS3b	52.57	53.39	54.35	15.09
		MS4	47.22	49.46	50.38	15.09
		MS5	48.58	50.02	51.19	15.09
		MS6	48.93	50.00	52.09	15.09
		MS7	48.53	50.23	51.33	15.09
	Late	HRV	68.15	72.99	77.04	36.21
		MS1	43.19	49.81	50.56	36.21
		MS2	45.24	46.48	48.88	36.21
		MS3a	44.00	45.62	46.43	36.21
		MS3b	42.06	43.36	44.34	36.21
		MS4	45.52	47.31	48.66	36.21
		MS5	43.03	44.52	45.71	36.21
		MS6	41.42	43.07	44.38	36.21
		MS7	40.74	43.16	44.39	36.21
Sierran Mixed Conifer – Xeric						
	Early	HRV	7.17	9.54	12.46	19.48
		MS1	0.57	2.35	7.82	19.48
		MS2	4.83	6.84	10.06	19.48
		MS3a	4.52	5.12	6.07	19.48

(Table D4 continued on next page.)

(Table D4 continued)

Cover type	Development stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS3b	4.75	5.47	7.42	19.48
		MS4	4.92	5.47	8.25	19.48
		MS5	6.52	7.29	9.31	19.48
		MS6	8.95	9.46	10.97	19.48
		MS7	8.01	9.11	10.93	19.48
	Mid	HRV	10.35	12.96	15.23	38.36
		MS1	15.29	17.05	19.81	38.36
		MS2	20.83	22.19	23.64	38.36
		MS3a	23.98	24.87	26.52	38.36
		MS3b	26.80	28.59	29.37	38.36
		MS4	21.05	22.88	24.38	38.36
		MS5	24.39	25.20	26.32	38.36
		MS6	26.83	28.04	29.31	38.36
		MS7	24.97	27.08	28.47	38.36
	Late	HRV	75.42	77.29	79.81	42.16
		MS1	75.11	80.71	82.25	42.16
		MS2	69.05	70.74	73.08	42.16
		MS3a	68.60	69.76	70.63	42.16
		MS3b	65.18	65.98	66.67	42.16
		MS4	67.94	71.41	72.89	42.16
		MS5	65.90	67.23	68.01	42.16
		MS6	61.36	62.56	63.16	42.16
		MS7	62.61	63.72	64.43	42.16

Table D5—Range of variability (ROV) in the percentage of each major cover type (i.e., those with >1,000 ha extent) in each canopy cover class (open, moderate, closed) for the simulated historical range of variability (circa 1550–1850) (HRV) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2-7) in the Upper Yuba River watershed. Select percentiles of the simulated ROV are given as well as the current landscape condition.

Cover type	Canopy cover class	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
Mixed Evergreen – Mesic						
	Open	HRV	6.14	13.29	26.01	17.08
		MS1	0.35	1.58	12.31	17.08
		MS2	5.78	9.07	22.64	17.08
		MS3a	5.48	8.73	11.94	17.08
		MS3b	7.79	11.13	15.56	17.08
		MS4	13.64	15.93	20.69	17.08
		MS5	15.90	17.28	21.59	17.08
		MS6	23.01	26.09	30.07	17.08
		MS7	19.34	22.24	27.09	17.08
	Moderate	HRV	10.47	15.71	23.74	17.07
		MS1	0.44	2.86	8.68	17.07
		MS2	12.80	15.16	21.98	17.07
		MS3a	10.14	12.30	13.89	17.07
		MS3b	14.07	15.83	18.89	17.07
		MS4	24.71	26.03	28.19	17.07
		MS5	21.09	22.78	25.21	17.07
		MS6	21.52	22.62	24.38	17.07
		MS7	22.69	25.80	29.30	17.07
	Closed	HRV	57.71	69.28	80.12	65.85
		MS1	80.34	94.89	99.21	65.85
		MS2	57.48	74.79	80.42	65.85
		MS3a	76.06	79.00	82.60	65.85
		MS3b	66.13	73.32	77.94	65.85
		MS4	51.98	58.30	60.65	65.85
		MS5	55.16	59.18	63.36	65.85
		MS6	46.65	50.95	55.22	65.85
		MS7	47.00	51.87	55.89	65.85

(Table D5 continued on next page.)

(Table D5 continued)

Cover type	Canopy cover class	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
Mixed Evergreen – Xeric						
	Open	HRV	8.57	15.70	25.15	25.12
		MS1	0.59	2.90	10.71	25.12
		MS2	4.95	7.50	17.56	25.12
		MS3a	6.87	8.62	11.03	25.12
		MS3b	13.49	15.82	20.30	25.12
		MS4	12.02	13.23	20.08	25.12
		MS5	18.24	20.52	22.82	25.12
		MS6	26.03	28.62	31.38	25.12
		MS7	21.16	23.45	27.77	25.12
	Moderate	HRV	13.27	17.98	23.75	13.23
		MS1	0.99	3.25	9.98	13.23
		MS2	11.06	13.65	19.02	13.23
		MS3a	13.40	15.46	18.08	13.23
		MS3b	23.06	24.80	26.77	13.23
		MS4	19.92	23.68	27.53	13.23
		MS5	22.55	24.71	25.82	13.23
		MS6	21.11	22.44	24.64	13.23
		MS7	24.92	26.49	29.01	13.23
	Closed	HRV	53.90	66.06	75.51	61.64
		MS1	79.38	93.66	98.43	61.64
		MS2	65.31	77.19	83.93	61.64
		MS3a	73.10	75.94	78.27	61.64
		MS3b	54.60	59.56	63.04	61.64
		MS4	55.18	61.84	67.00	61.64
		MS5	52.15	54.95	56.84	61.64
		MS6	46.34	48.64	51.34	61.64
		MS7	45.64	49.59	52.92	61.64
Oak-Conifer Forest and Woodland						
	Open	HRV	21.69	34.38	51.94	45.43
		MS1	1.69	4.83	26.95	45.43

(Table D5 continued on next page.)

(Table D5 continued)

Cover type	Canopy cover class	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS2	7.95	13.41	30.17	45.43
		MS3a	7.15	10.18	15.51	45.43
		MS3b	10.95	12.54	23.39	45.43
		MS4	12.39	14.56	29.78	45.43
		MS5	17.04	19.23	25.58	45.43
		MS6	25.65	26.52	30.19	45.43
		MS7	25.71	29.26	33.36	45.43
	Moderate	HRV	20.86	25.61	31.05	15.63
		MS1	2.43	6.05	20.90	15.63
		MS2	12.65	17.34	23.00	15.63
		MS3a	10.51	12.60	17.62	15.63
		MS3b	13.50	15.21	20.21	15.63
		MS4	21.37	23.62	27.82	15.63
		MS5	21.00	23.10	24.87	15.63
		MS6	20.20	21.88	25.00	15.63
		MS7	20.17	22.03	28.62	15.63
	Closed	HRV	20.98	39.78	53.92	38.93
		MS1	55.87	88.34	96.12	38.93
		MS2	47.14	69.32	77.82	38.93
		MS3a	68.33	76.38	81.79	38.93
		MS3b	54.43	71.83	75.53	38.93
		MS4	45.18	61.09	66.11	38.93
		MS5	50.07	57.67	62.11	38.93
		MS6	46.53	51.22	53.41	38.93
		MS7	42.15	48.23	52.93	38.93
Oak-Conifer Forest and Woodland – Ultramafic						
	Open	HRV	89.90	97.31	98.85	51.59
		MS1	34.87	41.80	65.59	51.59
		MS2	41.72	49.16	58.00	51.59
		MS3a	47.80	53.89	57.07	51.59
		MS3b	62.46	64.86	70.59	51.59

(Table D5 continued on next page.)

(Table D5 continued)

Cover type	Canopy cover class	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS4	57.57	62.81	70.36	51.59
		MS5	61.73	64.92	67.26	51.59
		MS6	62.39	67.58	71.17	51.59
		MS7	69.59	71.67	75.79	51.59
	Moderate	HRV	1.13	2.52	9.47	13.74
		MS1	19.82	24.68	31.14	13.74
		MS2	22.50	27.12	31.09	13.74
		MS3a	19.27	23.60	28.87	13.74
		MS3b	18.60	21.05	23.52	13.74
		MS4	17.38	20.59	25.25	13.74
		MS5	17.42	19.61	22.17	13.74
		MS6	13.67	17.55	22.22	13.74
		MS7	13.67	17.16	20.05	13.74
	Closed	HRV	0.01	0.08	0.89	34.67
		MS1	14.92	31.06	36.68	34.67
		MS2	16.62	24.52	28.45	34.67
		MS3a	20.17	23.53	25.55	34.67
		MS3b	10.82	13.60	14.73	34.67
		MS4	10.60	15.75	19.60	34.67
		MS5	13.27	14.96	16.83	34.67
		MS6	11.89	14.42	16.70	34.67
		MS7	8.94	10.77	13.00	34.67
Red Fir – Mesic						
	Open	HRV	5.34	12.70	25.74	45.04
		MS1	0.49	2.38	14.79	45.04
		MS2	6.32	9.11	25.01	45.04
		MS3a	8.29	9.80	12.53	45.04
		MS3b	13.16	15.82	21.16	45.04
		MS4	13.89	16.82	25.61	45.04
		MS5	24.03	25.50	30.32	45.04
		MS6	30.98	32.81	37.91	45.04

(Table D5 continued on next page.)

(Table D5 continued)

Cover type	Canopy cover class	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS7	24.46	25.82	31.78	45.04
	Moderate	HRV	5.81	7.50	9.27	40.63
		MS1	1.16	3.12	5.85	40.63
		MS2	9.46	13.30	20.38	40.63
		MS3a	13.26	15.49	17.93	40.63
		MS3b	16.52	18.27	20.63	40.63
		MS4	21.89	23.71	26.98	40.63
		MS5	21.39	23.55	26.04	40.63
		MS6	20.40	21.82	23.57	40.63
		MS7	23.28	24.80	26.09	40.63
	Closed	HRV	65.44	79.77	88.39	14.33
		MS1	79.82	94.45	98.33	14.33
		MS2	61.95	75.99	82.23	14.33
		MS3a	69.79	73.91	78.06	14.33
		MS3b	59.60	66.16	69.69	14.33
		MS4	47.61	59.44	62.68	14.33
		MS5	46.18	50.72	53.45	14.33
		MS6	41.29	45.31	47.72	14.33
		MS7	44.94	49.51	50.57	14.33
Red Fir – Xeric						
	Open	HRV	37.50	49.48	63.70	48.07
		MS1	5.42	16.64	31.14	48.07
		MS2	14.13	21.67	46.19	48.07
		MS3a	27.96	33.32	41.51	48.07
		MS3b	39.12	46.33	57.60	48.07
		MS4	23.82	29.98	44.97	48.07
		MS5	40.48	44.47	52.06	48.07
		MS6	42.91	45.25	56.11	48.07
		MS7	39.43	43.94	52.38	48.07
	Moderate	HRV	15.21	19.68	24.50	33.22
		MS1	14.00	16.67	22.66	33.22

(Table D5 continued on next page.)

(Table D5 continued)

Cover type	Canopy cover class	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS2	19.25	24.01	28.64	33.22
		MS3a	30.58	32.51	35.00	33.22
		MS3b	26.41	31.34	35.17	33.22
		MS4	24.03	28.00	32.51	33.22
		MS5	25.14	27.05	29.00	33.22
		MS6	22.44	23.78	27.36	33.22
		MS7	23.29	26.65	30.42	33.22
	Closed	HRV	19.78	30.15	41.11	18.71
		MS1	51.96	62.94	79.35	18.71
		MS2	32.16	52.84	65.89	18.71
		MS3a	28.66	33.36	38.42	18.71
		MS3b	16.28	21.52	25.38	18.71
		MS4	29.54	40.55	48.58	18.71
		MS5	21.46	28.20	31.53	18.71
		MS6	19.56	30.39	33.16	18.71
		MS7	20.20	29.41	32.73	18.71
Sierran Mixed Conifer – Mesic						
	Open	HRV	16.39	28.61	44.10	34.87
		MS1	0.99	2.62	15.40	34.87
		MS2	7.39	10.66	24.72	34.87
		MS3a	6.91	9.32	12.62	34.87
		MS3b	10.51	12.45	20.14	34.87
		MS4	12.48	14.32	28.37	34.87
		MS5	15.48	17.71	25.64	34.87
		MS6	24.68	25.75	28.15	34.87
		MS7	23.34	25.27	30.59	34.87
	Moderate	HRV	20.60	25.26	33.23	32.16
		MS1	1.38	4.24	16.78	32.16
		MS2	12.01	15.10	26.68	32.16
		MS3a	10.81	12.67	16.66	32.16
		MS3b	13.91	15.35	22.59	32.16

(Table D5 continued on next page.)

(Table D5 continued)

Cover type	Canopy cover class	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS4	22.02	23.24	26.86	32.16
		MS5	21.39	22.38	27.26	32.16
		MS6	21.21	22.67	25.11	32.16
		MS7	22.89	23.95	29.25	32.16
	Closed	HRV	29.20	45.65	58.50	32.98
		MS1	72.81	92.76	96.66	32.98
		MS2	55.19	70.72	80.27	32.98
		MS3a	72.00	76.96	82.16	32.98
		MS3b	55.84	71.78	75.41	32.98
		MS4	43.72	61.95	65.07	32.98
		MS5	52.42	58.99	62.70	32.98
		MS6	46.86	51.78	53.10	32.98
		MS7	42.02	50.10	53.48	32.98
Sierran Mixed Conifer – Ultramafic						
	Open	HRV	49.54	57.59	67.55	57.30
		MS1	15.36	22.70	40.90	57.30
		MS2	20.76	27.15	38.26	57.30
		MS3a	43.27	46.72	52.75	57.30
		MS3b	52.18	57.44	64.76	57.30
		MS4	34.15	41.84	55.19	57.30
		MS5	46.25	50.84	57.11	57.30
		MS6	47.05	52.45	57.18	57.30
		MS7	52.50	55.31	61.07	57.30
	Moderate	HRV	21.32	25.84	30.67	15.28
		MS1	24.00	31.73	39.84	15.28
		MS2	29.70	38.91	45.23	15.28
		MS3a	25.93	31.95	35.59	15.28
		MS3b	23.38	29.34	34.60	15.28
		MS4	27.17	36.34	43.10	15.28
		MS5	24.14	30.62	35.93	15.28
		MS6	25.53	29.62	34.15	15.28

(Table D5 continued on next page.)

(Table D5 continued)

Cover type	Canopy cover class	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS7	24.79	29.61	32.42	15.28
	Closed	HRV	9.89	16.22	21.96	27.42
		MS1	24.88	45.86	55.68	27.42
		MS2	26.48	31.43	45.75	27.42
		MS3a	19.06	21.38	23.77	27.42
		MS3b	10.47	12.74	15.94	27.42
		MS4	16.00	20.82	27.19	27.42
		MS5	16.45	18.94	21.06	27.42
		MS6	15.66	17.71	21.68	27.42
		MS7	13.01	15.23	16.76	27.42
Sierran Mixed Conifer – Xeric						
	Open	HRV	44.95	56.55	71.14	35.09
		MS1	5.55	10.54	28.63	35.09
		MS2	16.88	23.11	40.81	35.09
		MS3a	28.26	32.75	37.86	35.09
		MS3b	40.83	44.50	53.94	35.09
		MS4	30.39	33.80	44.76	35.09
		MS5	42.02	44.97	53.13	35.09
		MS6	42.84	44.83	48.18	35.09
		MS7	43.07	46.30	51.64	35.09
	Moderate	HRV	21.39	28.98	34.89	28.23
		MS1	10.21	15.71	26.45	28.23
		MS2	20.15	23.58	27.67	28.23
		MS3a	28.49	29.90	31.99	28.23
		MS3b	27.67	30.08	30.93	28.23
		MS4	26.17	28.88	31.93	28.23
		MS5	23.36	25.05	27.66	28.23
		MS6	21.07	22.64	25.68	28.23
		MS7	22.58	24.19	26.67	28.23
	Closed	HRV	6.92	14.01	22.01	36.68
		MS1	39.97	71.72	82.43	36.68

(Table D5 continued on next page.)

(Table D5 continued)

Cover type	Canopy cover class	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
		MS2	36.65	53.56	63.01	36.68
		MS3a	31.87	37.58	42.14	36.68
		MS3b	17.62	25.59	28.95	36.68
		MS4	25.79	36.47	43.49	36.68
		MS5	23.42	29.21	33.16	36.68
		MS6	27.71	32.63	35.53	36.68
		MS7	23.89	28.58	33.29	36.68

Table D6—Range of variability (ROV) in the percentage of each major cover type (i.e., those with >1,000 ha extent) in each vegetation seral stage (i.e., combinations of developmental stage and canopy cover class) for the simulated historical range of variability (circa 1550–1850)(HRV) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2-7) in the Upper Yuba River watershed. Select percentiles of the simulated ROV are given as well as the current landscape condition.

			Percentile of range of variability			
Cover type	Seral stage	Scenario	5th	50th	95th	Current
Mixed Evergreen – Mesic						
	Early – All Structures	HRV	2.72	6.65	13.05	8.21
		MS1	0.13	0.77	6.47	8.21
		MS2	4.53	6.96	14.33	8.21
		MS3a	4.21	6.80	9.29	8.21
		MS3b	4.50	6.51	8.42	8.21
		MS4	5.19	7.44	10.41	8.21
		MS5	6.58	7.69	10.89	8.21
		MS6	7.40	10.16	12.77	8.21
		MS7	6.59	9.29	11.69	8.21
	Mid – Open	HRV	0.10	0.30	0.96	6.37
		MS1	0.00	0.01	0.20	6.37
		MS2	0.17	0.49	1.28	6.37
		MS3a	0.23	0.58	0.76	6.37
		MS3b	0.14	0.62	1.10	6.37
		MS4	0.24	0.60	0.87	6.37
		MS5	0.58	0.99	1.40	6.37
		MS6	1.59	1.99	2.55	6.37
		MS7	1.31	1.65	1.99	6.37
	Mid – Moderate	HRV	1.80	4.41	9.98	9.76
		MS1	0.03	0.58	2.73	9.76
		MS2	2.63	4.82	6.05	9.76
		MS3a	1.84	4.47	5.50	9.76
		MS3b	3.52	5.35	6.44	9.76
		MS4	2.87	4.44	5.81	9.76
		MS5	3.91	5.25	6.89	9.76
		MS6	4.16	5.83	7.52	9.76

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS7	4.38	5.76	8.45	9.76
	Mid – Closed	HRV	0.14	0.79	3.04	36.53
		MS1	0.00	0.04	0.93	36.53
		MS2	0.27	0.71	2.02	36.53
		MS3a	0.30	0.76	1.58	36.53
		MS3b	0.40	0.92	2.09	36.53
		MS4	0.33	0.96	1.44	36.53
		MS5	0.39	0.95	1.54	36.53
		MS6	0.35	0.76	1.87	36.53
		MS7	0.49	0.78	1.57	36.53
	Late – Open	HRV	3.06	6.39	12.53	2.50
		MS1	0.25	0.59	6.09	2.50
		MS2	1.07	1.82	6.92	2.50
		MS3a	0.76	1.61	2.55	2.50
		MS3b	3.12	4.11	6.99	2.50
		MS4	6.48	8.14	9.72	2.50
		MS5	7.73	8.68	10.43	2.50
		MS6	12.81	14.13	15.39	2.50
		MS7	10.36	11.45	13.25	2.50
	Late – Moderate	HRV	7.56	11.05	15.39	7.31
		MS1	0.41	2.01	7.74	7.31
		MS2	7.89	10.36	17.03	7.31
		MS3a	6.68	7.77	9.73	7.31
		MS3b	8.77	10.64	13.98	7.31
		MS4	20.13	21.67	23.72	7.31
		MS5	16.26	17.54	19.38	7.31
		MS6	15.21	17.04	18.43	7.31
		MS7	17.91	19.62	21.67	7.31
	Late – Closed	HRV	56.99	68.29	78.63	29.31
		MS1	79.45	94.82	99.21	29.31

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
		MS2	57.20	73.93	78.24	29.31
		MS3a	75.41	78.05	81.64	29.31
		MS3b	64.85	71.75	77.01	29.31
		MS4	51.66	57.28	59.66	29.31
		MS5	54.74	58.55	61.82	29.31
		MS6	45.97	50.25	53.79	29.31
		MS7	46.43	51.19	54.98	29.31
Mixed Evergreen – Xeric						
	Early – All Structures	HRV	3.71	7.56	13.03	10.88
		MS1	0.26	1.34	5.42	10.88
		MS2	3.49	5.12	10.17	10.88
		MS3a	2.95	4.32	6.26	10.88
		MS3b	3.77	4.75	6.11	10.88
		MS4	3.99	4.59	8.82	10.88
		MS5	5.06	6.10	8.60	10.88
		MS6	6.78	8.91	10.81	10.88
		MS7	6.25	7.57	9.34	10.88
	Mid – Open	HRV	0.26	0.59	1.26	12.87
		MS1	0.00	0.01	0.20	12.87
		MS2	0.26	0.43	0.76	12.87
		MS3a	0.22	0.37	0.62	12.87
		MS3b	0.60	0.80	1.27	12.87
		MS4	0.19	0.49	0.86	12.87
		MS5	1.00	1.25	1.50	12.87
		MS6	2.61	3.30	3.52	12.87
		MS7	1.96	2.11	2.59	12.87
	Mid – Moderate	HRV	2.80	5.48	9.57	9.39
		MS1	0.08	0.62	3.63	9.39
		MS2	2.42	3.26	5.39	9.39
		MS3a	2.97	4.17	5.51	9.39

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS3b	4.77	5.64	6.93	9.39
		MS4	2.34	3.40	4.62	9.39
		MS5	4.30	4.86	5.76	9.39
		MS6	4.58	5.84	6.99	9.39
		MS7	5.04	6.13	7.69	9.39
	Mid – Closed	HRV	0.96	2.43	5.08	48.80
		MS1	0.01	0.44	1.62	48.80
		MS2	0.70	1.23	2.51	48.80
		MS3a	1.16	1.76	3.07	48.80
		MS3b	1.31	2.03	2.77	48.80
		MS4	0.96	1.63	3.09	48.80
		MS5	1.11	1.69	2.51	48.80
		MS6	1.33	2.01	2.58	48.80
		MS7	1.30	1.89	2.49	48.80
	Late – Open	HRV	4.20	7.48	12.47	1.38
		MS1	0.26	1.10	5.72	1.38
		MS2	0.89	2.04	6.67	1.38
		MS3a	3.34	3.88	4.95	1.38
		MS3b	8.06	9.82	12.34	1.38
		MS4	6.75	8.43	10.53	1.38
		MS5	11.48	12.76	14.13	1.38
		MS6	15.41	16.90	17.89	1.38
		MS7	12.46	13.60	15.36	1.38
	Late – Moderate	HRV	9.24	12.35	16.24	3.84
		MS1	0.77	2.22	6.89	3.84
		MS2	7.49	10.23	15.13	3.84
		MS3a	10.26	11.04	12.58	3.84
		MS3b	17.88	19.15	20.09	3.84
		MS4	17.42	20.40	23.33	3.84
		MS5	18.06	19.72	20.76	3.84

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS6	15.48	16.73	18.37	3.84
		MS7	19.62	20.47	22.07	3.84
	Late – Closed	HRV	51.06	63.39	72.35	12.84
		MS1	77.86	93.28	97.84	12.84
		MS2	64.66	75.72	82.68	12.84
		MS3a	70.75	73.72	76.08	12.84
		MS3b	53.00	57.58	61.29	12.84
		MS4	53.05	60.40	65.36	12.84
		MS5	50.81	53.25	55.09	12.84
		MS6	44.36	46.62	49.40	12.84
		MS7	43.60	47.98	50.45	12.84
Oak-Conifer Forest and Woodland						
	Early – All Structures	HRV	8.91	15.05	23.33	19.97
		MS1	0.58	1.64	11.83	19.97
		MS2	5.53	8.29	17.39	19.97
		MS3a	5.44	6.76	9.62	19.97
		MS3b	5.84	6.67	9.45	19.97
		MS4	5.51	7.01	14.67	19.97
		MS5	6.92	8.17	12.95	19.97
		MS6	9.67	10.71	13.22	19.97
		MS7	7.68	9.99	11.84	19.97
	Mid – Open	HRV	6.27	9.47	14.68	24.34
		MS1	0.35	0.84	6.71	24.34
		MS2	1.40	1.84	4.94	24.34
		MS3a	1.11	1.59	2.45	24.34
		MS3b	2.21	2.86	6.28	24.34
		MS4	2.24	2.80	6.26	24.34
		MS5	3.67	4.40	5.20	24.34
		MS6	7.42	8.08	9.00	24.34
		MS7	7.68	8.79	10.04	24.34

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
	Mid – Moderate	HRV	8.33	10.50	14.24	14.61
		MS1	0.47	1.23	9.62	14.61
		MS2	5.59	6.55	8.62	14.61
		MS3a	4.68	5.84	7.25	14.61
		MS3b	6.06	6.90	8.74	14.61
		MS4	5.73	7.95	9.35	14.61
		MS5	7.95	8.54	10.87	14.61
		MS6	9.92	10.51	11.47	14.61
		MS7	8.59	9.43	11.90	14.61
	Mid – Closed	HRV	7.65	15.05	22.12	37.36
		MS1	7.25	11.17	22.24	37.36
		MS2	8.90	13.81	17.92	37.36
		MS3a	11.16	14.57	19.72	37.36
		MS3b	10.14	14.63	19.20	37.36
		MS4	7.99	12.18	16.30	37.36
		MS5	8.73	12.86	16.21	37.36
		MS6	10.89	12.78	16.65	37.36
		MS7	10.74	11.49	15.65	37.36
	Late – Open	HRV	5.47	9.40	15.96	1.12
		MS1	0.57	1.83	9.05	1.12
		MS2	0.63	2.64	8.67	1.12
		MS3a	0.50	1.86	3.79	1.12
		MS3b	2.61	3.18	8.54	1.12
		MS4	3.63	4.77	10.71	1.12
		MS5	5.53	6.80	8.85	1.12
		MS6	7.65	8.05	9.14	1.12
		MS7	9.26	10.27	11.07	1.12
	Late – Moderate	HRV	11.80	14.81	18.69	1.02
		MS1	1.92	4.78	11.64	1.02
		MS2	6.50	10.07	16.04	1.02

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS3a	5.03	7.35	10.15	1.02
		MS3b	7.10	7.84	12.22	1.02
		MS4	14.20	15.78	21.05	1.02
		MS5	12.76	14.41	15.54	1.02
		MS6	10.13	11.35	13.34	1.02
		MS7	10.89	13.04	15.77	1.02
	Late – Closed	HRV	12.63	24.36	33.09	1.58
		MS1	49.43	74.27	85.58	1.58
		MS2	40.03	55.61	64.62	1.58
		MS3a	56.25	60.94	66.67	1.58
		MS3b	44.80	56.77	61.23	1.58
		MS4	37.19	46.24	54.58	1.58
		MS5	38.57	43.51	48.11	1.58
		MS6	31.85	37.57	40.49	1.58
		MS7	30.61	36.40	38.88	1.58
Oak-Conifer Forest and Woodland – Ultramafic						
	Early – All Structures	HRV	0.99	3.70	12.78	17.76
		MS1	0.88	3.38	9.79	17.76
		MS2	1.18	2.61	6.15	17.76
		MS3a	0.55	1.48	3.52	17.76
		MS3b	0.86	1.58	3.55	17.76
		MS4	0.65	2.38	7.95	17.76
		MS5	2.25	3.53	7.76	17.76
		MS6	3.36	4.59	6.76	17.76
		MS7	3.88	5.06	7.03	17.76
	Mid – Open	HRV	1.45	4.35	14.33	33.49
		MS1	8.54	12.58	15.58	33.49
		MS2	11.44	14.14	17.45	33.49
		MS3a	16.38	17.75	22.17	33.49
		MS3b	18.02	20.64	22.82	33.49

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
		MS4	11.13	14.10	16.07	33.49
		MS5	13.71	17.97	20.60	33.49
		MS6	15.70	18.52	24.57	33.49
		MS7	17.44	19.36	22.10	33.49
	Mid – Moderate	HRV	0.12	0.56	2.51	11.54
		MS1	4.00	5.34	9.80	11.54
		MS2	2.57	5.29	8.99	11.54
		MS3a	1.51	3.42	5.49	11.54
		MS3b	2.67	4.11	5.74	11.54
		MS4	3.62	5.06	9.91	11.54
		MS5	2.20	3.38	5.52	11.54
		MS6	2.82	3.97	6.82	11.54
		MS7	2.47	3.61	5.33	11.54
	Mid – Closed	HRV	0.01	0.03	0.19	29.32
		MS1	0.28	1.60	4.17	29.32
		MS2	0.22	0.81	2.23	29.32
		MS3a	0.16	0.80	2.15	29.32
		MS3b	0.11	0.71	1.52	29.32
		MS4	0.19	0.53	2.23	29.32
		MS5	0.09	0.81	1.52	29.32
		MS6	0.16	0.55	2.18	29.32
		MS7	0.19	0.44	0.81	29.32
	Late – Open	HRV	66.87	88.27	94.01	0.34
		MS1	22.06	28.22	38.70	0.34
		MS2	26.76	31.23	37.40	0.34
		MS3a	28.97	32.96	36.74	0.34
		MS3b	40.29	42.96	45.12	0.34
		MS4	43.47	46.43	51.33	0.34
		MS5	41.44	43.56	45.42	0.34
		MS6	39.53	43.43	48.08	0.34

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
		MS7	45.09	47.26	50.59	0.34
	Late – Moderate	HRV	0.81	1.69	8.09	2.20
		MS1	15.05	19.09	24.54	2.20
		MS2	18.00	21.92	24.17	2.20
		MS3a	15.84	20.38	24.80	2.20
		MS3b	15.29	17.10	19.18	2.20
		MS4	11.84	15.14	19.13	2.20
		MS5	14.37	16.29	18.23	2.20
		MS6	10.04	13.47	17.67	2.20
		MS7	10.33	13.42	15.58	2.20
	Late – Closed	HRV	0.01	0.06	0.79	5.35
		MS1	14.72	29.13	34.73	5.35
		MS2	16.22	23.95	27.76	5.35
		MS3a	19.71	22.48	24.74	5.35
		MS3b	10.53	13.02	13.97	5.35
		MS4	10.22	14.54	19.08	5.35
		MS5	12.73	14.17	15.52	5.35
		MS6	11.35	13.57	15.77	5.35
		MS7	8.30	10.25	12.63	5.35
Red Fir – Mesic						
	Early – All Structures	HRV	2.42	7.77	19.68	24.21
		MS1	0.10	1.03	10.32	24.21
		MS2	4.89	6.93	17.36	24.21
		MS3a	4.94	5.77	7.14	24.21
		MS3b	4.65	5.43	6.74	24.21
		MS4	4.43	6.28	12.96	24.21
		MS5	7.02	7.72	12.46	24.21
		MS6	8.49	10.12	13.56	24.21
		MS7	7.76	9.28	13.42	24.21
	Mid – Open	HRV	0.43	0.89	1.96	16.70

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS1	0.01	0.06	0.23	16.70
		MS2	0.08	0.30	0.88	16.70
		MS3a	0.07	0.23	0.42	16.70
		MS3b	0.31	0.48	0.91	16.70
		MS4	0.12	0.43	0.94	16.70
		MS5	0.83	1.12	1.54	16.70
		MS6	3.20	3.44	3.73	16.70
		MS7	2.03	2.40	2.99	16.70
	Mid – Moderate	HRV	0.47	0.90	1.64	18.67
		MS1	0.01	0.05	0.22	18.67
		MS2	1.54	2.75	3.76	18.67
		MS3a	1.44	2.46	3.18	18.67
		MS3b	1.48	2.71	3.40	18.67
		MS4	2.12	3.07	4.14	18.67
		MS5	3.01	3.98	5.24	18.67
		MS6	5.83	6.52	7.85	18.67
		MS7	4.40	5.39	6.24	18.67
	Mid – Closed	HRV	11.69	18.81	28.87	3.63
		MS1	1.90	5.12	12.32	3.63
		MS2	4.63	7.08	12.42	3.63
		MS3a	4.34	5.99	6.91	3.63
		MS3b	6.79	8.45	10.28	3.63
		MS4	4.23	7.29	12.49	3.63
		MS5	5.45	7.51	9.18	3.63
		MS6	7.01	8.22	11.28	3.63
		MS7	6.76	8.35	11.52	3.63
	Late – Open	HRV	2.31	3.85	6.66	4.13
		MS1	0.26	1.13	3.94	4.13
		MS2	1.32	2.19	6.27	4.13
		MS3a	2.89	3.75	5.45	4.13

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS3b	7.88	9.69	14.29	4.13
		MS4	8.62	10.06	12.18	4.13
		MS5	15.57	16.43	17.57	4.13
		MS6	18.40	19.39	20.45	4.13
		MS7	13.57	14.44	15.72	4.13
	Late – Moderate	HRV	5.21	6.51	8.03	21.96
		MS1	1.15	3.01	5.69	21.96
		MS2	7.08	10.58	16.63	21.96
		MS3a	11.15	12.75	15.75	21.96
		MS3b	13.47	15.66	17.10	21.96
		MS4	18.85	20.51	23.47	21.96
		MS5	17.98	19.83	21.98	21.96
		MS6	14.02	15.12	16.18	21.96
		MS7	18.41	19.35	20.60	21.96
	Late – Closed	HRV	47.21	59.83	69.91	10.70
		MS1	69.59	85.27	96.00	10.70
		MS2	56.60	68.04	76.19	10.70
		MS3a	63.69	68.24	71.91	10.70
		MS3b	51.21	57.43	61.98	10.70
		MS4	43.32	52.76	56.97	10.70
		MS5	40.09	43.01	45.32	10.70
		MS6	33.03	36.74	38.90	10.70
		MS7	34.96	40.72	42.55	10.70
Red Fir – Xeric						
	Early – All Structures	HRV	16.13	25.57	39.46	32.39
		MS1	1.28	4.99	19.70	32.39
		MS2	3.69	6.57	30.12	32.39
		MS3a	3.73	4.88	9.25	32.39
		MS3b	4.18	5.12	7.56	32.39
		MS4	4.68	7.23	17.97	32.39

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS5	6.53	8.40	14.16	32.39
		MS6	8.34	10.32	16.96	32.39
		MS7	8.11	10.51	21.81	32.39
	Mid – Open	HRV	9.67	16.08	23.44	12.58
		MS1	2.54	4.76	12.03	12.58
		MS2	5.57	7.21	13.35	12.58
		MS3a	12.74	13.92	17.63	12.58
		MS3b	17.31	19.68	23.40	12.58
		MS4	7.49	10.66	19.36	12.58
		MS5	12.76	14.31	17.81	12.58
		MS6	14.31	16.41	19.56	12.58
		MS7	13.34	16.51	19.74	12.58
	Mid – Moderate	HRV	4.63	8.08	13.05	18.66
		MS1	5.76	7.96	12.45	18.66
		MS2	7.66	8.74	11.04	18.66
		MS3a	8.48	10.18	11.97	18.66
		MS3b	7.37	10.25	12.36	18.66
		MS4	6.85	9.36	11.94	18.66
		MS5	7.48	9.07	10.56	18.66
		MS6	8.68	9.82	10.87	18.66
		MS7	6.16	8.06	11.15	18.66
	Mid – Closed	HRV	0.94	2.23	4.79	8.26
		MS1	7.17	11.41	14.65	8.26
		MS2	4.20	9.72	12.56	8.26
		MS3a	2.72	4.01	5.06	8.26
		MS3b	2.17	2.82	4.12	8.26
		MS4	4.09	7.41	10.17	8.26
		MS5	4.01	5.81	7.22	8.26
		MS6	3.80	6.12	7.33	8.26
		MS7	3.58	5.66	6.92	8.26

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
	Late – Open	HRV	4.78	6.91	9.51	3.10
		MS1	0.91	2.28	5.82	3.10
		MS2	3.20	5.12	8.53	3.10
		MS3a	10.37	13.32	15.74	3.10
		MS3b	17.41	21.04	29.15	3.10
		MS4	9.31	11.65	14.23	3.10
		MS5	19.34	21.12	23.53	3.10
		MS6	17.97	19.26	21.81	3.10
		MS7	14.13	16.15	18.23	3.10
	Late – Moderate	HRV	8.82	11.21	13.90	14.57
		MS1	6.49	8.89	12.11	14.57
		MS2	12.60	15.29	18.93	14.57
		MS3a	19.60	22.52	24.45	14.57
		MS3b	18.70	20.87	23.71	14.57
		MS4	16.42	18.67	20.70	14.57
		MS5	15.94	17.66	19.46	14.57
		MS6	13.48	14.10	16.55	14.57
		MS7	16.68	18.30	21.71	14.57
	Late – Closed	HRV	18.13	27.84	38.15	10.45
		MS1	41.82	51.74	65.10	10.45
		MS2	27.95	43.12	54.07	10.45
		MS3a	24.56	29.68	34.15	10.45
		MS3b	14.11	18.74	21.83	10.45
		MS4	24.13	33.21	39.74	10.45
		MS5	17.10	22.17	25.14	10.45
		MS6	16.69	24.03	26.27	10.45
		MS7	16.46	23.70	26.84	10.45
Sierran Mixed Conifer – Mesic						
	Early – All Structures	HRV	3.57	7.25	13.55	14.98
		MS1	0.19	0.89	5.26	14.98

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS2	4.77	5.90	11.73	14.98
		MS3a	4.68	5.30	7.65	14.98
		MS3b	5.11	5.57	9.23	14.98
		MS4	5.15	5.78	10.37	14.98
		MS5	5.75	6.39	10.32	14.98
		MS6	7.85	8.52	9.08	14.98
		MS7	6.69	7.42	10.00	14.98
	Mid – Open	HRV	4.07	6.47	9.71	16.29
		MS1	0.05	0.15	1.47	16.29
		MS2	1.40	1.95	3.75	16.29
		MS3a	1.28	1.63	2.27	16.29
		MS3b	1.69	2.21	4.82	16.29
		MS4	1.35	1.89	2.85	16.29
		MS5	2.49	2.93	3.83	16.29
		MS6	5.73	6.23	6.61	16.29
		MS7	4.97	5.50	6.23	16.29
	Mid – Moderate	HRV	4.87	6.94	9.67	17.97
		MS1	0.13	0.60	3.13	17.97
		MS2	4.82	6.07	10.77	17.97
		MS3a	4.96	5.61	6.97	17.97
		MS3b	5.57	6.27	9.62	17.97
		MS4	5.14	6.01	7.65	17.97
		MS5	6.45	7.39	8.08	17.97
		MS6	8.92	9.50	10.56	17.97
		MS7	8.33	8.82	10.64	17.97
	Mid – Closed	HRV	6.99	10.93	15.42	9.74
		MS1	2.09	4.84	12.35	9.74
		MS2	7.54	9.23	14.33	9.74
		MS3a	7.06	8.37	10.93	9.74
		MS3b	8.08	9.82	11.42	9.74

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS4	6.77	8.54	13.03	9.74
		MS5	6.84	8.96	10.67	9.74
		MS6	8.41	9.72	11.40	9.74
		MS7	8.73	9.62	11.87	9.74
	Late – Open	HRV	7.87	14.22	23.38	3.60
		MS1	0.49	1.51	9.85	3.60
		MS2	0.77	2.23	8.27	3.60
		MS3a	0.76	2.23	4.61	3.60
		MS3b	3.64	4.26	10.09	3.60
		MS4	5.80	6.76	14.77	3.60
		MS5	6.75	7.90	11.78	3.60
		MS6	10.74	11.15	12.47	3.60
		MS7	11.49	11.99	14.77	3.60
	Late – Moderate	HRV	14.82	18.43	24.29	14.18
		MS1	1.26	3.00	15.39	14.18
		MS2	6.69	9.29	17.43	14.18
		MS3a	5.33	6.97	9.69	14.18
		MS3b	8.14	9.30	14.28	14.18
		MS4	15.89	17.50	20.34	14.18
		MS5	14.01	15.12	19.22	14.18
		MS6	11.94	13.09	15.22	14.18
		MS7	14.12	14.93	19.04	14.18
	Late – Closed	HRV	21.15	34.46	44.86	23.23
		MS1	58.78	85.36	92.78	23.23
		MS2	46.26	60.43	71.46	23.23
		MS3a	63.51	69.02	73.82	23.23
		MS3b	47.76	61.14	65.95	23.23
		MS4	36.96	52.16	56.94	23.23
		MS5	44.05	50.05	53.39	23.23
		MS6	37.35	41.46	44.15	23.23

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
		MS7	33.12	40.32	43.44	23.23
Sierran Mixed Conifer – Ultramafic						
	Early – All Structures	HRV	9.07	12.61	17.09	48.70
		MS1	1.12	2.12	10.75	48.70
		MS2	2.25	4.34	5.84	48.70
		MS3a	1.96	3.67	4.59	48.70
		MS3b	2.02	3.23	5.56	48.70
		MS4	2.00	2.98	6.05	48.70
		MS5	3.81	5.41	7.14	48.70
		MS6	5.43	7.00	8.04	48.70
		MS7	5.59	6.65	8.95	48.70
	Mid – Open	HRV	7.75	10.77	14.42	5.33
		MS1	9.89	15.45	24.86	5.33
		MS2	12.02	15.95	24.40	5.33
		MS3a	27.83	31.66	36.91	5.33
		MS3b	29.50	34.24	41.79	5.33
		MS4	18.19	22.62	29.36	5.33
		MS5	24.60	29.48	36.59	5.33
		MS6	24.98	28.46	34.43	5.33
		MS7	28.65	31.33	36.94	5.33
	Mid – Moderate	HRV	1.52	2.92	5.10	6.77
		MS1	13.80	24.01	31.63	6.77
		MS2	16.93	26.73	31.10	6.77
		MS3a	12.54	17.18	20.91	6.77
		MS3b	10.12	15.96	20.79	6.77
		MS4	14.34	21.21	26.82	6.77
		MS5	11.66	16.37	22.41	6.77
		MS6	13.25	17.60	22.34	6.77
		MS7	10.25	15.69	18.36	6.77
	Mid – Closed	HRV	0.13	0.35	0.85	2.99

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
		MS1	3.05	7.37	18.07	2.99
		MS2	3.27	5.37	13.69	2.99
		MS3a	1.05	2.05	4.73	2.99
		MS3b	1.28	2.38	5.51	2.99
		MS4	2.40	4.68	8.18	2.99
		MS5	1.28	3.75	5.85	2.99
		MS6	1.49	3.45	6.22	2.99
		MS7	1.06	2.80	4.19	2.99
	Late – Open	HRV	27.89	33.58	41.57	3.27
		MS1	3.20	4.54	10.31	3.27
		MS2	4.58	6.85	10.21	3.27
		MS3a	10.82	11.55	13.02	3.27
		MS3b	18.00	19.36	20.96	3.27
		MS4	12.40	15.70	18.92	3.27
		MS5	14.57	15.77	16.80	3.27
		MS6	14.38	16.12	17.12	3.27
		MS7	14.68	16.37	18.27	3.27
	Late – Moderate	HRV	19.06	22.81	26.94	8.51
		MS1	6.78	8.56	11.58	8.51
		MS2	9.60	13.06	16.83	8.51
		MS3a	13.34	14.21	16.56	8.51
		MS3b	12.52	13.40	16.17	8.51
		MS4	12.31	14.76	17.22	8.51
		MS5	11.71	13.75	15.06	8.51
		MS6	11.13	12.31	13.83	8.51
		MS7	11.76	14.17	15.06	8.51
	Late – Closed	HRV	9.68	15.87	21.41	24.43
		MS1	20.67	36.18	39.83	24.43
		MS2	22.25	26.22	32.10	24.43
		MS3a	17.99	18.98	20.77	24.43

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
		MS3b	8.85	9.98	11.43	24.43
		MS4	13.37	16.63	20.27	24.43
		MS5	13.80	15.26	16.05	24.43
		MS6	13.23	14.39	16.04	24.43
	Late – Closed	MS7	10.58	12.44	13.60	24.43
Sierran Mixed Conifer – Xeric						
	Early – All Structures	HRV	7.17	9.54	12.46	19.48
		MS1	0.57	2.35	7.82	19.48
		MS2	4.82	6.84	10.06	19.48
		MS3a	4.52	5.12	6.07	19.48
		MS3b	4.75	5.47	7.42	19.48
		MS4	4.92	5.47	8.25	19.48
		MS5	6.51	7.29	9.31	19.48
		MS6	8.94	9.45	10.97	19.48
		MS7	8.01	9.10	10.93	19.48
	Mid – Open	HRV	7.24	9.08	10.74	11.48
		MS1	1.44	2.59	5.86	11.48
		MS2	6.31	7.54	9.74	11.48
		MS3a	11.61	12.62	14.79	11.48
		MS3b	16.05	17.44	18.70	11.48
		MS4	9.04	10.07	13.01	11.48
		MS5	14.28	15.05	16.04	11.48
		MS6	16.13	16.73	17.30	11.48
		MS7	15.39	16.89	17.93	11.48
	Mid – Moderate	HRV	1.90	3.16	4.64	14.92
		MS1	3.51	4.92	7.31	14.92
		MS2	6.46	7.50	8.84	14.92
		MS3a	8.49	9.08	9.96	14.92
		MS3b	7.22	8.69	9.39	14.92
		MS4	6.04	7.96	9.35	14.92

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability			Current
			5th	50th	95th	
		MS5	6.33	7.21	7.94	14.92
		MS6	6.97	7.66	7.97	14.92
		MS7	6.33	7.07	7.66	14.92
	Mid – Closed	HRV	0.30	0.69	1.33	11.96
		MS1	4.52	9.43	11.35	11.96
		MS2	5.43	7.19	8.74	11.96
		MS3a	2.35	2.98	3.88	11.96
		MS3b	1.51	2.67	3.25	11.96
		MS4	3.29	4.34	5.61	11.96
		MS5	2.22	2.93	3.94	11.96
		MS6	3.13	3.74	4.50	11.96
		MS7	2.61	3.18	3.73	11.96
	Late – Open	HRV	28.56	37.83	49.66	4.13
		MS1	2.49	5.49	15.08	4.13
		MS2	4.70	8.81	21.00	4.13
		MS3a	11.53	14.50	18.17	4.13
		MS3b	19.34	21.77	28.64	4.13
		MS4	15.53	17.82	25.55	4.13
		MS5	20.75	22.94	28.18	4.13
		MS6	17.37	18.68	20.46	4.13
		MS7	17.76	20.39	23.82	4.13
	Late – Moderate	HRV	19.63	25.85	30.53	13.31
		MS1	6.48	10.28	20.56	13.31
		MS2	13.13	15.42	20.54	13.31
		MS3a	19.45	20.80	23.14	13.31
		MS3b	19.89	21.19	22.09	13.31
		MS4	18.15	21.24	23.58	13.31
		MS5	17.11	18.08	19.76	13.31
		MS6	13.79	14.88	18.17	13.31
		MS7	15.43	17.32	19.24	13.31

(Table D6 continued on next page.)

(Table D6 continued)

Cover type	Seral stage	Scenario	Percentile of range of variability 5th	50th	95th	Current
	Late – Closed	HRV	6.58	13.29	20.98	24.72
		MS1	35.66	63.01	71.93	24.72
		MS2	31.23	46.25	54.31	24.72
		MS3a	29.63	34.64	38.12	24.72
		MS3b	16.11	22.95	25.94	24.72
		MS4	22.37	32.21	37.89	24.72
		MS5	21.20	26.28	29.32	24.72
		MS6	24.58	28.94	31.14	24.72
		MS7	21.10	25.35	29.59	24.72

(Table D6 continued on next page.)

Table D7—Range of variability (ROV) in landscape metrics (see *Landscape Configuration under Methods* for description of each landscape metric) computed on the basis of the landscape classified into vegetation developmental stages (none, early, mid, late) for the simulated historical range of variability (HRV) (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed. Select percentiles of the simulated ROV are given, as well as the current landscape condition.

		Percentile of range of variability			
Landscape metric	Scenario	5th	50th	95th	Current
LPI	HRV	17.94	29.87	38.72	5.72
	MS1	26.42	44.70	53.61	5.72
	MS2	17.19	31.74	36.64	5.72
	MS3a	24.33	35.26	36.73	5.72
	MS3b	21.08	32.30	35.22	5.72
	MS4	19.99	33.13	37.48	5.72
	MS5	20.16	30.93	35.10	5.72
	MS6	19.06	27.99	29.19	5.72
	MS7	18.64	21.97	31.28	5.72
AREA_AM	HRV	13,564	22,738	34,699	1,808
	MS1	29,224	51,199	68,238	1,808
	MS2	12,253	26,237	33,069	1,808
	MS3a	20,795	31,971	34,384	1,808
	MS3b	16,472	25,696	33,842	1,808
	MS4	14,742	30,223	35,542	1,808
	MS5	16,256	25,921	32,276	1,808
	MS6	13,963	21,237	24,836	1,808
	MS7	14,469	18,135	25,533	1,808
GYRATE_AM	HRV	5,955	8,009	9,826	2,397
	MS1	8,803	11,565	13,046	2,397
	MS2	5,826	8,214	9,037	2,397
	MS3a	6,788	8,922	9,373	2,397
	MS3b	6,199	8,044	9,330	2,397
	MS4	6,099	8,819	9,806	2,397
	MS5	6,068	7,818	8,939	2,397
	MS6	5,873	7,324	8,174	2,397

(Table D7 continued on next page.)

(Table D7 continued)

Landscape metric	Scenario	Percentile of range of variability 5th	50th	95th	Current
	MS7	5,943	6,846	7,918	2,397
SHAPE_AM	HRV	42.82	54.07	69.39	8.65
	MS1	23.36	26.13	30.74	8.65
	MS2	18.46	22.12	25.19	8.65
	MS3a	24.06	29.88	31.91	8.65
	MS3b	37.38	42.92	49.01	8.65
	MS4	20.14	23.92	27.42	8.65
	MS5	34.86	42.91	47.03	8.65
	MS6	44.91	55.48	59.64	8.65
	MS7	43.17	49.23	57.25	8.65
DCORE_AM	HRV	380	1150	2511	682
	MS1	9777	29954	44088	682
	MS2	6069	9009	15566	682
	MS3a	9004	12221	14675	682
	MS3b	2522	4991	7795	682
	MS4	5637	11705	15862	682
	MS5	1661	3444	4797	682
	MS6	791	1313	1710	682
	MS7	657	1138	1756	682
CAI_AM	HRV	33.53	39.69	44.44	62.03
	MS1	63.57	71.68	74.17	62.03
	MS2	60.00	64.81	67.61	62.03
	MS3a	60.59	62.27	63.73	62.03
	MS3b	47.79	52.01	53.30	62.03
	MS4	59.70	64.80	67.54	62.03
	MS5	50.03	52.04	53.71	62.03
	MS6	40.99	42.76	43.85	62.03
	MS7	41.81	43.38	44.42	62.03
TECI	HRV	44.80	46.50	48.79	44.43
	MS1	49.92	53.78	56.76	44.43

(Table D7 continued on next page.)

(Table D7 continued)

Landscape metric	Scenario	Percentile of range of variability 5th	50th	95th	Current
	MS2	48.44	49.81	50.87	44.43
	MS3a	46.01	47.18	47.96	44.43
	MS3b	42.74	43.06	43.97	44.43
	MS4	47.08	49.28	51.15	44.43
	MS5	45.24	45.79	46.72	44.43
	MS6	44.29	44.49	44.80	44.43
	MS7	44.02	44.49	44.97	44.43
IJI	HRV	60.00	65.61	69.64	84.95
	MS1	53.44	60.87	73.94	84.95
	MS2	70.32	74.70	79.37	84.95
	MS3a	62.25	66.23	69.39	84.95
	MS3b	53.34	54.71	60.99	84.95
	MS4	67.64	72.34	79.28	84.95
	MS5	65.11	66.57	69.71	84.95
	MS6	66.16	66.74	67.77	84.95
	MS7	63.42	65.05	67.46	84.95
AREA_MN	HRV	2.77	3.30	3.83	21.00
	MS1	11.97	21.35	27.65	21.00
	MS2	9.87	13.37	15.63	21.00
	MS3a	6.07	6.44	6.80	21.00
	MS3b	2.71	2.91	2.98	21.00
	MS4	9.21	12.57	15.27	21.00
	MS5	3.55	3.70	3.81	21.00
	MS6	2.51	2.57	2.63	21.00
	MS7	2.57	2.62	2.67	21.00
SHAPE_MN	HRV	1.32	1.33	1.33	1.63
	MS1	1.36	1.40	1.42	1.63
	MS2	1.37	1.38	1.39	1.63
	MS3a	1.18	1.19	1.21	1.63
	MS3b	1.13	1.14	1.16	1.63

(Table D7 continued on next page.)

(Table D7 continued)

Landscape metric	Scenario	Percentile of range of variability 5th	50th	95th	Current
	MS4	1.36	1.36	1.37	1.63
	MS5	1.23	1.23	1.24	1.63
	MS6	1.26	1.27	1.27	1.63
	MS7	1.23	1.24	1.25	1.63
DCORE_MN	HRV	3.41	4.68	5.73	12.30
	MS1	18.15	28.90	40.31	12.30
	MS2	12.12	16.12	19.03	12.30
	MS3a	13.11	15.26	17.61	12.30
	MS3b	7.30	9.56	10.87	12.30
	MS4	11.74	15.67	19.47	12.30
	MS5	7.43	8.07	8.96	12.30
	MS6	4.68	5.05	5.46	12.30
	MS7	4.66	5.20	5.56	12.30
CAI_MN	HRV	0.83	0.98	1.11	17.92
	MS1	4.44	6.87	8.52	17.92
	MS2	5.68	7.31	8.39	17.92
	MS3a	3.13	3.27	3.47	17.92
	MS3b	1.31	1.42	1.50	17.92
	MS4	5.15	6.96	8.20	17.92
	MS5	1.76	1.82	1.93	17.92
	MS6	1.15	1.19	1.23	17.92
	MS7	1.21	1.24	1.30	17.92
ED	HRV	135.17	148.59	168.54	70.95
	MS1	38.13	47.10	65.41	70.95
	MS2	55.44	63.08	76.35	70.95
	MS3a	67.16	72.08	78.31	70.95
	MS3b	101.75	106.32	118.00	70.95
	MS4	55.78	64.57	76.72	70.95
	MS5	103.17	108.54	112.24	70.95
	MS6	148.39	151.63	156.02	70.95

(Table D7 continued on next page.)

(Table D7 continued)

Landscape metric	Scenario	Percentile of range of variability			Current
		5th	50th	95th	
	MS7	139.31	142.16	147.19	70.95
CWED	HRV	62.16	70.04	81.29	32.25
	MS1	22.67	25.21	34.98	32.25
	MS2	28.86	31.95	38.58	32.25
	MS3a	32.54	34.30	36.70	32.25
	MS3b	44.53	46.40	52.70	32.25
	MS4	28.67	31.86	40.08	32.25
	MS5	48.06	50.19	52.98	32.25
	MS6	66.68	68.03	70.73	32.25
	MS7	62.22	63.94	66.77	32.25
AI	HRV	74.69	77.68	79.70	89.35
	MS1	90.17	92.91	94.26	89.35
	MS2	88.53	90.52	91.67	89.35
	MS3a	88.24	89.17	89.91	89.35
	MS3b	82.28	84.03	84.72	89.35
	MS4	88.48	90.30	91.62	89.35
	MS5	83.14	83.70	84.50	89.35
	MS6	76.57	77.23	77.71	89.35
	MS7	77.90	78.65	79.08	89.35
CONTAG	HRV	36.91	41.30	45.24	41.51
	MS1	56.19	66.25	70.10	41.51
	MS2	49.47	54.30	57.67	41.51
	MS3a	53.09	54.22	56.23	41.51
	MS3b	45.55	48.92	50.62	41.51
	MS4	49.96	54.67	57.77	41.51
	MS5	44.88	46.66	48.68	41.51
	MS6	37.76	39.07	40.14	41.51
	MS7	38.94	40.95	42.29	41.51

Table D8—Range of variability (ROV) in landscape metrics (see *Landscape Configuration under Methods* for description of each landscape metric) computed on the basis of the landscape classified into vegetation canopy cover classes (none, open, moderate, closed) for the simulated historical range of variability (HRV) (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed. Select percentiles of the simulated ROV are given, as well as the current landscape condition.

		Percentile of range of variability			
Landscape metric	Scenario	5th	50th	95th	Current
LPI	HRV	4.06	8.57	16.39	5.97
	MS1	16.99	45.89	56.97	5.97
	MS2	10.72	18.98	30.71	5.97
	MS3a	11.31	16.22	27.62	5.97
	MS3b	5.76	7.74	16.44	5.97
	MS4	5.24	9.06	14.73	5.97
	MS5	3.20	5.69	7.63	5.97
	MS6	4.31	5.68	6.31	5.97
	MS7	3.47	5.42	6.43	5.97
AREA_AM	HRV	1,459	2,957	7,559	1,720
	MS1	9,169	49,577	75,291	1,720
	MS2	5,305	12,435	25,888	1,720
	MS3a	7,057	9,488	17,776	1,720
	MS3b	2,131	3,587	7,167	1,720
	MS4	1,737	3,972	6,245	1,720
	MS5	948	1,615	2,122	1,720
	MS6	1,190	1,591	1,981	1,720
	MS7	1,043	1,506	1,799	1,720
GYRATE_AM	HRV	2,041	2,655	4,036	2,302
	MS1	4,764	11,199	12,863	2,302
	MS2	3,239	5,351	7,571	2,302
	MS3a	4,170	5,420	7,058	2,302
	MS3b	2,461	3,091	4,501	2,302
	MS4	2,123	3,085	3,895	2,302
	MS5	1,762	1,997	2,331	2,302
	MS6	1,868	2,026	2,251	2,302
	MS7	1,751	1,996	2,154	2,302

(Table D8 continued on next page.)

(Table D8 continued)

Landscape metric	Scenario	Percentile of range of variability 5th	50th	95th	Current
SHAPE_AM	HRV	21.95	29.27	48.37	9.05
	MS1	31.76	38.93	51.61	9.05
	MS2	18.07	22.90	30.13	9.05
	MS3a	29.97	33.11	44.38	9.05
	MS3b	22.06	27.31	35.32	9.05
	MS4	12.94	14.62	20.12	9.05
	MS5	12.27	13.72	16.84	9.05
	MS6	12.18	13.50	15.62	9.05
	MS7	12.94	14.46	17.55	9.05
DCORE_AM	HRV	136	266	625	449
	MS1	2,554	22,745	41,568	449
	MS2	1,530	4,864	10,666	449
	MS3a	350	516	856	449
	MS3b	114	214	266	449
	MS4	252	563	1,590	449
	MS5	196	456	691	449
	MS6	176	724	1,099	449
	MS7	127	358	1,284	449
CAI_AM	HRV	16.47	20.22	23.97	60.70
	MS1	32.52	59.58	68.18	60.70
	MS2	36.40	51.03	60.21	60.70
	MS3a	32.22	35.66	39.41	60.70
	MS3b	19.94	25.07	26.83	60.70
	MS4	35.21	45.28	51.82	60.70
	MS5	28.65	33.30	36.80	60.70
	MS6	33.71	36.89	39.46	60.70
	MS7	29.08	33.25	34.66	60.70
TECI	HRV	42.74	43.99	44.99	46.07
	MS1	46.44	50.54	54.44	46.07
	MS2	45.61	47.72	50.39	46.07
	MS3a	45.63	46.55	46.81	46.07

(Table D8 continued on next page.)

(Table D8 continued)

Landscape metric	Scenario	Percentile of range of variability 5th	50th	95th	Current
	MS3b	45.14	46.26	46.65	46.07
	MS4	44.52	45.37	46.72	46.07
	MS5	43.82	44.26	44.92	46.07
	MS6	43.78	44.29	44.53	46.07
	MS7	42.86	43.88	44.44	46.07
IJI	HRV	70.30	72.27	73.02	87.14
	MS1	67.77	73.59	78.08	87.14
	MS2	74.33	78.25	80.87	87.14
	MS3a	73.73	74.29	74.82	87.14
	MS3b	73.05	73.52	73.82	87.14
	MS4	75.57	77.67	80.10	87.14
	MS5	74.08	74.87	75.82	87.14
	MS6	74.63	75.37	75.81	87.14
	MS7	73.42	74.61	75.17	87.14
AREA_MN	HRV	1.18	1.38	1.62	21.53
	MS1	2.37	4.86	8.84	21.53
	MS2	2.28	4.00	6.89	21.53
	MS3a	1.78	1.90	2.09	21.53
	MS3b	1.30	1.44	1.46	21.53
	MS4	2.26	3.87	5.28	21.53
	MS5	1.87	2.10	2.26	21.53
	MS6	2.05	2.28	2.43	21.53
	MS7	1.77	2.04	2.16	21.53
SHAPE_MN	HRV	1.29	1.32	1.34	1.68
	MS1	1.31	1.33	1.36	1.68
	MS2	1.32	1.33	1.36	1.68
	MS3a	1.21	1.23	1.26	1.68
	MS3b	1.24	1.26	1.28	1.68
	MS4	1.33	1.34	1.35	1.68
	MS5	1.29	1.30	1.32	1.68
	MS6	1.28	1.29	1.30	1.68

(Table D8 continued on next page.)

(Table D8 continued)

Landscape metric	Scenario	Percentile of range of variability 5th	50th	95th	Current
	MS7	1.29	1.30	1.32	1.68
DCORE_MN	HRV	1.17	1.55	1.98	10.17
	MS1	3.28	16.69	30.50	10.17
	MS2	3.14	8.10	12.75	10.17
	MS3a	2.94	3.84	4.39	10.17
	MS3b	1.59	2.14	2.47	10.17
	MS4	3.23	4.90	6.79	10.17
	MS5	2.06	2.50	2.97	10.17
	MS6	2.57	3.10	3.47	10.17
	MS7	1.96	2.50	2.77	10.17
CAI_MN	HRV	0.22	0.32	0.43	21.31
	MS1	0.41	1.02	1.70	21.31
	MS2	0.89	1.82	3.21	21.31
	MS3a	0.79	0.90	1.01	21.31
	MS3b	0.44	0.58	0.61	21.31
	MS4	1.30	2.60	3.87	21.31
	MS5	0.93	1.21	1.34	21.31
	MS6	1.08	1.26	1.38	21.31
	MS7	0.82	1.06	1.16	21.31
ED	HRV	237.86	257.78	280.16	74.08
	MS1	60.92	92.80	196.09	74.08
	MS2	79.25	118.16	181.73	74.08
	MS3a	149.08	167.48	183.42	74.08
	MS3b	204.46	214.18	246.47	74.08
	MS4	104.33	133.14	184.01	74.08
	MS5	164.72	181.03	204.93	74.08
	MS6	154.92	166.60	182.47	74.08
	MS7	175.01	181.94	208.14	74.08
CWED	HRV	105.09	113.59	124.83	34.88
	MS1	33.29	47.46	86.80	34.88
	MS2	40.77	57.59	84.29	34.88

(Table D8 continued on next page.)

(Table D8 continued)

Landscape metric	Scenario	Percentile of range of variability 5th	50th	95th	Current
	MS3a	70.26	78.91	84.76	34.88
	MS3b	96.52	99.83	111.62	34.88
	MS4	49.66	60.42	84.01	34.88
	MS5	73.95	80.64	91.11	34.88
	MS6	69.45	74.39	81.44	34.88
	MS7	78.18	80.75	93.85	34.88
AI	HRV	57.93	61.29	64.28	88.88
	MS1	70.55	86.05	90.83	88.88
	MS2	72.71	82.26	88.10	88.88
	MS3a	72.46	74.85	77.61	88.88
	MS3b	62.99	67.84	69.30	88.88
	MS4	72.37	80.01	84.34	88.88
	MS5	69.23	72.82	75.27	88.88
	MS6	72.60	74.99	76.74	88.88
	MS7	68.75	72.68	73.72	88.88
CONTAG	HRV	20.26	21.75	23.92	39.11
	MS1	33.66	56.09	66.38	39.11
	MS2	28.67	40.32	49.48	39.11
	MS3a	30.87	33.63	37.54	39.11
	MS3b	22.07	26.91	28.42	39.11
	MS4	26.55	33.86	38.66	39.11
	MS5	25.09	27.80	30.17	39.11
	MS6	27.30	29.17	30.72	39.11
	MS7	24.67	27.30	28.26	39.11

Table D9—Range of variability (ROV) in landscape metrics computed on the basis of the landscape classified into vegetation seral stages[a] for the simulated historical range of variability (HRV) (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2–MS7) in the upper Yuba River watershed. Select percentiles of the simulated ROV are given, as well as the current landscape condition.

		Percentile of Range of Variability			
Landscape metric	**Scenario**	**5th**	**50th**	**95th**	**Current**
LPI	HRV	2.50	2.58	5.06	2.50
	MS1	9.59	35.93	45.28	2.50
	MS2	8.57	12.48	18.53	2.50
	MS3a	7.69	11.37	16.46	2.50
	MS3b	3.87	5.69	8.74	2.50
	MS4	3.54	6.08	8.54	2.50
	MS5	2.64	5.11	6.37	2.50
	MS6	3.60	4.88	5.61	2.50
	MS7	2.50	4.91	5.64	2.50
AREA_AM	HRV	290	500	916	303
	MS1	4,029	33,653	45,698	303
	MS2	2,666	5,583	11,704	303
	MS3a	3,079	5,877	10,409	303
	MS3b	971	1,588	3,450	303
	MS4	665	1,458	2,453	303
	MS5	535	996	1,190	303
	MS6	492	829	978	303
	MS7	290	773	896	303
GYRATE_AM	HRV	942	1,138	1,447	1,055
	MS1	3,642	9,308	10,626	1,055
	MS2	2,174	3,693	5,320	1,055
	MS3a	2,767	3,755	4,948	1,055
	MS3b	1,608	1,978	3,131	1,055
	MS4	1,268	1,788	2,275	1,055
	MS5	1,203	1,435	1,602	1,055
	MS6	1,045	1,257	1,431	1,055
	MS7	939	1,245	1,344	1,055
SHAPE_AM	HRV	8.92	10.81	13.66	4.52

(Table D9 continued on next page.)

(Table D9 continued)

Landscape metric	Scenario	Percentile of Range of Variability 5th	50th	95th	Current
	MS1	26.22	32.20	41.16	4.52
	MS2	11.36	15.55	19.42	4.52
	MS3a	19.17	25.20	32.75	4.52
	MS3b	13.55	17.34	25.45	4.52
	MS4	7.19	9.35	11.05	4.52
	MS5	8.14	9.01	9.79	4.52
	MS6	6.81	7.31	8.10	4.52
	MS7	7.14	7.74	9.08	4.52
DCORE_AM	HRV	90	121	192	93
	MS1	1,810	8,345	15,901	93
	MS2	556	1,586	4,258	93
	MS3a	183	231	324	93
	MS3b	81	94	138	93
	MS4	120	265	938	93
	MS5	121	283	436	93
	MS6	114	489	860	93
	MS7	98	238	1,153	93
CAI_AM	HRV	4.29	7.04	10.36	33.16
	MS1	21.69	46.80	55.31	33.16
	MS2	22.53	35.17	43.93	33.16
	MS3a	19.54	22.30	25.73	33.16
	MS3b	8.79	12.91	14.59	33.16
	MS4	21.37	30.50	36.90	33.16
	MS5	13.59	17.52	20.74	33.16
	MS6	14.70	17.63	19.68	33.16
	MS7	11.27	15.17	16.57	33.16
TECI	HRV	26.37	27.72	29.70	37.84
	MS1	24.59	28.50	33.30	37.84
	MS2	26.13	29.76	34.10	37.84
	MS3a	25.21	26.27	26.81	37.84
	MS3b	24.84	25.03	25.37	37.84

(Table D9 continued on next page.)

(Table D9 continued)

Landscape metric	Scenario	Percentile of Range of Variability 5th	50th	95th	Current
	MS4	26.28	27.22	29.21	37.84
	MS5	27.12	27.98	28.25	37.84
	MS6	30.79	31.65	32.03	37.84
	MS7	28.60	29.58	30.03	37.84
IJI	HRV	64.81	66.96	69.26	75.31
	MS1	53.91	57.60	60.31	75.31
	MS2	61.80	66.72	70.46	75.31
	MS3a	62.67	65.40	68.55	75.31
	MS3b	64.02	67.09	69.90	75.31
	MS4	64.07	67.89	69.21	75.31
	MS5	67.70	70.45	71.60	75.31
	MS6	71.60	72.26	75.50	75.31
	MS7	70.37	73.62	74.50	75.31
AREA_MN	HRV	0.63	0.73	0.84	10.83
	MS1	1.71	3.64	6.33	10.83
	MS2	1.57	2.78	4.50	10.83
	MS3a	1.27	1.37	1.52	10.83
	MS3b	0.76	0.85	0.88	10.83
	MS4	1.52	2.55	3.59	10.83
	MS5	1.03	1.15	1.23	10.83
	MS6	0.89	0.95	0.99	10.83
	MS7	0.84	0.94	0.98	10.83
SHAPE_MN	HRV	1.25	1.27	1.28	1.63
	MS1	1.31	1.32	1.35	1.63
	MS2	1.31	1.32	1.35	1.63
	MS3a	1.18	1.20	1.24	1.63
	MS3b	1.18	1.19	1.23	1.63
	MS4	1.32	1.33	1.34	1.63
	MS5	1.24	1.25	1.27	1.63
	MS6	1.24	1.25	1.25	1.63
	MS7	1.24	1.24	1.26	1.63

(Table D9 continued)

Landscape metric	Scenario	Percentile of Range of Variability 5th	50th	95th	Current
DCORE_MN	HRV	0.78	1.19	1.57	4.59
	MS1	3.37	12.30	20.94	4.59
	MS2	2.74	6.19	9.45	4.59
	MS3a	2.42	3.08	3.54	4.59
	MS3b	1.22	1.63	1.98	4.59
	MS4	2.53	3.58	4.87	4.59
	MS5	1.63	2.11	2.59	4.59
	MS6	2.23	2.80	3.16	4.59
	MS7	1.55	2.03	2.33	4.59
CAI_MN	HRV	0.05	0.09	0.13	9.95
	MS1	0.36	1.00	1.82	9.95
	MS2	0.53	1.23	2.18	9.95
	MS3a	0.43	0.50	0.60	9.95
	MS3b	0.18	0.26	0.27	9.95
	MS4	0.84	1.72	2.65	9.95
	MS5	0.36	0.47	0.53	9.95
	MS6	0.30	0.35	0.39	9.95
	MS7	0.25	0.31	0.36	9.95
ED	HRV	293.88	318.64	344.07	96.30
	MS1	76.10	110.69	217.97	96.30
	MS2	96.90	137.83	205.06	96.30
	MS3a	165.33	184.95	203.28	96.30
	MS3b	237.67	249.21	288.09	96.30
	MS4	120.59	153.16	207.52	96.30
	MS5	204.66	223.42	248.00	96.30
	MS6	224.24	236.49	254.16	96.30
	MS7	235.63	243.95	269.90	96.30
CWED	HRV	79.61	88.68	100.90	37.06
	MS1	25.85	32.00	51.49	37.06
	MS2	33.60	40.70	55.65	37.06
	MS3a	44.72	48.69	52.46	37.06

(Table D9 continued on next page.)

(Table D9 continued)

Landscape metric	Scenario	Percentile of Range of Variability 5th	50th	95th	Current
	MS3b	60.39	62.93	72.12	37.06
	MS4	35.63	42.06	55.55	37.06
	MS5	58.20	61.93	68.37	37.06
	MS6	72.42	75.26	80.28	37.06
	MS7	70.54	73.03	79.77	37.06
AI	HRV	48.36	52.18	55.90	85.60
	MS1	67.30	83.39	88.58	85.60
	MS2	69.25	79.34	85.48	85.60
	MS3a	69.51	72.26	75.20	85.60
	MS3b	56.77	62.61	64.34	85.60
	MS4	68.88	77.04	81.93	85.60
	MS5	62.80	66.49	69.30	85.60
	MS6	61.87	64.52	66.36	85.60
	MS7	59.51	63.40	64.65	85.60
CONTAG	HRV	30.91	32.88	35.43	46.63
	MS1	47.72	63.65	71.28	46.63
	MS2	43.04	51.78	57.26	46.63
	MS3a	43.39	45.79	50.12	46.63
	MS3b	33.53	37.41	41.64	46.63
	MS4	40.23	46.39	49.67	46.63
	MS5	35.39	38.48	40.45	46.63
	MS6	33.33	36.44	38.04	46.63
	MS7	31.13	34.73	36.24	46.63

[a] ED = Early - all structures; MDO = Mid-open; MDM = Mid-moderate; MDC = Mid-closed; LDO = Late-open; LDM = Late-moderate; LDC = Late-closed; ED-A = Early – Aspen; MD-A = Mid – Aspen; MD-AC = Mid - Aspen and Conifer; LD-CA = Late - Conifer and Aspen.

Table D10—Range of variability (ROV) in landscape metrics (see Landscape Configuration under Methods for description and units for each landscape metric) computed on the basis of the landscape classified into combinations of cover type and seral stage classes (see Appendix B for the classification) for the simulated historical range of variability (HRV) (ca. 1550–1850) and management scenarios with a modified fire regime (MS1) and varying intensities and types of vegetation treatments (MS2-MS7) in the upper Yuba River watershed. Select percentiles of the simulated ROV are given, as well as the current landscape condition.

		Percentile of range of variability			
Landscape metric	Scenario	5th	50th	95th	Current
LPI	HRV	2.08	2.08	2.08	2.08
	MS1	2.08	4.32	4.60	2.08
	MS2	2.08	2.08	3.08	2.08
	MS3a	2.08	2.32	2.91	2.08
	MS3b	2.08	2.08	2.80	2.08
	MS4	2.08	2.08	2.08	2.08
	MS5	2.08	2.08	2.08	2.08
	MS6	2.08	2.08	2.08	2.08
	MS7	2.08	2.08	2.08	2.08
AREA_AM	HRV	126	151	196	119
	MS1	322	908	1,167	119
	MS2	185	292	411	119
	MS3a	260	312	416	119
	MS3b	157	237	312	119
	MS4	133	161	177	119
	MS5	133	151	183	119
	MS6	122	133	149	119
	MS7	118	132	145	119
GYRATE_AM	HRV	588	636	694	616
	MS1	914	1,344	1,550	616
	MS2	706	881	981	616
	MS3a	802	852	943	616
	MS3b	657	767	830	616
	MS4	622	695	727	616
	MS5	618	652	683	616
	MS6	584	614	638	616
	MS7	572	612	630	616
SHAPE_AM	HRV	5.17	5.63	6.19	3.27
	MS1	6.78	7.31	7.77	3.27

(Table D10 continued on next page.)

(Table D10 continued)

Landscape metric	Scenario	Percentile of range of variability 5th	50th	95th	Current
	MS2	4.51	4.84	5.19	3.27
	MS3a	5.34	5.51	5.79	3.27
	MS3b	5.35	6.02	6.47	3.27
	MS4	3.93	4.10	4.26	3.27
	MS5	4.27	4.35	4.48	3.27
	MS6	3.93	3.98	4.15	3.27
	MS7	4.12	4.20	4.33	3.27
DCORE_AM	HRV	96.68	121.21	152.13	45.27
	MS1	213.30	366.76	457.35	45.27
	MS2	91.71	138.96	180.21	45.27
	MS3a	71.06	84.49	169.31	45.27
	MS3b	72.57	81.90	108.16	45.27
	MS4	58.02	64.28	91.28	45.27
	MS5	67.15	76.61	89.81	45.27
	MS6	67.58	78.89	91.39	45.27
	MS7	69.11	83.26	104.01	45.27
CAI_AM	HRV	5.22	7.42	10.28	38.78
	MS1	20.98	47.75	58.61	38.78
	MS2	24.21	37.09	46.37	38.78
	MS3a	17.13	19.95	23.02	38.78
	MS3b	8.52	12.00	13.45	38.78
	MS4	21.08	29.54	36.16	38.78
	MS5	13.96	17.19	20.49	38.78
	MS6	15.92	18.79	21.07	38.78
	MS7	12.60	15.90	17.73	38.78
TECI	HRV	21.72	22.22	22.98	26.14
	MS1	21.96	23.47	24.70	26.14
	MS2	22.52	24.30	25.61	26.14
	MS3a	22.32	22.81	23.14	26.14
	MS3b	21.42	21.72	21.84	26.14
	MS4	22.72	23.53	24.51	26.14
	MS5	22.33	22.65	22.87	26.14

(Table D10 continued on next page.)

(Table D10 continued)

Landscape metric	Scenario	Percentile of range of variability			Current
		5th	50th	95th	
	MS6	23.08	23.37	23.55	26.14
	MS7	22.27	22.77	22.91	26.14
IJI	HRV	54.90	55.81	56.78	63.80
	MS1	49.61	51.89	54.23	63.80
	MS2	55.96	58.41	59.06	63.80
	MS3a	55.67	56.22	56.42	63.80
	MS3b	56.03	56.26	56.76	63.80
	MS4	58.03	59.50	60.46	63.80
	MS5	58.44	59.77	60.24	63.80
	MS6	61.02	61.46	61.86	63.80
	MS7	59.33	60.64	61.06	63.80
AREA_MN	HRV	0.51	0.58	0.67	3.60
	MS1	1.23	2.34	3.56	3.60
	MS2	1.14	1.85	2.78	3.60
	MS3a	1.00	1.08	1.21	3.60
	MS3b	0.61	0.69	0.72	3.60
	MS4	1.10	1.73	2.28	3.60
	MS5	0.81	0.90	0.96	3.60
	MS6	0.70	0.76	0.79	3.60
	MS7	0.66	0.74	0.78	3.60
SHAPE_MN	HRV	1.23	1.24	1.26	1.42
	MS1	1.30	1.34	1.36	1.42
	MS2	1.30	1.32	1.35	1.42
	MS3a	1.22	1.23	1.25	1.42
	MS3b	1.19	1.20	1.21	1.42
	MS4	1.29	1.31	1.32	1.42
	MS5	1.24	1.24	1.25	1.42
	MS6	1.23	1.23	1.24	1.42
	MS7	1.23	1.23	1.24	1.42
DCORE_MN	HRV	0.89	1.17	1.46	2.26
	MS1	3.55	5.32	6.30	2.26
	MS2	2.60	3.36	3.95	2.26

(Table D10 continued on next page.)

(Table D10 continued)

Landscape metric	Scenario	Percentile of range of variability			Current
		5th	50th	95th	
	MS3a	1.61	1.77	1.94	2.26
	MS3b	1.08	1.35	1.49	2.26
	MS4	1.76	2.29	2.70	2.26
	MS5	1.34	1.49	1.74	2.26
	MS6	1.48	1.68	1.82	2.26
	MS7	1.25	1.45	1.60	2.26
CAI_MN	HRV	0.16	0.28	0.48	18.78
	MS1	2.35	9.04	16.50	18.78
	MS2	2.46	6.53	11.66	18.78
	MS3a	1.46	1.90	2.36	18.78
	MS3b	0.53	0.87	0.97	18.78
	MS4	2.27	4.95	8.16	18.78
	MS5	1.16	1.56	1.99	18.78
	MS6	1.19	1.52	1.78	18.78
	MS7	0.94	1.27	1.42	18.78
ED	HRV	312.13	335.58	360.03	139.71
	MS1	124.93	153.54	245.37	139.71
	MS2	139.31	174.03	233.70	139.71
	MS3a	198.11	215.58	231.39	139.71
	MS3b	263.59	273.58	309.62	139.71
	MS4	155.52	183.39	232.52	139.71
	MS5	233.05	248.85	271.45	139.71
	MS6	253.69	264.21	280.09	139.71
	MS7	261.73	269.77	293.58	139.71
CWED	HRV	69.20	75.04	81.42	36.96
	MS1	31.20	36.41	52.12	36.96
	MS2	36.18	42.27	53.78	36.96
	MS3a	46.21	49.47	52.28	36.96
	MS3b	58.03	59.80	66.18	36.96
	MS4	38.54	43.52	53.22	36.96
	MS5	53.51	56.48	61.19	36.96
	MS6	59.93	62.12	65.66	36.96

(Table D10 continued on next page.)

(Table D10 continued)

Landscape metric	Scenario	Percentile of range of variability 5th	50th	95th	Current
	MS7	60.32	61.93	67.28	36.96
AI	HRV	46.11	49.79	53.32	79.33
	MS1	63.36	77.14	81.43	79.33
	MS2	65.15	74.12	79.34	79.33
	MS3a	65.48	67.85	70.48	79.33
	MS3b	53.71	59.12	60.62	79.33
	MS4	65.34	72.73	76.92	79.33
	MS5	59.47	62.86	65.24	79.33
	MS6	58.17	60.56	62.14	79.33
	MS7	56.14	59.72	60.93	79.33
CONTAG	HRV	44.65	45.54	46.92	50.89
	MS1	52.65	60.19	63.54	50.89
	MS2	49.33	53.56	56.60	50.89
	MS3a	51.27	52.41	53.90	50.89
	MS3b	46.29	48.94	49.81	50.89
	MS4	47.83	51.04	52.95	50.89
	MS5	46.64	47.49	48.41	50.89
	MS6	44.50	45.71	46.18	50.89
	MS7	44.53	45.51	46.06	50.89

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