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silviculture

Resistance and Resilience: A Conceptual Framework for Silviculture

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Increasingly, forest management goals include building or maintaining resistance and/or resilience to disturbances in the face of climate change. Although a multitude of *descriptive* definitions for resistance and resilience exist, to evaluate whether specific management activities (silviculture) are effective, *prescriptive* characterizations are necessary. We introduce a conceptual framework that explicitly differentiates resistance and resilience, denotes appropriate scales, and establishes the context for evaluation—structure and composition. Generally, resistance is characterized as the influence of structure and composition on disturbance, whereas resilience is characterized as the influence of disturbance on subsequent structure and composition. Silvicultural utility of the framework is demonstrated by describing disturbance-specific, time-bound structural and compositional objectives for building resistance and resilience to two fundamentally different disturbances: wildfires and spruce beetle outbreaks. The conceptual framework revealed the crucial insight that attempts to build stand or landscape resistance to spruce beetle outbreaks will ultimately be unsuccessful. This frees the silviculturist to focus on realistic goals associated with building resilience to likely inevitable outbreaks. Ultimately, because structure and composition, at appropriate scales, are presented as the standards for evaluation and manipulation, the framework is broadly applicable to many kinds of disturbance in various forest types.

Keywords: adaptation, desired future conditions, forest management objectives, forest service, planning rule

The terms resistance and resilience have been used in the ecological literature for nearly 40 years (Holling 1973). Despite this long-term recognition, the terms have yet to be incorporated into forest management. For example, the preamble to the newly published US Department of Agriculture (USDA) Forest Service Planning Rule includes many references to the term resilience; however, the final rule eliminates the term noting “public concern over how to define and measure” resilience (USDA 2012).

Instead, the USDA recently publicized a purely descriptive definition of resilience for public comment (USDA 2013). Passage into law as currently defined would have catastrophic consequences on public land management. National Forest System silviculturists would be expected to incorporate into management “resilience” with no context for explicit consideration of disturbance type, forest type, or spatial and temporal scales. Under these circumstances defining or assessing objectives and evaluation criteria would be virtually impossible (Long et al. 2010, Long and Kurtzman 2012) and would almost certainly result in lengthy litigation. Using currently accepted definitions, we introduce a conceptual framework that explicitly differentiates resistance and resilience, delimits appropriate scales, and establishes a useful context for evaluation that can be effectively applied by, in particular, Forest Service silviculturists, but is generally applicable to forest management.

Commonly, building resistance and resilience is cited as a general goal of forest management in the context of climate change for adaptation (Millar et al. 2007, Stephens et al. 2010). By meeting this goal, it is presumed that desired forest characteristics such as ecological goods and services will be maintained within reasonable values of change if/when the forest faces a broad range of disturbances (e.g., drought, insects, or fire; Puettmann 2011, O’Hara and Ramage 2013). Although easy to describe in forest management planning, the development and evaluation of specific, measurable objectives (Long et al. 2010, Long and Kurtzman 2012) becomes a time-consuming and laborious process for silviculturists, particularly when the ambiguities of managing uncertainties associated with climate change are added to traditional planning constraints. Frustrations associated with these ambiguities can be alleviated if instead silviculturists focus attention on how climate change will probably affect the environment, and therefore, structure and composition. For

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This article uses metric units; the applicable conversion factor is: hectares (ha): 1 ha = 2.47 ac.

Table 1. Conceptual framework of stand and landscape resistance and resilience to disturbance.

	Resistance	Resilience[a]
Stand	Influence of structure and composition on disturbance severity Wildfire: influence of structure and composition on the severity of fire behavior Spruce beetle: influence of structure and composition on the severity of spruce mortality due to high beetle population levels arising from *within* the stand	Influence of disturbance on subsequent structure and composition Wildfire[b]: Influence of fire on subsequent structure and composition Spruce beetle[c]: Influence of spruce beetle infestation on subsequent structure and composition
Landscape	Influence of structure and composition on the spread of disturbance Wildfire: influence of multistand structure and composition on the spread of fire Spruce beetle: influence of multistand structure and composition on the severity of spruce mortality due to the transition from endemic to epidemic beetle populations	Influence of disturbance on subsequent forest structure and composition Wildfire: Influence of fire on subsequent proportion of landscape age classes and species dominance Spruce beetle: Influence of spruce beetle outbreak on proportion of landscape age classes and spruce-dominated stands

[a] Structural and compositional indicators of stand and landscape resilience are a function of management goals relating to desired conditions in a specified period after a disturbance, e.g., immediately after the disturbance or longer term. Desired conditions need not be limited to live trees and may include important ecosystem attributes such as snags, coarse woody debris, or decadent crowns.

[b] Indicators of stand and landscape resilience to wildfire typically reflect specified reference conditions, e.g., large, widely spaced trees of fire-tolerant species (stand) and diversity of successional stages (landscape).

[c] Indicators of stand and landscape resilience to spruce beetle might include, e.g., surviving large trees (stand) and the potential for future spruce dominance (landscape).

example, expected climate change might result in drastic alterations to the variability in disturbance regimes (Miller et al. 2009), fundamental shifts in species ranges (Rehfeldt et al. 2006), or shifting requirements for germination and establishment (McKenney et al. 2009). Viewed this way, the potential effects of climate change are reduced from large-scale generalities to more explicit processes and attributes (disturbance intensity, structure, or composition) that can be used by the silviculturist to characterize, and plan for, resistance and resilience.

We integrate previous definitions of resistance and resilience into a conceptual framework that explicitly couches them in the context of forest structure and composition. Our intent is NOT to provide new definitions but rather to provide guidelines for assessing resistance and resilience that are consistent with current theoretical definitions and also practical for silviculturists. We show how our basic conceptual framework allows one to compare and contrast resistance and resilience to specific disturbances for stands and landscapes to establish the context for evaluation and manipulation—*structure* and *composition*. This conceptual framework has utility and broad applicability for characterizing disturbance-specific, time-bound, structural, and compositional objectives for building resistance and resilience. We illustrate the framework using two fundamentally different types of forest disturbances: wildfires and spruce beetle (*Dendroctonus rufipennis* Kirby) outbreaks.

Resistance and Resilience: A Conceptual Framework

In general, resistance is the ability of a community to remain unchanged when challenged by disturbances (Grimm and Wissel 1997), and resilience is "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" as originally defined by Holling (1973) and modified by Walker et al. (2004). The terms resistance and resilience are used in a variety of ways, which are often ambiguous (Grimm and Wissel 1997), qualitative, and seemingly independent of disturbance type (Carpenter et al. 2001). There is also still some confusion over the use of terms "engineering" resilience versus "ecological" resilience (Holling 1996, Gunderson 2000); we focus this article on the latter. Furthermore, sometimes characterization of resistance focuses on the system (Grimm and Wissel 1997) and sometimes on the disturbance (e.g., the amount of disturbance necessary to change the system; Peterson et al. 1998, Carpenter et al. 2001, Folke et al. 2004, Walker et al. 2004), as disturbance intensity has been shown to influence both resistance and resilience (Halpern 1988). Rarely is resilience characterized in the context of both the system and associated disturbances (but see Drever et al. 2006). Appropriately, it has been suggested that resilience be defined as resilience "of what, to what" (Carpenter et al. 2001) at appropriate scales of space and time (Westman 1978), something rarely done in contemporary literature.

If management goals include building resistance and/or resilience to disturbances that potentially affect large areas, then their definitions should reflect whether the disturbance affects individual stands or entire landscapes. In some contexts, *descriptive* definitions of resistance and resilience may be useful, but to evaluate whether objectives are achieved in a silvicultural or operational context (Carpenter et al. 2001, Puettmann 2011), they must be defined in measurable and consistent terms (Brand and Jax 2007, Stephens et al. 2010). Structure and composition of stands and landscapes are measurable and can be used in *prescriptive* characterizations of resistance and resilience to disturbance.

Given the above definitions from the literature, we propose that it is appropriate to characterize stand resistance to disturbance as the influence of structure and composition on the severity of disturbance (Table 1). Of course, many disturbances occur at the scale of many stands; consequently, landscape resistance is characterized as the influence of landscape structure and composition on the spread of disturbance. In other words, do stands of particular structural and/or compositional attributes occur spatially on the landscape in such a way that they mitigate the possibility of or resist disturbance?

In contrast, we characterize resilience as the influence of a particular disturbance on subsequent structure and composition (Table 1). To be silviculturally relevant, resilience of stands and landscapes must be framed in the context of quantitative attributes associated with desired future conditions. "Future" explicitly represents a specified time frame and could incorporate information about potential shifts associated with climate change. Stand resilience is the influence of disturbance on subsequent vegetation structure and composition in terms of, e.g., stand age, tree size distribution, or species dominance. Landscape resilience is the influence of a disturbance on the subsequent structure and composition of multiple stands (forest-wide). For example, do postdisturbance stands within a landscape include the variation in structural and/or compositional attributes (age-class diversity or size-class diversity) required by the forest management goals within a specified time frame?

The conceptual framework makes explicit the distinction between resistance and resilience, which are not interchangeable. The structure- and composition-based characterizations are silviculturally relevant so that prescriptions to build resistance and/or resilience can be designed, implemented, and evaluated for success—all necessary to avoid litigation on federal land. By following the framework, one can avoid using the terms resistance and resilience as an end in and of themselves. We demonstrate the robustness of the framework by using it to assess resistance and resilience to two fundamentally different disturbances: wildfire and spruce beetle outbreak.

Resistance and Resilience to Wildfire

Fires are a natural part of many forested systems, and their management is a topic of considerable interest (Baker 2009). Recently, a strong case has been made for shifting the focus of wildland fire management in dry, mixed-conifer forests from suppression and control to the maintenance of fire-resilient forests (Agee and Skinner 2005, Reinhardt et al. 2008) capable of absorbing inevitable fires without fundamentally changing the system at the landscape scale. Using the conceptual framework, we can characterize the structure and composition of fire-resistant and fire-resilient stands and landscapes. Because of the strong research focus on dry-site forests the following silvicultural approaches are not necessarily appropriate in other forest types such as coastal temperate or subalpine forests.

In our conceptualization, resistance is the influence of structure and composition on the severity of fire (Table 1). Management objectives for a stand might include creating and maintaining a fuels profile to minimize the likelihood of a crown fire if an ignition were to occur under extreme weather conditions. To assess how stand or landscape resistance is achieved, specific structural and compositional attributes are evaluated with respect to their expected influence on fire behavior. Evaluation criteria are based on predetermined thresholds of extreme fire behavior, such as the mitigation of unwanted fire effects. Characterization of extreme fire weather typically quantifies temperatures, moistures, and wind speeds that are unusual but not unprecedented. For example, 97th percentile weather might be chosen as a threshold under which to evaluate whether treatment goals are met (Stephens et al. 2009).

To build resistance, thinning and fuel reduction treatments are used to redistribute and/or remove fuels (Ritchie et al. 2007). Models and empirical observations provide compelling evidence that thinning to reduce canopy bulk density and eliminate ladder fuels, combined with surface fuel reduction, can result in dramatically altered fire behavior (Skinner and Ritchie 2008). Whereas stand-level treatments for resistance are demonstrably effective in influencing the behavior of fire within treated stands (Graham et al. 2004, Agee and Skinner 2005), they are costly, and the effects are short-term and small-scale. Furthermore, most wildfires occur over large areas composed of many stands, making characterization of resistance in the context of the landscape important.

Landscape resistance is characterized as the influence of multistand structure and composition on the spread of fire (Table 1). A highly resistant landscape could in principle be composed entirely of highly resistant stands; however, as a management strategy this is unrealistic in terms of scale and in particular over the long-term. In the absence of continued treatment, extreme fire behavior is inevitable. Ultimately, fuels treatments are not intended to eliminate fire but to modify fire behavior, such as reducing potential fire behavior from crown fire to surface fire to increase fire suppression effectiveness and lessen impacts on the overstory (Agee and Skinner 2005, Reinhardt et al. 2008) without compromising other ecological goods and services (Stephens et al. 2012a). This could be accomplished by using strategically placed area treatments (SPLATs). SPLATs can, at least in theory, slow fire rate of spread by as much as 60% with as little as 20% of the area treated, compared with spread on untreated landscapes (Finney 2001). SPLATs also reduce fire intensity and severity in untreated areas juxtaposed to the lee side of treated areas (Finney et al. 2005). The strategic placement of fuel treatments across the landscape increases the likelihood that a large proportion of the forest, substantially greater than the proportion actually treated, will be resistant to high-severity wildfire. For example, Agar et al. (2010) simulated fuel treatments on a large landscape (16,000 ha) in eastern Oregon that had species composition ranging from dry-site ponderosa pine to cold forests of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.). Their results suggested that strategic treatment of ~10% of the study area might reduce the loss of large trees by 70%.

Stand resilience is characterized as the influence of fire on subsequent mortality and species composition relative to those that are desired after a fire (Table 1). Stand resilience to wildfire could be defined as low mortality in the overstory as a result of a fire. It is different from stand resistance in that it *explicitly* focuses on long-term strategies for maintaining desired vegetation structure and composition rather than on the influence of vegetation structure and composition on fire behavior. Strategies for building stand resilience to fire will depend on the forest type and specifics of the desired future condition but might include retention of large, fire-adapted trees or increasing live tree spatial heterogeneity (Fule et al. 2001, Agee and Skinner 2005, Stephens et al. 2009, Churchill et al. 2013). Although these strategies might also be used to build fire-resistant stands, the crucial difference is the assumption that fire will occur, which shifts the focus from changing fire behavior to maintaining attributes consistent with the desired future conditions.

An example focuses on building forest type-specific, fire-resistant and -resilient stands based on desired future conditions. First, historically many presettlement ponderosa pine (*Pinus ponderosa* Dougl.) forests in the western United States were resistant to fire so that relatively frequent, low-intensity surface fires only rarely became high-intensity, crown fires (Moore et al. 1999). However, after ~100 years of fire exclusion, many of these forests have “missed” a dozen or more surface fires, resulting in uncharacteristically dense stands (Busse et al. 2009) that exhibit both reduced resistance and resilience. Extreme severe fire is now much more likely to occur, reflecting decreased resistance (Figure 1A). In this forest type, presettlement structural and compositional attributes characterize the historical range of variability and provide a reasonable basis for defining a desired future condition. Building resilient stands of ponderosa pine could involve creating and maintaining large, widely spaced trees of fire-tolerant species (Figure 1B). When challenged by wildfire, these stands are more likely to exhibit limited mortality of the largest trees.

A second example highlights the necessity of explicitly accounting for time in characterizing stand resilience. Aspen (*Populus tremuloides* Michx.) is a shade-intolerant clonal species that regenerates primarily via root suckering. Because aspen trees (ramets) rarely

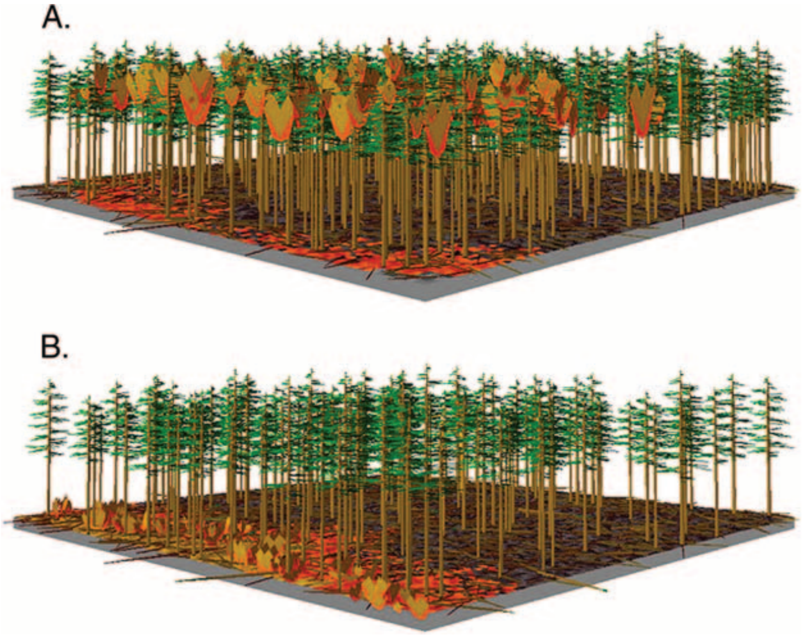

Figure 1. (A) Stand visualization system images of 150-year-old unthinned ponderosa pine stand (72% stand density index) that was predicted to exhibit stand-replacing fire behavior. This stand was neither resistant nor resilient to fire. (B) The same stand after thinning to ~30% stand density index the previous decade was predicted to exhibit surface fire behavior. In the short-term this stand will be resistant to wildfire. However, with the explicit recognition that future fires will occur, the long-term goal should be to build resilience, which could focus on retention of large, fire-adapted trees and increasing live tree spatial heterogeneity.

survive fire, if resilience is characterized as maintenance of mature aspen trees, aspen stands clearly lack resilience in a short-term time frame (Table 1). However, vegetative reproduction of aspen is typically prolific after fire, and within a few years vigorous aspen shoots will dominate the fire-affected area. Therefore, in the midterm, a mature aspen stand will dominate the site and in the context of this time frame, the aspen stand is highly resilient. In the very long absence of fire, aspen stands can be displaced by tolerant conifers, and in the context of this long-term time frame, aspen stand resilience is problematic if the goal is to maintain aspen.

Landscape resilience is characterized as the influence of fire on the distribution of age classes and species dominance relative to those that are desired (Table 1). In other words, do postfire stands across a landscape include the variation in structural and/or compositional attributes required by the management goals within a specified time frame? Objectives for building resilience over a landscape might include maintaining biological legacies, age-class diversity, size-class diversity, or a diversity of successional stages and maintaining these within the range of historical conditions (Agee and Skinner 2005). Silvicultural regeneration methods could be used to regenerate stands of "over-represented" age classes and increase age-class diversity. Finally, the time frame is a crucial component in assessment of landscape resilience. Specifically, the effectiveness of treatments, whether stand or landscape, is short-lived, and, therefore, planning for retreatment is a necessary part of maintaining resilience to wildfire (Reinhardt et al. 2008, Stephens et al. 2012b).

Resistance and Resilience to Spruce Beetle Outbreak

The magnitude of recent spruce beetle outbreaks (Bentz et al. 2009, 2010) has silviculturists and entomologists questioning what, if anything, can be done to mitigate spruce beetle activity. Given the host specificity of the spruce beetle, planning for and evaluating resistance and resilience to outbreaks are *fundamentally* different from those processes for wildfires. The conceptual framework provides a template to evaluate resistance and resilience of spruce-dominated stands and landscapes faced with increasing populations of spruce beetle.

Engelmann spruce stand resistance to spruce beetle is characterized as the influence of structure and composition on the likelihood of beetle populations increasing from within the stand (Table 1); i.e., the likelihood is small that large numbers of beetles could develop within, and spread from, a resistant stand. Such resistance can result from a high percentage of nonhost species, induced or constitutive resistance mechanisms (Lombardero et al. 2000), or low susceptibility associated with either low relative density and high vigor or young stands of small spruce trees (Veblen et al. 1994). All of these attributes reduce the availability of suitable breeding material for spruce beetle and thus limit population increases (Schmid and Frye 1977, Fettig et al. 2007).

In other words, stand resistance is characterized as the structural and compositional attributes that negatively influence the beetle and can be manipulated with stand management. In contrast to methods intended to directly protect individual trees from successful colonization by beetles (removal of infested trees and insecticide treatments), building resistance via manipulation of stand structure and composition is a strategy intended to indirectly influence a beetle population. For example, spacing increases residual tree vigor and alters within-stand microclimate, both of which can negatively affect beetle populations. Whitehead et al. (2006) suggested that spacing may prevent transition from endemic to incipient populations of mountain pine beetle (*Dendroctonus ponderosae* Hopkins); however, spacing has only been retrospectively tested for the spruce beetle (Hansen et al. 2010). Because of costs and legal challenges, thinning to create resistance is typically conducted over small spatial extents representing at most hundreds of ha. Operational barriers also make impractical the follow-up thinning necessary to maintain the resistant structure over time. Silviculture focused at the stand level will, at best, only "buy time" until conditions are again conducive for beetle population growth (Fettig et al. 2007, DeRose and Long 2012). Maintaining long-term stand resistance would require repeated entries to increase spruce vigor that would ultimately result in stands of mature, large spruce, which are, paradoxically, particularly susceptible to spruce beetle mass attack (Schmid and Frye 1976). Judiciously working to promote stand resistance to spruce beetle outbreaks may actually contribute to an increase in susceptibility in the long term.

As a result of the scale of beetle outbreaks, it is not likely that any stand activity *where susceptible host trees remain* will ultimately "resist" a spruce beetle epidemic originating from outside the stand (DeRose and Long 2012). For example, an Engelmann spruce thinning treatment conducted in the Dixie National Forest had the express objective of increasing resistance to spruce beetle populations. The stand did in fact remain unattacked longer than the surrounding forest, but the effect was very short-lived as epidemic beetle populations from adjacent, untreated stands overwhelmed the treatment area (P. Eisenhauer, USDA Forest Service, pers. comm., July 7, 2006). Thinning a spruce stand to provide resistance to the spruce beetle is realistically only a short-term stopgap measure and should be carefully considered in the context of adjacent stands of susceptible host and beetle population levels.

Landscape resistance to spruce beetle is characterized as the influence of multistand structure and composition on the transition of beetle populations from endemic to epidemic (Table 1). For example, a landscape would be resistant if a large percentage of its stands consist of young, vigorous trees unsuitable for spruce beetle to produce a brood. Such resistance, however, would ultimately be ephemeral. In the long-term and in the absence of disturbance, increasing tree sizes and stand relative densities create excellent brood-rearing substrate. In principle, landscape resistance can be created and maintained with timely stand treatments; however, in practice, economic and political barriers may make such landscape-wide treatments unrealistic and expensive to establish and maintain. Although landscape resistance to wildfire might be achieved with treatment of as little as 20% (Finney 2001), landscape resistance to spruce beetle would almost certainly require treatment, and subsequent retreatment, of a substantially greater area (Figure 2A) given the lack of synchronicity in building beetle populations (DeRose and Long 2012). As with fuels treatments, it should be clear that the effectiveness of treatments for resistance to spruce beetle, both stand and landscape, is ephemeral.

Stand resilience is characterized as the influence of a spruce beetle outbreak on subsequent structure and composition (Table 1). Objectives for stand resilience need to be framed in the context of what is desired postoutbreak. Depending on the specific management objectives, indicators of stand resilience might be the following: (1) maintenance of mature trees (any species); (2) maintenance of mature spruce; or (3) the potential for spruce-dominated forests in the long-term, represented by abundant spruce advance reproduction. Stand resilience for objective 1 could be achieved with management that favors nonhost species in the overstory. Stand resilience for objective 2 is more problematic but might be achieved by treatment well in advance of substantial increases in spruce beetle numbers. Silvicultural activities that increase the percentage of nonhost species, especially in stands of large average spruce diameter, can potentially mitigate tree mortality. For example, DeRose and Long (2007) found that the few large Engelmann spruce surviving an outbreak were located in stands with high percentages of nonhost trees. Stand resilience for objective 3 might be achieved by the presence of abundant young spruce. This could be represented by a combination of young spruce stands (<70 years; Veblen et al. 1994), young mixed-species stands, and mature stands with abundant spruce advance reproduction in the understory. In the absence of young spruce, an outbreak might result in a long-term shift in species composition (DeRose and Long 2010). An unanticipated effect of the Dixie National Forest thinning described above was the serendipitous establishment of Engelmann spruce seedlings. Fifty plots on a systematic grid with a random starting point were established within the treatment boundary, and measurements of seedling age showed that ~33% of the spruce had established *as a result of* the thinning (R.J. DeRose, USDA Forest Service, unpubl. data, July 20, 2010). Although not an objective of the intermediate treatment, this "catch" of spruce seedlings suggests that timely regeneration treatments could effectively increase the long-term resilience of a stand.

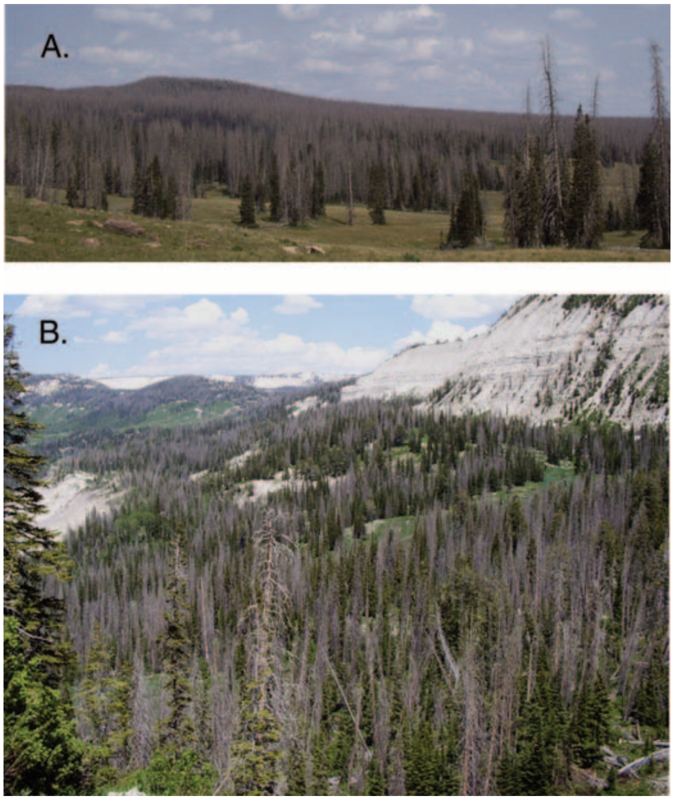

Figure 2. Engelmann spruce mortality from landscape-wide spruce beetle outbreaks is typically more severe when the host structure and composition are homogeneous. (A) This landscape lacked resistance, and resilience is problematic due to a paucity of live remnant spruce. (B) The landscape with more species diversity and age-class diversity also lacked resistance to the spruce beetle. In contrast, this landscape was resilient if desired future conditions include live overstory trees.

Landscape resilience is reflected in the influence of a spruce beetle outbreak on the landscape-wide distribution of stand ages, structures, and compositions relative to those desired (Table 1; Figure 2B). Landscape resilience could be characterized to reflect the goal that spruce dominance be maintained over the long term. Such resilience might be represented by landscape-wide tree species diversity and spruce age-class diversity. When challenged by an outbreak that killed all mature spruce, both the old forest character (surviving nonhost species) and the potential for future spruce-dominated stands (advance reproduction) would be maintained. In Engelmann spruce landscapes with limited species and age-class diversity, silviculturists might consider implementing an aggressive program of regeneration harvests focused on stands with high spruce beetle hazard ratings (Schmid and Frye 1976). Increasing the representation of stands of young spruce and increasing species diversity before an outbreak should increase both short- and long-term resilience.

To promote Engelmann spruce establishment, silvicultural intervention would need to be conducted well in advance of an outbreak. These treatments should leave large, seed-bearing spruce so that a catch of spruce can become established. Group selection methods are conventionally used to regenerate spruce in the Rocky Mountains (Alexander 1987); however, the shelterwood regeneration method could feasibly, in the short term, result in the establishment of a much larger area of young spruce than is possible with group selection because much larger areas could be treated. Specifically, a uniform shelterwood can quickly and effectively create the necessary microsite conditions for timely spruce establishment (Long 1994), resulting in young spruce stands that should not be susceptible for at least 70 years.

Postoutbreak planting is often part of a management plan to mitigate the effects of a spruce beetle outbreak. Therefore, collection and storage of Engelmann spruce seed from a range of appropriate seed zones should be a priority. Given the relative infrequency of Engelmann spruce cone crops (Long 1994), seed collection should be conducted well before an outbreak begins. Traditionally, seed would not be used for artificial regeneration if it came from seed zones lower in latitude or elevation. However, recent rapid shifts in climate create the possibility that planting stock produced from seed coming from trees established centuries ago, may not be the best option for planting (McKenney et al. 2009). Adaptive decisions concerning appropriate seed sources should take into consideration possible local climatic changes so that collected seed will be matched to potential growing conditions. Finally, without thoughtful implementation, an aggressive postoutbreak planting program will result in a spruce forest with limited age-class diversity, which in turn may make a future landscape-wide beetle outbreak inevitable.

Discussion and Conclusion

The conceptual framework explicitly differentiates resistance and resilience, focuses on appropriate scales, and provides a context for evaluation and manipulation: structure and composition. Application of the framework encourages silviculturists to think beyond very general, ambiguous goals of resistance and resilience and focuses attention on what is ultimately ecologically meaningful and silviculturally achievable. For example, by divorcing the generalities of managing uncertainties associated with climate change from the actual or predicted effects of changing climate on forested systems and disturbance processes, silviculturists can focus on quantifying the attributes of resistance and resilience with respect to particular disturbances and desired future conditions. If accepted as currently defined (USDA 2013), the term resilience could be incorporated into the Forest Service Planning Rule, and public land managers will be expected to quantify resilience with respect to management objectives to avoid or survive lengthy procedural problems commonly subject to litigation.

Our characterization of resistance and resilience helps in making these important theoretical concepts silviculturally relevant. Both have everything to do with the nature of interactions between vegetation and disturbance but with a fundamental difference. It is important to distinguish interactions in which the focus is on how vegetation influences disturbance behavior and interactions in which the focus is on how a disturbance influences the nature of vegetation. This basic dichotomy is an important difference between resistance and resilience, and its recognition is critically important for translating broad management goals into focused objectives ultimately necessary for the design, implementation, and monitoring of silvicultural systems.

The conceptual framework accounts for two silviculturally important scales, stand and landscape, and can accommodate additional scales if warranted. The stand is the basic unit for which silvicultural prescriptions are written, implemented, and monitored. Landscape encompasses scales across which many disturbance processes occur (Turner et al. 2001). Stand and landscape capture the range of scale most relevant in the framing of objectives and the design and implementation of silvicultural systems intended to accomplish those objectives.

The conceptual framework is centered on structure and composition. There are situations in which interest might be focused on a particular ecosystem good or service. However, structure and composition influence and are influenced by system processes and functions, and structure and composition can be directly manipulated by silviculturists. Understanding the structural and compositional attributes that make a particular forest type resistant and/or resilient in the context of a particular disturbance and explicitly defined desired current and future conditions are key to designing a silvicultural system that addresses resistance and/or resilience.

Judgment on the utility of any conceptual framework should be based on insights provided by the framework, especially to the extent that those insights may be unexpected or counterintuitive. Our framework meets this criterion. For example, the framework conceptualizes resilience as goal specific, and it must be defined in terms of the structural and compositional elements most valued in postdisturbance stands and landscapes. Furthermore, the desired postdisturbance conditions must be characterized in the context of an appropriate scale and time frame. Explicitly characterizing resilience objectives in terms of future structure and composition is a critical step in the design of a silvicultural system appropriate to the stand and/or landscape management goals. Therefore, except in particular situations where resistance is desired (e.g., the wildland-urban interface), we strongly suggest that silviculturists focus on building longterm stand and landscape resilience.

Another insight derived from the conceptual framework is that structure and composition appropriate to creating and maintaining resistance and/or resilience are not only goal specific but also disturbance specific. That is, creating resistance or resilience is not a “one size fits all” objective. Sometimes there will be congruence between disturbance types; combinations of structure and composition intended to create resistance and/or resilience for one disturbance may also increase resistance and/or resilience for another. For example, to increase resistance to stand-replacing wildfire, one short-term strategy is to drastically reduce stand density. The reduced density might confer resistance to a number of other environmental challenges (Mitchell et al. 1983, Cucchi and Bert 2003). In contrast, a strategy to increase resistance and/or resilience to one disturbance type may decrease it for another. The wildfire example above could result in decreased species diversity and increased mean tree size, which would result in a increased percentage of large trees of a particular species, raising the likelihood of a pathogen outbreak. This relationship applies to many bark beetle species that potentially affect a wide range of forest types (e.g., *Dendroctonus ponderosae*, in lodgepole pine, ponderosa pine, and whitebark pine types). The examples make clear that a very general goal of creating resistance and/or resilience as an end, in and of itself, is insufficient. The specificity demanded by the conceptual framework should help silviculturists avoid this pitfall by providing a means to quantify resistance and resilience.

Our conceptual framework enables a useful characterization of how to build resistance and resilience to two very different large-scale disturbances and should have broad applicability to other regions, forests, and types of disturbance. We are not offering new definitions of resistance and resilience; rather, we propose a practical framework that provides context for broad goals, specific objectives, and, ultimately, the development of appropriate silvicultural systems.

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