Complex Early Seral Forests of the Sierra Nevada: What are They and How Can They Be Managed for Ecological Integrity?

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RESEARCH NOTE

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Complex Early Seral Forests of the Sierra Nevada: What are They and How Can They Be Managed for Ecological Integrity?

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ABSTRACT: Complex early seral forests (CESFs) occupy potentially forested sites after a stand-replacement disturbance and before re-establishment of a closed-forest canopy. Such young forests contain numbers and kinds of biological legacies missing from those produced by commercial forestry operations. In the Sierra Nevada of California, CESFs are most often produced by mixed-severity fires, which include landscape patches burned at high severity. These forests support diverse plant and wildlife communities rarely found elsewhere in the Sierra Nevada. Severe fires are, therefore, essential to the region's ecological integrity. Ecologically detrimental management of CESFs, or unburned forests that may become CESF's following fire, is degrading the region's globally outstanding qualities. Unlike old-growth forests, CESFs have received little attention in conservation and reserve management. Thus, we describe important ecological attributes of CESFs and distinguish them from early seral conditions created by logging. We recommend eight best management practices in CESFs for achieving ecological integrity on federal lands in the mixed-conifer region of the Sierra Nevada.

Index terms: complex early seral forests, ecological integrity, mixed-severity fire, Sierra Nevada

INTRODUCTION

Early seral forests are ecosystems that occupy potentially forested sites after a stand-replacement disturbance and before re-establishment of a closed forest canopy (Swanson et al. 2011). Such forests are generated by disturbances that reset successional processes and follow a pathway that is influenced by biological legacies (e.g., large live and dead trees, downed logs, seed banks, resprout tissue, fungi, and other live and dead biomass) that were not removed during the initial disturbance (Franklin et al. 2000; Donato et al. 2012). Where these legacies are intact, complex early successional forests (CESFs) develop with rich biodiversity due to the function of the remaining biomass in providing resources to many life forms and because of habitat heterogeneity provided by mixed-severity fires that generated them (Odion and Sarr 2007; Swanson et al. 2011). In general, mixed-severity fires, which include patches of high-severity fire, create coarse-grained, high-contrast heterogeneity that results in CESFs, and, over time, a complex mosaic of seral stages at the landscape and local scales. Low to moderate fire severities create fine-grained, lower contrast heterogeneity that generate very little if any CESFs, although they create other conditions favorable to biodiversity. Many effects of fire cannot be mimicked by land-use disturbances (Odion and Sarr 2007). Suppression of fire and removal of biomass after a fire are thus causes of reduced biodiversity and ecological integrity.

While the unique "floral phoenix" that follows stand-replacing fire in many vegetation types such as the California chaparral has long inspired botanists in the United States (Brandegee 1891; Howell 1946) and elsewhere (Bond and van Wilgen 1996), similar attention has not been given to stand-replacing fire in Sierran forests. Instead, fire has been suppressed in these forests for many decades. Traditionally, stand-replacement processes have also been considered historically unimportant in these forests, simply because they occur less frequently than surface fires, which are largely non-lethal (Skinner and Chang 1996). Stand-replacing fire also has a negative connotation in resource management disciplines because of their narrow focus on impacts to timber values, and such fires frequently receive negative coverage from the mass media.

While much of the conservation attention in the Sierra Nevada has rightfully focused on iconic conifers like the giant sequoia (*Sequoiadendron giganteum*) and other old-growth forest types, even in the context of multiple-use management and conservation, there is still little appreciation for CESFs, which do not have the charismatic old-growth species and living structures (Swanson et al. 2011). Thus, for a variety of reasons, there is a paucity of literature on, or appreciation of, CESFs. Indeed, CESFs are not even recognized as a distinct habitat type in any current vegetation mapping used by the U.S. Forest Service in the Sierra Nevada (e.g., California Wildlife Habitat Relations). However, in terms of their contribution to biodiversity and

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vital life-history stages of many species, CESFs have disproportionately important ecological roles in the overall ecological integrity of forested landscapes. Thus, we call attention to this successional stage (Swanson et al. 2011) and the need for its inclusion in conservation strategies in the Sierra Nevada ecoregion.

It is timely to consider CESFs in Sierra conservation strategies because the Sequoia, Sierra, and Inyo National Forests (Figure 1) are undergoing forest plan revisions as part of the "early adopters" of the forest-planning rule (36 Code of Federal Regulations Part 219). The forest-planning rule directs the U.S. Forest Service to maintain or improve ecological integrity, defined as "the quality or condition of an ecosystem when its dominant ecological characteristics (for example, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence" (Forest Planning Rule 36 CFR 219.19). Given the global importance of the Sierra Nevada ecoregion (Ricketts et al. 1999), many scientists and the public expect a high level of protection and stewardship in forest-planning decisions and they support managing for ecological integrity. But, as an often-overlooked seral stage, the role of CESFs in ecological integrity and conserving biodiversity has not been addressed.

We address three questions of management relevance to CESFs in the Sierra Nevada: (1) what are CESFs and why are they important to ecological integrity; (2) are there tradeoffs for managing species of conservation concern that occur at opposite ends of the successional continuum such as Black-backed Woodpeckers (*Picoides villosus*; avian taxonomy follows American Ornithologists' Union checklist of North and Middle American birds; http://checklist.aou.org/; active May 20, 2013) and California Spotted Owls (*Strix occidentalis occidentalis*); and (3) what are the principal threats to these forests? We also provide general recommendations for conserving, restoring, and researching the ecological integrity and biodiversity of Sierran CESFs.

STUDY AREA

The Sierra Nevada ecoregion spans some 63,111 km^2 along a north-south axis in California, and the USDA Forest Service manages the majority of montane forests in this region (Davis and Stoms 1996; Figure 1). The ecoregion is among the most diverse temperate conifer forests in the world and its conservation status is considered critically endangered due to extensive forest fragmentation and other land-use stressors (Ricketts et al. 1999). An extraordinary assortment of vegetation types and diverse forest successional stages occur across the region. For instance, based on potential vegetation mapping, 25 conifer, 23 hardwood forest/woodland types, 34 shrub and chaparral, and 5 herbaceous alliances are distributed across elevations, slopes, aspects, and soil types (USDA Forest Service 2008). Plant alliances mix together at zones of overlap resulting in high levels of beta diversity (change in numbers of species across environmental gradients). There are exceptional levels of endemic plants (e.g., approximately 405 vascular plants are endemic and 218 taxa are rare; Shevock 1996), especially in the southern Sierra, and some of the highest levels of mammal endemism in North America (Ricketts et al. 1999). Notably, areas with high concentrations of endemic species are a conservation priority because the restricted distribution of endemics predisposes them to extinction from habitat losses.

Mixed-conifer forests are the predominant forests in the Sierra that are typically found at middle elevations (760–1400 m) in the northern Sierra, higher elevations south (915–3050 m), and, to a lesser extent, on upper elevations (2130 m to 3040 m) along the east slopes (Chang 1996). They are replaced at higher elevations by pure red fir (*Abies magnifica,* Andr. Murray) and red and white fir (*A. concolor,* Gordon & Glend.) (Barbour et al. 2007). There are three forest types that comprise mixed-conifer forests in this region: (1) white fir/ Jeffrey pine (*Pinus jeffreyi,* Grev. & Balf.) /lodgepole pine (*P. contorta,* Loudon); (2) Pacific Douglas-fir (*Pseudotsuga menziesii menziesii,* Franco), and ponderosa pine (*P. ponderosa*; at lower elevations); and (3) mid-elevation Douglas-fir (does not occur south of Yosemite National Park). These more typical conifers are associated with sugar pine (*P. lambertiana,* Douglas), incense cedar (*Calocedrus decurrens,* Torrey), black oak (*Quercus kelloggii,* Newb.), and patches of giant sequoia. Mixed-conifer forest types also support shrubs such as greenleaf manzanita (*Arctostaphylos patula,* E. Greene), huckleberry oak (*Q. vaccinifolia*, Kellogg), curleaf mountain mahogany (*Cercocarpus ledifolius,* Nutt.), snowbrush (*Ceanothus velutinus,* Dougl.), mountain alder (*Alnus incana* ssp. *tenuifolia,* Nutt.), mountain sagebrush (*Artemisia tridentate* ssp. *vaseyana,* Rydb.), and bitterbrush (*Purshia tridentata,* Pursh) (USDA Forest Service 2013a). Most of these forests consist of mid-sized trees that average 30–60 cm dbh and include areas with larger trees (>60 cm dbh; North 2013); nearly half of the mixed-conifer forest in the giant sequoia type is late seral (USDA Forest Service 2013a).

Very-long-interval, stand-replacement fire occurs in a patchwise fashion within low- and mixed-severity fires in moist mixed-conifer and white fir forests in this region, and variable (both short- and long-interval) stand-replacement fires occur in Douglas-fir and lodgepole pine (*Pinus contorta,* Loudon) forests (Leiberg 1902; Chang 1996). Prior to fire suppression, drier low-elevation forests burned relatively frequently and often at a low severity; but they also had significant mixed-severity effects, including occasional large high-severity fire patches (USDA Forest Service 1911).

What are Early Seral Forests and Why Are They Important?

In general, CESFs are rich in post-disturbance legacies (Photo Plates 1a, 1b, 1c) and post-fire vegetation (e.g., native fire-following shrubs/herbs, resprouting broad-leaved trees, and natural conifer regeneration) (Photo Plates 2a, 2b, 2c). We identify 12 ecological attributes that contribute to the prolific biological response common in CESFs and which are, therefore, key to the ecological integrity present in CESFs

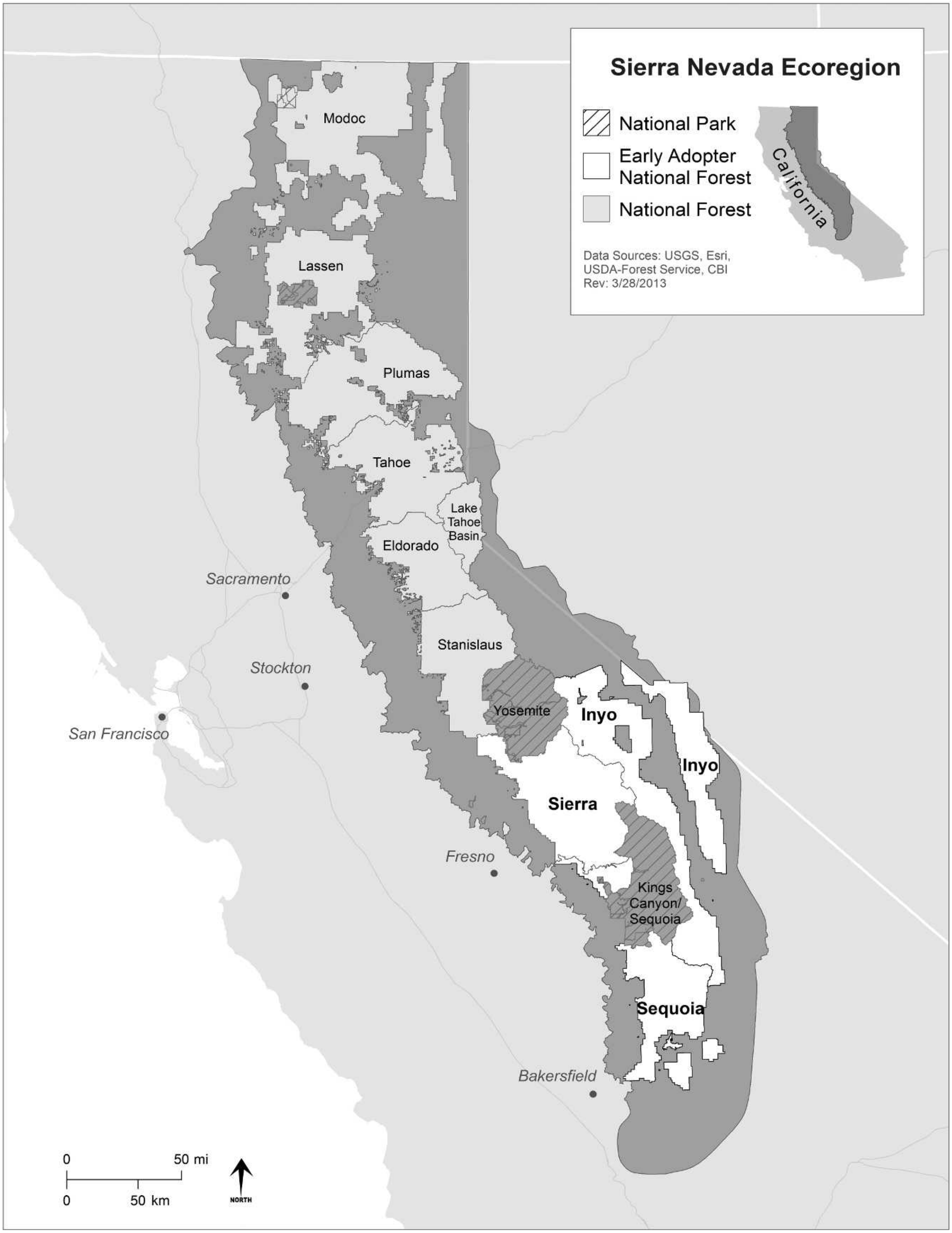

Figure 1. Location of Sierra Nevada ecoregion, northern California, and "early adopters" of the forest-planning rule involved in forest plan revisions.

Photo Plates. Extensive biological legacies, abundant forb cover, and abundant conifer regeneration present in complex early seral forests vs. early seral that has been post-fire logged. Post-fire logging in the Sierra Nevada and elsewhere sets back ecosystem processes creating a successional debt.

Photo Plate 1. Star Fire of 2001, Northern Sierra, CA. (a) unmanaged with forbs (Doug Bevington, 2008); (b) natural conifer re-establishment (Chad Hanson, 2012); Storrie fire of 2000, Southern Cascades, CA. (c) unmanaged with snags and forbs (Chad Hanson, 2007).

Photo Plate 2. Postfire logged portions of Fred's fire in the Eldorado National Forest, CA, showing lack of nitrogen-fixing shrubs (a) and presence of Klamath weed (*Hypericum perfoliatum*) and many readily ignitable, invasive grasses (b) (Dennis Odion, August 2011); (c) simplified system from Dinkey post-fire thin on west slopes of Southern Sierra (Chad Hanson, 2012).

(Table 1). When logging compounds the natural disturbance that created a CESF (Photo Plates 3a, 3b, 3c), each of these attributes is reduced or eliminated (Table 1). Such multiple disturbances often lead to alternative successional pathways, or loss of resilience (Paine et al. 1998; Odion and Sarr 2007), as has been documented in the Sierra Nevada following post-fire logging, which leads to dominance by the non-native ecosystem transformer, cheatgrass (*Bromus tectorum,* Linnaeus) (McGinnis et al. 2010).

Overall, compared to logged areas, CESFs are structurally more complex, contain more large trees and snags that originated from the pre-disturbed forest, have more diverse understories, functional ecosystem processes, and more diverse gene pools that, theoretically, should provide greater resilience in the face of climate change than that provided by the simplified early seral forests produced by logging. CESF attributes promote a high level of species richness, particularly bird communities that utilize these forests extensively (Hutto 1995; Kotliar et al. 2002; Fontaine et al. 2009; Appendix). The residual biomass of CESFs reduces disturbance stressors and provides for the rapid proliferation of new life (Odion and Sarr 2007). For example, seed banks and vegetation tissues give rise to dense, often rampant, forb cover, abundant grasses, and shrubs – especially nitrogen fixers (e.g., *Ceanothus* spp.) (Conard 1985; Busse et al. 1996; Busse 2001) and ectomycorrhizal associates (e.g., *Manzanita* spp.) that facilitate conifer growth (Zavitovsky and Newton 1968; Horton et al. 1999). Serotinous (closed cone) conifers like giant sequoia (Stephenson et al. 1991) also do well in these forests. Other plants that can abundantly colonize burns, such as conifers and fireweed (*Epilobium angustifolium,* Linnaeus), arrive by wind or animal dispersed seed. Thus, plant species richness of CESFs can be much higher than in unburned forests (Donato et al. 2009).

Other bird and small mammal communities that utilize CESFs forage extensively on the abundant insects and increased abundance of seeds from the post-fire flora (Lawrence 1966; Fontaine et al. 2009). These species, in turn, support an increase in raptors (Lawrence 1966). Bird species such as the Black-backed Woodpecker, Olive-sided Flycatcher (*Contopus cooperi*), Mountain Bluebird (*Sialia currucoides*), Chipping Sparrow (*Spizella passerina*), and Mountain Quail (*Oreortyx pictus*) (Appendix)

Table 1. Differences between early seral systems produced by natural disturbance processes vs. logging. For natural disturbances, assume that a disturbance originates from within a late-successional forest as legacies are maintained throughout succession. For logged sites, assume site preparation includes conifer plantings but no herbicides, which, if also applied, would magnify noted differences.

Attribute	Regeneration Harvest or Postfire Logged	Natural Disturbance
Large trees	rare	abundant and widely distributed
Large snags/downed logs	rare	abundant and widely distributed
Understory	dense conifer plantings followed by sparse vegetation as conifer crowns close (usually within 15-20 years depending on site productivity)	varied and rich flora
Species composition	few species mostly commercially stocked, deer initially abundant then excluded as conifer crowns close	varied and rich flora, rich invertebrates and birds, abundant deer
Structural complexity	simplified	highly complex; many biological legacies
Soils and below-ground processes	compacted and reduced mycorrhizae	complex and functional below ground mats
Genetic diversity	low due to emphasis on commercial species and nursery genomes	complex and varied
Ecosystem processes (predation, pollination)	moderate initially then sparse as conifer crowns close; limited food web dynamics	rich pollinators and complex food web dynamics
Susceptibility to invasives	moderate to high depending on site preparation, soil disturbances, livestock, road densities (see McGinnis et al. 2010)	low due to resistance by diverse and abundant native species and low soil disturbances
Disturbance frequency	commercial rotations (40-100 years or so)	varied and complex
Landscape heterogeneity	low	high; shifting mosaics and disturbance dynamics
Resilience/resistance to climate change	low due to nursery stock genomes but conifer plantings can be adjusted for locally anticipated climate envelopes	varied and complex genomes allow for resilience and resistance to climate change

achieve highest abundances in CESFs. In fact, in the Sierra Nevada, CESF habitat is comparable or higher in bird species richness and total bird abundance relative to unburned mature forest (Burnett et al. 2010). Bats (*Myotis, Idionycteris, Lasionycteris*, and *Eptesicus)*, which are an increasing conservation concern, are also favored by CESFs, likely because of greater insect prey as well as suitable roosts (Buchalski et al. 2013). Stand-replacing fires stimulate a flux of aquatic prey to terrestrial habitats, driving increases in riparian consumers (Malison and Baxter 2010). The trees killed by fire are highly beneficial to the ecological integrity of stream communities because they are a main source of large woody debris inputs (Minshall et al. 1997). There is also reproduction by some forest fungi species that are restricted to burns (e.g., morels, *Morchella* spp.) and the dead wood provides substrate for fungal growth that supports many arthropod species, including unique fire-following native beetles (Lindsey 1943; Bradley and Tueller 2001). Beetles, in general, colonize fire-killed trees in CESFs and their abundant larvae support species like Black-backed Woodpeckers (Hutto 2008).

Indicator Species for CESF Biodiversity (Figure 3)

Indicator species are valuable tools for conservation management because it is not practicable to monitor all biodiversity. When burned forests are logged after fire, one species that serves well as an ecological indicator for post-fire biodiversity, the Black-backed Woodpecker, declines substantially (Hutto 2008). Given that this woodpecker already is an indicator of the biodiversity supported by CESFs in the Sierra Nevada (USDA Forest Service 2013b), and is a fire specialist, we propose it as a Species of Conservation Concern. Designated Species of Conservation Concern are those whose population viability, or continued representation within a particular plan area, is of management concern. The forest-planning rule provides guidance to forest managers to use Species of Conservation Concern as a means for maintaining species diversity and wildlife population viability.

CESF habitat represented by Black-backed Woodpeckers is biologically unique (Hutto 1995; Bond et al. 2012). The Black-backed Woodpecker is an important primary excavator of nesting holes for many other cavity-nesting birds and mammals because it discards cavities after excavating them, and it uses a given cavity for one year (Tarbill 2010). Under a scenario with stand-replacing fire operating in a patchwise fashion in a landscape containing healthy populations of Black-backed Woodpeckers, the availability of nesting cavities across the landscape over time may be greatly enhanced compared to where fire is suppressed and/or fire-killed trees are removed. Black-backed Woodpeckers use CESFs for only several years (typically seven or eight) after fire and they depend upon the regular creation of CESFs to replenish their habitat (Hanson and North 2008; Tarbill 2010; Dudley et al. 2012; Siegel et al. 2013). When this does not occur, many other species that rely on nesting cavities are likely to be negatively affected. Thus, many species probably depend directly, or indirectly, on the continued occurrence of high-intensity natural disturbance across large landscapes to maintain their populations (Hanson and North 2008; Tarbill 2010; Dudley et al. 2012; Siegel et al. 2013).

Black-backed Woodpeckers have become increasingly rare because their optimal habitat has shrunk to a fraction of its historical extent (Figure 2 a – d); populations are estimated at <700 nesting pairs in burned forests (Bond et al. 2012). Importantly, the CESF habitat that the remaining pairs depend on has little or no protection on public lands managed by the U.S. Forest Service. Much of this CESF habitat is under mounting pressure from fire suppression and both pre- and post-fire logging (Hutto and Gallo 2006; Hanson and North 2008; Hutto 2008; Siegel et al. 2013), which prevent high-quality woodpecker habitat. That, in turn, may affect the biodiversity for which this woodpecker serves as an indicator.

Figure 3. Black-backed woodpecker – a fire dependent species in the Sierra (Photo – Monica Bond).

Are There Management Tradeoffs for Species of Conservation Concern at Opposite Ends of the Successional Continuum?

Wildlife management often involves tradeoffs when habitat for a particular species is emphasized. That is a problem with single-species management (managing for what one species needs), but is not a problem when managing for the maintenance of natural systems that a species may indicate. In the latter case, we would not enhance but would maintain natural levels of habitat for CESF indicators like the Black-backed Woodpecker, and for the biodiversity associated with its presence.

However, the California Spotted Owl is also a management indicator species but for late-seral forests in this region. Notably, all three subspecies (Mexican, California, Northern; Bond et al. 2002; Jenness et al. 2004; Roberts 2008; Bond et al. 2009; Clark et al. 2011; Roberts et al. 2011; Lee et al. 2012; Clark et al. 2013) appear to tolerate, or even benefit, from some degree of moderate- to high-severity fire within territories.

Managing CESFs for high levels of ecological integrity may provide important prey habitat (e.g., dusky-footed woodrat *Neotoma fuscipes*; Munton et al. 2002) for the spotted owl. In fact, the owl is known to reproduce in territories burned at all fire severities in this region, and preferentially selects high-severity fire areas for foraging (Bond et al. 2009). Owl reproduction has been found to be 60% higher in unmanaged mixed-severity fire areas than in unburned forests (Roberts 2008), and mixed-severity fire (with an average of 32% high severity) (Lee et al. 2012) does not reduce owl occupancy, though post-fire logging may precipitate territory abandonment (Clark et al. 2011, 2013; Lee et al. 2012). Moreover, because high-severity fire has been reduced by fire suppression, and current high-severity fire rotations are very long in the Sierra Nevada, if high-severity fire rates increased by even two- or three-fold, it would benefit CESF-associated species like the Black-backed Woodpecker, but would only reduce current old forest by a very small amount given old forest recruitment from ingrowth (Odion and Hanson 2013). Thus, protecting CESFs from post-fire logging and maintaining the spatial heterogeneity created by mixed-severity fires should provide habitat for all seral associates – there really are no management trade-offs when we manage for the maintenance of natural processes and systems.

What are Principal Threats to CESFS?

Management of CESFs has most often included post-fire (salvage) logging followed by tree planting, including burning of slash piles and associated soil disturbances, reseeding with grasses (often introducing invasive species inadvertently), use of straw-bales and other erosion prevention methods, herbicides to reduce shrub competition with conifers,

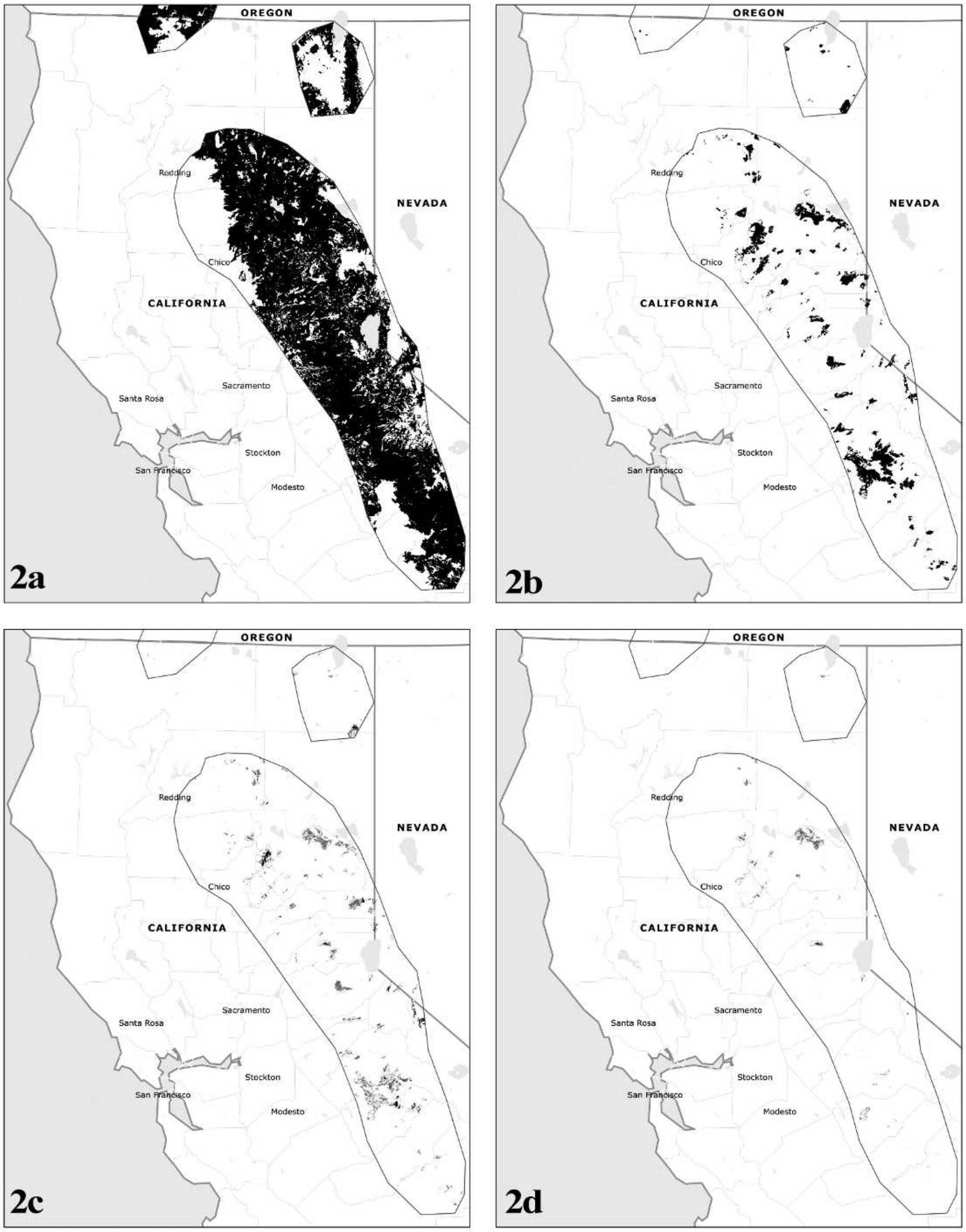

Figure 2. (a) Forest types used by Black-backed Woodpeckers in the Sierra Nevada management region; (b) fires since 1984 within the relevant forest types (private lands not included since they are rapidly logged); (c) moderate/high-severity fires resulting in >50% mortality (RdNBR >574 – see Hanson et al. 2010) of forests on public lands within the relevant forest types in the most recent decade for which there are fire severity data (2001–2010) (i.e., both high quality Black-backed Woodpecker habitat and moderate/low quality (older) habitat combined); and (d) moderate/high-severity fire on public lands within the relevant forest types in the most recent 5-year period for which fire severity data are available.

planting with conifer nursery stock, and livestock grazing (Swanson et al. 2011; Long et al. 2013; Table 1). These activities remove, or severely degrade, CESFs or, at a minimum, can narrow the window of duration for CESFs (Swanson et al. 2011), contributing to "landscape traps," whereby entire landscapes are shifted into, and then maintained in, a highly altered state as the result of cumulative impacts (Lindenmayer et al. 2011).

Climate change and forest fragmentation also have been identified as threats to biodiversity in the Sierra Nevada (USDA Forest Service 2013b). Since the 1980s, the region has experienced a decrease in annual number of days with below-freezing temperatures at higher elevations with more rain and less snowfall mainly in northern latitudes, more extreme heat days at lower elevations, earlier (5 to 10 days) snowmelt than decades ago, earlier (5–15 days) peak stream flows (Safford et al. 2012; Harpold et al. 2012), as well as an increase of approximately 1 °C since the early twentieth century, though some areas of the northern Sierra Nevada have seen a decrease in temperature (North 2012). Some regional climate models project further decreases in mountain snowpack, earlier snowmelt and peak stream flows, and greater drought severity (Overpeck et al. 2012). Such climatic changes are likely to affect the low-elevation ponderosa pine, which is projected to extend upward, while red fir and subalpine communities are projected to lose much of their climate envelope in the coming century (USDA Forest Service 2013b). It is unclear how such changes will affect CESFs. If fire increases in severity or frequency (Miller et al. 2009; Miller and Safford 2012), this could provide more opportunities for development of CESFs. This assumes there is not a concomitant increase in post-fire logging, and that fire suppression activities either cannot keep pace with climate-related fire events or prove ineffective due to the increasing influence of climate as a top-down driver of fire behavior. On the other hand, a number of climate models predict decreasing fire activity in these forests – even as temperatures rise – due to increasing precipitation, including summer precipitation and changes in vegetation (McKenzie et al. 2004; Krawchuk et al. 2009), and recent research using the largest fire severity data set to date has found no increase in fire severity in the Sierra Nevada since 1984 (Hanson and Odion, 2014; also see Odion et al. 2014 for related discussion).

Land-use stressors also magnify climate change effects on forest communities. For instance, Thorne et al. (2008) documented significant regional changes due to climate and land-use practices resulting in greater levels of disturbance compared to historical. Millar (1996) identified three paramount influences on Sierra Nevada ecosystems: (1) climate change and shifting hydrological patterns; (2) dense forests; and (3) rapidly expanding human populations. It is not known, however, whether these changes will act in concert to make CESFs more vulnerable to invading species, particularly those more suited to the changing climate and land-use disturbances.

Suggested Best Management Practices for CESF

For all the reasons outlined above, CESFs represent a neglected seral stage subject to multiple stressors that compromise ecological integrity. We, therefore, propose eight "best management practices" for stimulating conservation, restoration, and research interests in these unique forests. These principles can serve as appropriate guidelines where management goals include the maintenance of ecological integrity.

Conservation Focus

Principle 1 – "Rehabilitation" Is Not Needed After Fire Creates a Complex Early Seral Forest (Beschta et al. 2004; Swanson et al. 2011).

Fire acts as a natural restorative agent by resetting the successional clock and providing habitat for disturbance-dependent species. Although CESFs lack live trees initially and are populated by dead ones, this does not mean they require site rehabilitation or are "unhealthy" forests. In the context of ecological integrity, a functional forest system is one where the natural fire regime is of mixed-severity and has all stages of succession following stand-replacing fire. CESFs should be mapped and managed as a distinct forest habitat type.

Principle 2 – Protect Large, Old Forest Structures Across Seral Stages, and Retain Dense, Old Forests to Improve Ecological Integrity at Landscape Scales.

Large old-forest structures take decades to centuries to develop, and forest management has created a deficit through extraction. Dense, old forests provide high-quality habitat not only when they are green, but also when they experience mixed-severity fire (Hutto 2006, 2008), or snag pulses from beetles (Bond et al. 2012), as biological legacies remaining also serve to connect seral stages along the successional gradient.

Principle 3 – Mixed-severity Fire Should Be a Management Goal for Reserves.

Robust, reserve-based conservation strategies are needed to maintain the suite of seral stages and allow for climate-forced wildlife dispersals into suitable habitat. Thus, managers should allow fires to run their course in the backcountry and in reserves when not a risk to people or dwellings. This includes maintaining a landscape that includes diverse seral stages across environmental gradients (elevation, latitudinal).

Restoration and Management Focus

Principle 4 – Adopt Comprehensive Approaches to Restore Ecological Integrity in CESFs.

This starts with a restoration needs assessment (DellaSala et al. 2003) to evaluate and prioritize drivers of ecosystem degradation and best practices aimed at reducing specific stressors (see Principle 6). Most importantly, forests restored through fire usually do not need "restoration" otherwise.

Principle 5 – Limit Post-fire Management to Early Seral Forests Previously Degraded by Logging, Grazing, and Other Stressors.

Restoration approaches should identify comparable areas of high ecological integrity (e.g., unmanaged CESFs, DellaSala et al. 2003) to serve as a baseline or reference condition from which to restore degraded areas (e.g., burned plantations), and then surveillance, implementation, effectiveness, and ecological effects monitoring (Hutto and Belote 2013) should always be an integral part of the restoration activity.

Principle 6 – Reduce Land-use Stressors That Compromise the Ecological Integrity of CESFs.

Restorative measures can be active or passive depending on site-specific needs and should always be followed with well-funded monitoring (DellaSala et al. 2003). Examples include removal of livestock, invasive species abatement, road closures and obliteration, and reintroduction of fire.

Research Focus

Principle 7 – Determine Historical, Current, and Projected Future Distributions and Spatio-temporal Extent of CESFs as Well as Other Seral Stages Across the Planning Area.

This can be informed through "back-casting" approaches that reconstruct an historical baseline from combining age-structure reconstructions (e.g., from either FIA plot data or General Land Surveys from the 1800s; see techniques in Baker 2012; Williams and Baker 2012) with studies that link stand structure, disturbances and fire scar data (e.g., Sherriff and Veblen 2006), or other sources of information (e.g., USDA Forest Service 1911). Historical baselines can then be compared to current and future projected conditions under a changing climate in order to determine appropriate representation levels of CESFs and other seral stages in a planning area.

Principle 8 – Designate the Black-backed Woodpecker a "Species of Conservation Concern."

Continue, and expand upon, current monitoring efforts and, in partnership with the U.S. Fish and Wildlife Service and other experts, determine how best to meet population viability and habitat needs of this important CESF species. Although Black-backed Woodpecker populations decline as this seral stage advances (within seven years following fire), this species still functions as an indicator of early successional species because stable woodpecker populations would mean a steady supply of CESFs over time. Olive-sided Flycatcher, Chipping Sparrow, Mountain Bluebird, and other early seral species that have population peaks after declines in woodpeckers, may need to be monitored to ensure CESF conservation.

CONCLUSIONS

The forest-planning rule and its emphasis on ecological integrity, plant and animal community diversity, and Species of Conservation Concern provides the Forest Service with a unique opportunity to revise forest plans in the Sierra Nevada to meet the primary and cumulative threats that these forests now face – climate change and land-use stressors. Where the region's forests are to be managed for ecological integrity, managers will need to determine spatio-temporal occurrence of CESFs (historical and current) to allow for adequate representation of all seral stages across planning areas, particularly the rare ones that occupy opposite ends of the successional continuum (CESFs and late seral). This also means conducting field inventories in CESFs to better describe their unique attributes and ecological importance, treating CESFs as a distinctive wildlife habitat type in habitat classifications, and incorporating mixed- to high-severity fire into management goals at middle to upper elevations.

Clearly, climate change introduces uncertainties regarding how fire and other disturbance agents will operate on these forests in the future. Whether this will increase or further reduce CESFs remains to be seen. While managing for resilient ecosystems is a desired ecological objective of climate adaptation planning on the national forest system (36 Code of Federal Regulations § 219.5), it is important for managers to go beyond mechanical fuel reduction as a means for maintaining resilient ecosystem properties, and this includes acceptance of mixed- and high-severity fires as important ecosystem processes. However, resilient to natural disturbance does not necessarily mean resistant to disturbance. Sierran forests are disturbance dependent; they require severe fire for the production of CESFs.

The eight principles recommended for best management practices in CESFs in the Sierra Nevada would promote ecological resilience and allow the National Forests in this globally outstanding ecoregion to better adapt to climate change and increasing human development in the surroundings. We encourage conservationists and park managers to emphasize CESFs in reserve design and related conservation strategies as these forests are at least as important as their late-successional counterparts.

AUTHORS ENDNOTE

At the time of this publication, the Stanislaus National Forest was proposing extensive (~18,000 ha) post-fire logging of live (injured) and dead trees (including "roadside-hazard trees"), conifer re-planting, and shrub-eradication in the wake of the 2013 Rim Fire along the border of Yosemite National Park. The agency also proposes to plant conifers in high severity patches, thereby leap frogging important non-conifer dominant stages. Post-fire logging is incompatible with the needs of legions of species that depend on the presence of standing dead trees and montane chaparral.

Because of the significance of the Rim Fire as a pulse disturbance for generating CESFs, its proximity to an iconic national park, and the opportunity to educate the public about the importance of burned forest habitat, we believe the area warrants consideration for a national monument designation as did Mount St. Helens after the historic 1980 eruption. We urge managers and conservationists to give more attention to the ecological importance of CESFs in new protected areas proposals. This is especially important as we see the threat to these unique forests escalating due to increasing emphasis by federal agencies on extensive and intensive post-fire management projects.

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Appendix. Bird species present in complex early seral forests in the Sierra Nevada based on comparisons of burned and unburned plots (Raphael et al. 1987: east slopes of Sierra, University of California Sagehen Creek Field Station, pine-fir forests, ridgetop at 2100-m elevation, Burnett et al. 2012: Plumas National Forest, northeastern CA, mixed conifers, elevations 1094–2190 m: Storrie, Moonlight, and Cub mixed-severity fires). Only the Burnett et al. (2012) performed statistical analyses on bird abundances between burned and unburned plots. Taxonomy follows American Ornithologists' Union checklist of North and Middle American birds (http://checklist.aou.org/; active May 20, 2013).

Species	Present in both studies	Difference in abundance burned vs. unburned[2]
Mountain quail[3,4] *Oreortyx pictus*	+	+
American kestrel[3] *Accipiter cooperii*		
Mourning dove[3] *Zenaida macroura*		
Common nighthawk[3] *Chordeiles minor*		
Calliope hummingbird *Selasphorus calliope*	+	NS
Williamson's sapsucker *Sphyrapicus thyroideus*		
Red-breasted sapsucker *Sphyrapicus ruber*		
Hairy woodpecker *Picoides villosus*	+	+
White-headed woodpecker *Picoides albolarvatus*	+	+
Black-backed woodpecker *Picoides arcticus*	+	+
Northern flicker *Colaptes auratus*		
Olive-sided flycatcher[3] *Contopus cooperi*	+	+
Western wood-pewee *Contopus sordidulus*	+	+
Hammond's flycatcher *Empidonax hammondii*		
Dusky flycatcher *Empidonax oberholseri*	+	-
Cassin's vireo *Vireo cassinii*		-
Warbling vireo *Vireo gilvus*		NS
Stellar's jay *Cyanocitta stelleri*	+	NS
Mountain chickadee *Poecile gambeli*	+	-
Red-breasted nuthatch *Sitta canadensis*		-
White-breasted nuthatch *Sitta carolinensis*		

Cont'd.

Appendix. (Continued)

Species	Present in both studies	Difference in abundance burned vs. unburned[2]
Pygmy nuthatch[3] *Sitta pygmaea*		
Brown creeper *Certhia Americana*	+	+
Golden-crowned kinglet *Regulus satrapa*		-
Mountain bluebird[3] *Sialia currucoides*	+	+
Townsend's solitaire *Myadestes townsendii*		
Hermit thrush *Catharus guttatus*		-
American robin *Turdus migratorius*	+	NS
House wren[3] *Troglodytes aedon*	+	+
Nashville warbler *Oreothylypis ruficapilla*	+	-
MacGillivray's warbler *Geothlypis tolmiei*		NS
Yellow warbler[3] *Setophaga petechia*		NS
Yellow-rumped warbler *Setophaga coronata*	+	-
Hermit warbler *Setophaga occidentalis*		-
Green-tailed towhee[3] *Pipilo chlorurus*	+	+
Spotted towhee *Pipilo maculatus*		+
Chipping sparrow *Spizella passerina*	+	+
Brewer's sparrow[3] *Spizella breweri*		
Fox sparrow *Passerella iliaca*	+	+
Dark-eyed junco *Junco hyemalis*	+	+
Western tanager *Piranga ludoviciana*	+	-
Black-headed grosbeak *Pheucticus melanocephalus*		-
Lazuli bunting[3] *Passerina amoena*	+	+

Cont'd.

Appendix. (Continued)

Species	Present in both studies	Difference in abundance burned vs. unburned[2]
Brown-headed cowbird[3] *Molothrus ater*		
Cassin's finch *Carpodacus cassinii*	+	+
Red crossbill *Loxia curvirostra*		
Pine siskin *Carduelis pinus*	+	-
Evening grosbeak *Coccothraustes vespertinus*	+	-

[1] No fire severity estimate was given by Raphael et al. (1987) other than the Donner Ridge fire "consumed about 18,000 ha of pine-fir forests," a "few scattered mature pines and firs survived," and the fire area was "dominated by brush (primarily Ceanothus velutinus) and by regenerating conifers" (thus probably a high severity burn).

[2] (+) indicates species was significantly more abundant in burned, (-) means it was significantly less abundant, and NS means non-significant (P>0.05; Burnett et al. 2012).