Forest management for novelty, persistence, and restoration influenced by policy and society

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The ecological literature offers many conflicting recommendations for how managers should respond to ecosystem change and novelty. We propose a framework in which forest managers may achieve desired forest characteristics by combining strategies for (1) restoring historical conditions, (2) maintaining current conditions, and (3) transitioning toward novel conditions. Drawing on policy studies and the ecological and social sciences, we synthesize research on factors that shape forest management responses to ecosystem novelty and change. Although the ecological literature often suggests the likelihood of transitions to novelty, we found that a management focus on restoration and persistence strategies was supported by landowners, private and public lands policy, and forest manager capacity and culture. In this era of unprecedented change, managers and policy makers must address ecosystem novelty to achieve desired forest futures without eroding support for forest conservation and management.

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Environmental changes present challenges and choices for forest managers and policy makers (Dale *et al*. 2001). In the future, forests will be subjected to more frequent megafires, insect outbreaks, diseases, storms, droughts, invasive species, fragmentation, and parcelization, as compared to the prior century (Grimm *et al*. 2013; Sample *et al*. 2016). Some of these changes result in highly novel abiotic or biotic conditions that are fundamentally different from a defined reference baseline (Radeloff *et al*. 2015). These changes are a global concern because forests provide important ecosystem services, including timber and non-timber products, carbon storage, water quality, recreation, and habitat (Reid *et al*. 2005). Although there is consensus among ecologists that rates of environmental change are high and can result in ecological novelty, there is little agreement on how managers should respond (Klenk and Larson 2015; Kareiva and Fuller 2016).

In a nutshell:

- Current policy and management focus primarily on persistence and restoration strategies, but more attention is needed on transitions to novelty that achieve desirable forest conditions and prevent undesirable conditions
- Our new framework allows managers to combine forest restoration, persistence, and transition-to-novelty strategies, providing an alternative to the resistance–resilience–transition framework
- Many factors influence the decision to pursue restoration, persistence, or transition-to-novelty strategies, including the characteristics of landowners, forest managers, forest policies, stakeholders, and forests
- Novelty in climate, species, and genes does not inherently preclude restoration and persistence of forest characteristics
- New approaches are needed to address novelty without undermining the basis for forest conservation

Debates about what goals and strategies are desirable continue. Managing for stable, persistent ecosystems is common in resource policy and management built on 20th-century science of ecosystem equilibrium (Holling and Meffe 1996). Restoration has become important for recovering degraded ecosystems, and is typically rooted in historical conditions, even if those conditions are not an exact template for management (www.ser.org; Temperton *et al*. 2014). In stark contrast, some ecologists have suggested that a high degree of novelty makes restoration infeasible, that novel ecosystems should be embraced rather than resisted (Hobbs *et al*. 2014; Ellis 2015), and that a variety of strategies should be used to transform forests to novel conditions and protect species and/or functions (Millar *et al*. 2007). These debates have suffered from two major shortcomings: (1) proponents of one approach frequently set up false dichotomies, argue for one-size-fits-all solutions, and ignore the possibility that a combination of approaches may be necessary given complex ecosystem dynamics and trade-offs; and (2) although such debates are supposed to provide guidance to managers, serious consideration of the social context for management and policy decisions is often lacking.

We examined forest management strategies in response to environmental change and novelty by addressing two ques-

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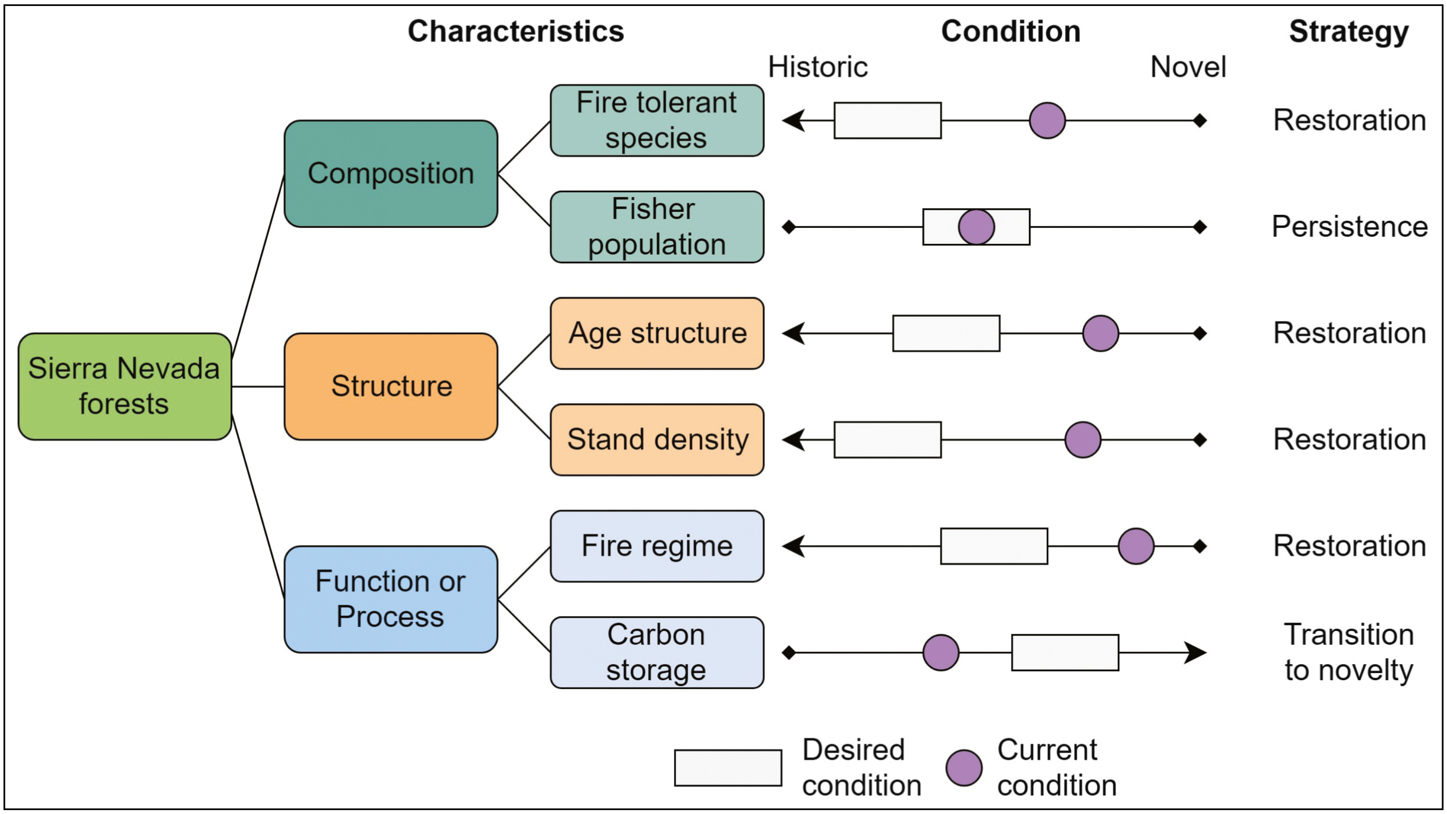

Figure 1. An example of restoration, persistence, and transition-to-novelty management strategies applied to Sierra Nevada mixed conifer forests. Baselines and goals depend on the specific context. A manager might seek to shift a specific characteristic from its current condition (purple circle) into the range of its desired condition (gray rectangle). The strategy is the direction that managers would need to move to transition from the current condition to the desired condition for each characteristic (direction depicted with arrows).

tions. First, what management strategies are available to forest managers responding to environmental change and novelty? We propose a gradient of management strategies ranging from restoration (ie reverting prior change) to persistence (managing against change) to transition-to-novelty (managing for change). Second, what factors influence management choices among restoration, persistence, and transition-to-novelty?

Drawing on the social–ecological systems framework, organizational learning, and the "reasoned action" approach to behavior change from psychology, we identified factors that influence forest management responses, such as public and private landowner goals, owner and manager organizational capacity and culture, individual forest manager attributes, and forestland characteristics.

Management responses

Forest characteristics such as composition, structure, and function may be within or outside both the historical range of variability and the range of desired future conditions. Classifying a management strategy as restoration, persistence, or transition-to-novelty depends on the relative position of current conditions compared to their historical and desired future range (Figure 1).

Restoration typically involves three components: forests that are degraded, damaged, or destroyed; purposeful interventions; and a goal of restoring ecological processes and biodiversity guided by historical conditions (Clewell and Aronson 2006). Managing for restoration can range from passive management (eg allowing natural regeneration) to active interventions (eg seeding native species) (Table 1; Benayas *et al.* 2008). The intensity of active management depends on many factors, including seed source presence, level of degradation, and restoration resources (Holl and Aide 2011).

Another common strategy is to maintain current forest characteristics, an approach we refer to as "persistence". The primary goal is to sustain current composition, structure, function, or services. Common persistence goals include sustained timber yields and water quality (eg US Forest Service [USFS] Organic Act of 1897), game populations, and biodiversity, along with prevention of forest conversion, invasive species, and severe wildfire. Persistence goals differentiate sustainable forest management from resource overuse and are fundamental to traditional management approaches.

The cost of restoration or persistence under changing conditions may become exorbitant and the results short-lived (Millar *et al.* 2007). Managers may therefore choose a transition-to-novelty strategy in order to adapt to current or anticipated environmental conditions (Hobbs *et al.* 2009; Joyce

Table 1. Examples of forest management goals and associated actions for achieving desired forest characteristics for restoration, persistence, and transition-to-novelty strategies (see WebTable 1 for references and additional examples)

Management strategy		Composition	Structure	Function
Restoration	**Goal**	Restore plant species diversity	Restore forest structure	Restore ecosystem functions
	Example action	Plant dispersal-limited tree species in Neotropical forest fragments	Thin to reduce conifer densities in western North America	Remove roads and dams for hydrologic connectivity in montane forests of southeast Asia
Persistence	**Goal**	Maintain tree species diversity	Maintain forest structure	Maintain forest functions
	Example action	Fence off seedlings to protect from browsers like the invasive red deer (*Cervus elaphus*) in New Zealand	Permit ungulate grazing to maintain open woodland, such as in central Europe	Selectively cut to maintain forest aesthetics in eastern hardwoods of North America
Transition-to-novelty	**Goal**	New tree species assemblages	New forest structure	New ecosystem functions
	Example action	Assist migration of tree species better adapted to current or future climate, such as northward movement of western larch (*Larix occidentalis*) in British Columbia	No removal of invasives that increase forest tree density, such as *Falcataria moluccana* in Hawaii and other Pacific islands	Plant genetically modified trees for faster growth to maximize production, such as *Populus* spp in China

et al. 2009). Transition strategies include assisted migration, acceptance of non-native species, and the planting of genetically modified trees, among others (Park *et al*. 2014). As with restoration and persistence management, transition management actions range from active to passive. For example, in assisted migration, populations or species are purposely moved beyond their current ranges in anticipation of predicted environmental conditions, whereas allowing non-native species to spread represents a passive approach that leads to transition (Waller *et al*. 2016).

Our restoration–persistence–transition-to-novelty framework builds on prior gradients for forest management, including the widely adopted USFS resistance–resilience–transition approach (USFS 2018a). This includes resilience (the capacity to recover from disturbance while retaining essential system features) as the midpoint of management strategies under climate change (Millar *et al*. 2007). We opted not to use resilience terminology in our framework, as "resilience" is a vague term, and some federal climate-change planners have suggested it is maladaptive because "any action may now claim to be one of 'resilience' in the name of adaptation" (Fisichelli *et al*. 2016). Instead, Fisichelli *et al.* (2016) proposed a gradient from resisting change to accommodating autonomous change to directing change. We build on these prior frameworks to advance terminology that ties strategies to desired forest conditions and separates changes that lead to ecosystem restoration or transition to novelty. Furthermore, we suggest that resilience can apply to restored or persistent forest characteristics, or after a transition to novelty has occurred. Our framework is applicable to global and regional changes beyond climate change.

Restoration, persistence, and transition-to-novelty strategies are not mutually exclusive. Managers may simultaneously restore one forest characteristic, such as diversity of native understory plants, while at the same time transitioning other characteristics to novel conditions, such as a new fire regime. Different viewpoints have resulted in passionate academic debates (eg single large versus several small reserves, land sparing versus land sharing, new versus old conservation), but have failed to provide meaningful conclusions and pragmatic management advice. Our framework highlights the potential for managers to bring together multiple strategies under changing conditions.

Factors influencing management choices

Many factors influence how organizations and individuals respond to environmental change and novelty with strategies that emphasize restoration, persistence, or transition-to-novelty. Key factors include private and public forest ownership and policy, the characteristics of forest managers, and the ecological features of lands and landscapes. Policy and management are part of the governance system, referring to the system of rules and political processes by which actors shape management choices. Management strategies and actions that shape forests are influenced by governance, socioeconomic, ecological, and climatic systems (Figure 2).

Private forest policy and management

Private lands are key for ecosystem services and biodiversity conservation (Kamal *et al.* 2015). Globally, only 14% of forests are privately owned, but in the US 56% are privately owned by over 11 million landowners (Siry *et al.* 2010). How private landowners respond to environmental change depends upon their values and goals, as well as their access to forest professionals, incentive programs, and local markets, among other factors. The diversity of private owners results in heterogeneous adoption of restoration, persistence, and transition-to-novelty strategies, with passive management being common. Private forest owners often assume that passive management will result in persistence of forest characteristics, but it can instead lead to transitions to novelty through succession, wildfires, and invasive species. Only 20% of family forest owners (owning 36% of private forests) in the US receive any professional advice about managing their land (Butler *et al.* 2016). Foresters advocating restoration- or transition-oriented silvicultural approaches must demonstrate to landowners their advantages over persistence-oriented prescriptions, as landowners may prefer status quo options (Wagner *et al*. 2000).

In contrast, Timber Investment Management Organizations (TIMOs) and Real Estate Investment Trusts (REITs) own about 5% of all forestland in the US and generally manage forests for timber production and investment goals (Bliss *et al*. 2010). Organizations with financial motivations may embrace transition-to-novelty if it promotes productivity. Investment landowners frequently manage with shorter rotations and may consider genetically modified trees, although a few investment owners are actively restoring forests.

Numerous state and federal policy tools, including financial incentives, property tax breaks, certification, and conservation easements, incentivize private forest management and typically favor restoration or persistence (Janota and Broussard 2008). These policies can mitigate harm due to forest conversion, invasive species, and genetically modified organisms, but they may also constrain transition-to-novelty options (Rissman *et al*. 2015).

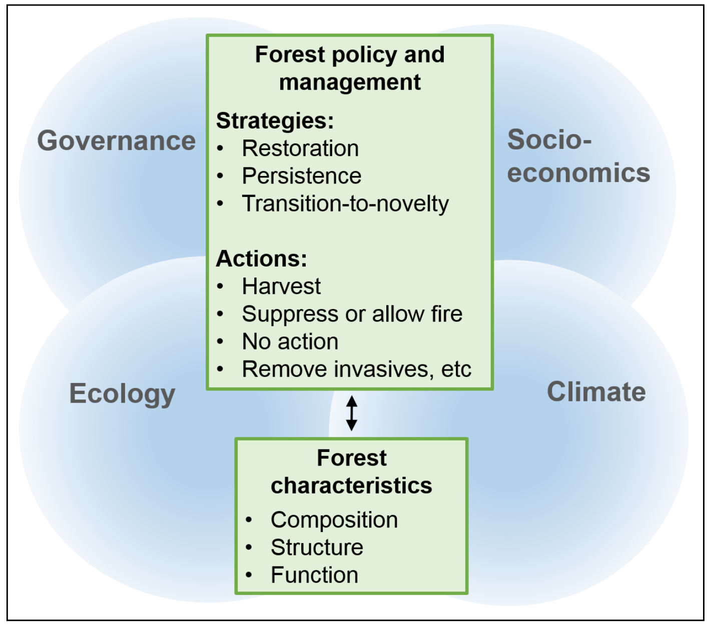

Figure 2. Forest policy and management strategies inform forest managers' actions, which influence (and are influenced by) forest characteristics. Forest policy and management occur in the context of social–ecological systems, including socioeconomic, governance, ecological, and climatic subsystems.

Public forest policy and management

Public agency approaches to forest management depend on their structure (eg laws, hierarchies, processes) and culture (eg norms, values, personal relationships) and on the input of stakeholders. According to research on organizational learning and change, agencies are more likely to adapt to changing conditions when they have clear missions and learning forums, employees have discretion to make choices, and employees do not have to avoid taboo topics (as climate change has become in certain organizations) (Berkhout *et al*. 2006; Moynihan and Landuyt 2009). Stakeholder demands for sustained ecosystem services, including timber, recreation, and water quality regulation, suggest an overall preference for persistence and restoration of current forest structures and functions, with the objective of increasing predictability and reducing variability. For instance, USFS regulations include having a goal to "maintain the diversity of plant and animal communities and support the persistence of most native species in the plan area" (USFS 36 CFR § 219.9). The formality of management goals varies by continent: thus, although 42% of forests globally have management plans, only 1% of African forests do (Siry *et al*. 2010). Natural resource agencies, like most bureaucracies, tend to be risk-averse and prefer to maintain the status quo (Wilson 1989). Restoration is also an accepted management strategy for public lands. A broad definition of restoration is central to the Healthy Forests Restoration Act of 2003 (https://bit.ly/2nEmlpb) and the 2012 USFS planning rule and its guidance directives (https://bit.ly/2nANrgG).

At times, public forest policy has promoted transition-to-novelty – largely to enhance timber yields – through the development of timber plantations, planting of non-native species, and the extensive use of herbicides, as well as unintentionally through fire suppression. However, intentional transitions to novel conditions can encounter policy-related and political barriers. For instance, national forests are often limited to stock from federally approved local seed zones, which can prevent the addition of trees with climate-adapted or pest-resistant genes (Millar *et al*. 2007), although the USFS Manual was updated in 2014 to recognize climate-change effects on restoration and seed sources (USFS 2018b). Managers may also avoid transitions to novelty that are likely to be contentious among stakeholders.

Limited management capacity is a major barrier to implementing management plans and experimenting with innovative strategies. Federal and some state natural resource agencies have experienced declining annual appropriations, workforce reductions, and loss of technical expertise (Brown *et al*. 2010). Some agencies are responding to disasters worsened by environmental change rather than prioritizing adaptation strategies. For instance, the cost of fire suppression for the USFS has increased sharply over the past decade, rising from 16% of the agency's budget in 1995 to over 50% in 2015 (Topik 2015; Steelman 2016).

Forest manager characteristics

On both private and public lands, forest managers have considerable discretion to implement management strategies on-the-ground. Their choices are influenced by psychological, cultural, and structural factors, including past choices, attitudes, social and professional norms, and perceived behavioral control, according to the "reasoned action" approach (Fishbein and Ajzen 2010; Primmer and Karppinen 2010).

Foresters pay attention to social and professional norms among diverse constituents (Primmer and Karppinen 2010). Information exchange via professional networks may increase

Figure 3. In response to the emerald ash borer (EAB, *Agrilus planipennis*) invasions of (a) black ash (*Fraxinus nigra*) wetlands in the midwestern US, managers may choose to (b) manage for black ash persistence by removing larger ash trees that attract EAB; (c) transition to a new mix of forested wetland species, such as planting tamarack (*Larix laricina*), northern white cedar (*Thuja occidentalis*), and American elm (*Ulmus americana*); or restore the ecological functions of forested wetlands through EAB-resistant ash.

forester willingness to try new practices (Knoot and Rickenbach 2014). In general, trained foresters prefer practices that have been tested over decades and may be hesitant to undertake transition activities until research and precedent demonstrate their benefits, which may reflect low perceived behavioral control (Lenart and Jones 2014). In the case of climate change, most foresters acknowledge that it is occurring and that it is human-caused (Lenart and Jones 2014), yet many barriers remain when it comes to carrying out practical adaptations (Laatsch and Ma 2015).

Ecological features of land and landscapes

The ecological features of forestlands influence management responses. If forest composition changes because current species have difficulty regenerating, a persistence-oriented intervention could improve regeneration of the current species (Holl and Aide 2011), or a transition-to-novelty approach could lead to the immigration of new species that regenerate more easily under anticipated future conditions. Important ecological features of forestlands that influence forest management responses include forest composition, climate, soil characteristics, the regenerative capacity of vegetation, provision of ecosystem services, disturbance regimes, development patterns, and spatial patterns of forest connectivity (Primmer and Karppinen 2010; Mwangi *et al.* 2011).

Forest function and species composition are among the most important ecological determinants of management responses. Preserving rare or endemic species and important ecosystem functions may encourage restoration or persistence strategies (Kareiva and Fuller 2016). To the extent that managers have flexibility in managing for certain tree species, keystone species and those that provide valuable ecosystem services are often higher priorities. For example, oaks (*Quercus* spp) are often a restoration priority because they provide valuable timber and wildlife forage despite their slow growth rates and regeneration difficulties in North American (Fralish 2004), Mediterranean, and Asian hardwood forests.

Broader landscape context is also important when deciding whether to restore, maintain, or transition communities (Hobbs *et al.* 2014). Small fragments of rare forest communities may be especially valuable, thereby leading to restoration or persistence strategies (Holl and Aide 2011). Conversely, lower quality forests in small remnants may be unsustainable due to their isolation, and transition to non-native species may be more likely. Scale plays an important role in shaping the feasibility and efficacy of forest management strategies.

Implications for policy, management, and future research

The science of ecosystems in steady states or in equilibrium that guided 20th-century resource and environmental policy is insufficient to deal with rapid environmental change and the increase in novel ecosystems (Radeloff *et al.* 2015), yet remains ingrained in policy (Craig 2010), management, and public expectations. Restoration, persistence, and transition-to-novelty strategies in non-equilibrium ecosystems will have important consequences for forest ecosystem services. Just as environmental change and novelty are occurring at an accelerating pace (Hobbs *et al.* 2009; Millar and Stephenson 2015), forest management budgets are declining as part of the defunding and decentralization of government functions (Milward and Provan 2000). These trends highlight the need for pragmatic approaches to achieve desired forest conditions.

Although this review distinguishes among restoration, persistence, and transition-to-novelty management strategies, we do not suggest that any one of these represents a "silver bullet". On the contrary, a combination of all three across a region, or within the same stand, may have the most widely appealing results (eg restore disturbance regimes and embrace novel species composition, or the reverse). The difficult choice is which forest characteristics to restore, maintain, or transition in the face of change. Management of emerald ash borer (EAB, *Agrilus planipennis*), fire in the Sierra Nevada, and restoration and timber production in southern US pine forests highlight how individual and combined strategies implemented in concert can be used to achieve specific goals within different social and policy contexts (see WebPanel 1 for additional details).

North American ash (*Fraxinus* spp) provides an example of choosing among management strategies to maintain ecological function despite native species declines (Figure 3). The EAB is poised to nearly extirpate native ash in the northern US and Canada (Iverson *et al.* 2016), and with it ash's critical ecological role as a water-table regulator and its cultural function in traditional basket making. A major experiment is underway in the Chippewa National Forest in central Minnesota to examine the effects of simulated EAB invasion and the effectiveness of replacing ash with southern-climate adapted species or non-native Manchurian ash (*Fraxinus mandshurica*), which is EAB-resistant (Looney *et al.* 2015). Alternatively, hybridization or genome editing with CRISPR (clustered regularly interspaced short palindromic repeats) technology could be used to produce EAB-resistant native ash. However, management is proceeding conservatively due to concerns about unintended ecological and political consequences.

Wildfire management in the Sierra Nevada of California demonstrates the difficulty of managing under an intense disturbance regime when all management options entail risks to people and forests (Figure 4). Wildfires in the Sierra Nevada were common prior to Euro-American settlement but have since been largely suppressed. Suppression and changes in climate have led to an undesirable novel state of increased understory fuel loads and higher risk of destructive, stand-replacing fires (Harvey *et al.* 2016). Restoration through managed wildfires puts human health and property at risk in both public and private forests, and mechanical fuel reduction is controversial. However, continued forest ingrowth promoted by suppression creates a heightened chance of stand-replacing fires, leading to undesirable transitions to shrub over large areas, extensive erosion, and loss of old-growth habitat. Restoring open forest structure and mixed conifer composition is desirable for ecosystem health and risk reduction, but restoration of these systems also has considerable drawbacks, including likely reductions in forest carbon storage (Chiono *et al.* 2017).

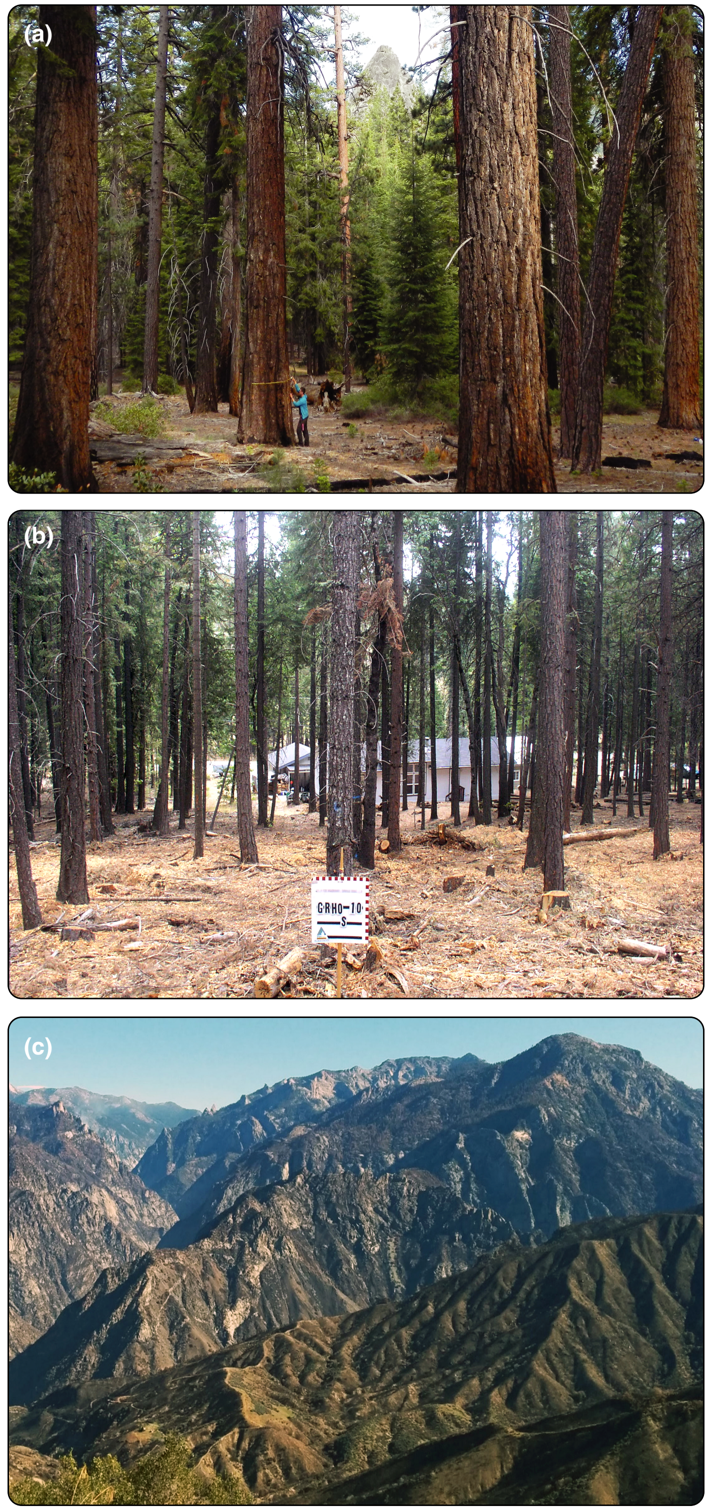

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Figure 4. Forests and fires in the Sierra Nevada mountains of the western US can be managed for (a) restoration through returned fire, (b) persistence of forest structure with controlled burning and mechanical thinning in the wildland–urban interface, and (c) unintentional transition to shrub and invasive grasses due to high-severity fire after years of fire suppression, such as after the 2013 Rim Fire.

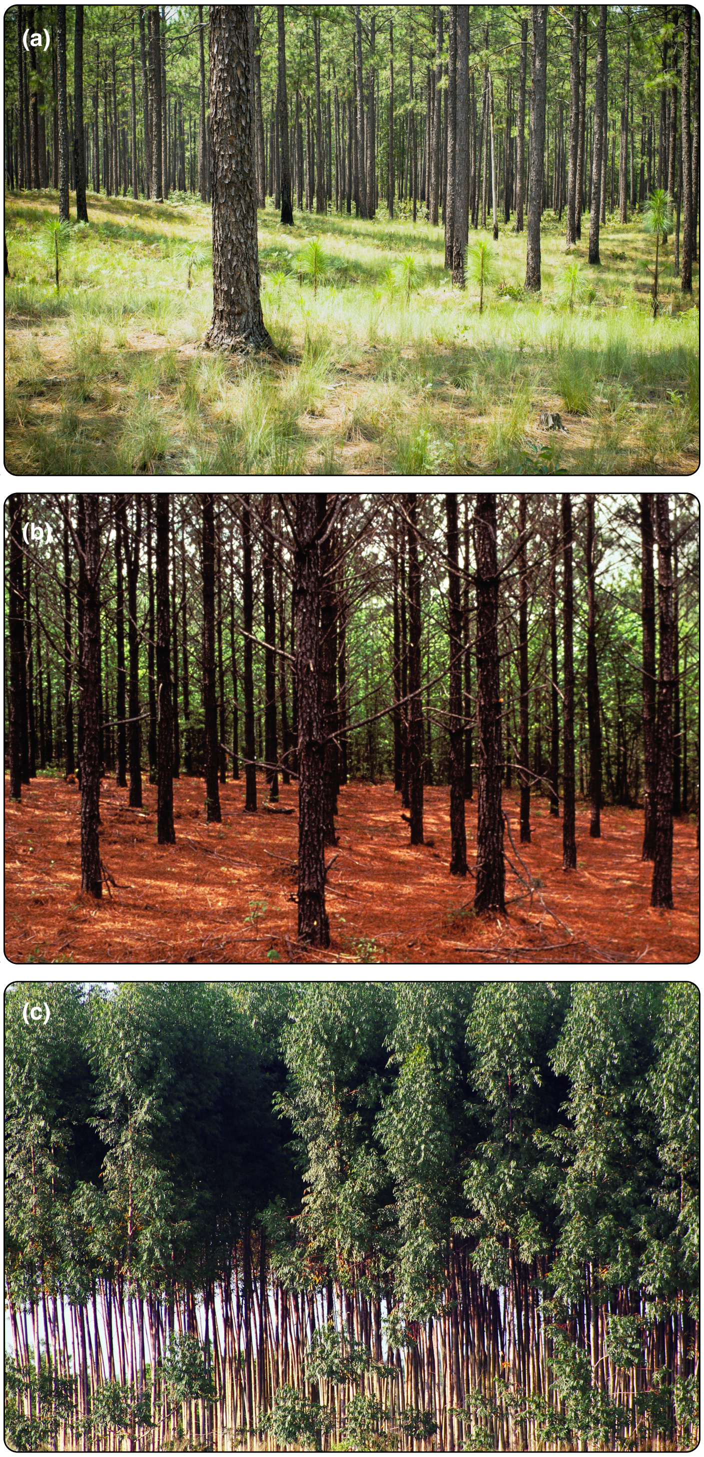

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Figure 5. Southeastern US forests are being managed for (a) restoration of longleaf pine (*Pinus palustris*), such as this North Carolina stand, and (b) persistence of loblolly pine (*Pinus taeda*) through herbicides and mechanical removal of understory vegetation, pictured here in Alabama, whereas others are considering (c) introduction of fast-growing eucalyptus genetically engineered or hybridized for freeze tolerance, as in this Florida plantation.

Restoration, persistence, and transition-to-novelty can reflect divergent approaches to timber production on private investment land (Figure 5). Longleaf pine (*Pinus palustris*) once dominated much of the landscape of the southeastern US but has been widely replaced with plantations of loblolly (*Pinus taeda*) and other native pines (Oswalt *et al.* 2012). Persistence of these pine plantations is the dominant strategy, with major federal research on maintaining planted pine under hotter and drier future climate conditions. Restoration of longleaf pine forests is also gaining traction, as longleaf forests produce timber and feature a low-intensity fire regime and diverse understory. In contrast, some industrial and investor owners are field-testing non-native *Eucalyptus* spp that have been genetically modified to improve their freeze tolerance, a biotechnology-driven shift to novelty that could replace pine plantations and provide biomass energy (Wear *et al.* 2015). In 2017, the US Department of Agriculture proposed allowing these *Eucalyptus* to be planted without regulation, although the genetic modification is ineffective, leading to renewed focus on hybridization (WebPanel 1).

Forest policies influence management choices and embed assumptions about what forest changes are acceptable based on social values and goals. Forest policy options include tax programs, cost-sharing incentives, forest certification, public land policies, fire management, silvicultural guidelines, conservation easements, and laws governing insect and plant pests. Additional relevant laws and regulations concern endangered species, wetlands, development, gene editing, and other overlapping sectors. Discussions about climate and environmental change have begun to influence these policies, but more flexible guidelines risk removing safeguards that prevent overharvesting, biodiversity loss, and development, leading to undesirable forest conditions. What is needed is a focus on adaptation that enhances desired forest conditions and prevents undesired conditions, as well as a transparent political process for defining these conditions. Many managers and rural landowners prefer constancy over change and may want to return to a more favorable past, whether real or idealized. However, the forest industry is rapidly changing, with an increased emphasis on multiple ecosystem services emerging in some places (Swanston and Janowiak 2012) and intensifying fiber and bioenergy production elsewhere, all against a backdrop of shifting ecological conditions. Programs that encourage collaboration between scientists and forest managers may help to successfully adapt forests to future change. Capacity for forest management, research, and collaborative stakeholder processes is essential, yet is strained by declining budgets. Allocations for extreme events should not reduce annual operating budgets; for instance, the wildfire-funding fix passed by the US Congress in 2018 will help prevent large wildfires from draining USFS resources. This is particularly crucial given the more frequent occurrence of large-scale disturbances (Millar and Stephenson 2015).

Whether forest managers restore, maintain, or transition forest ecosystems, or embrace a combination of these approaches, they cannot escape global change and novel ecosystems. Novelty can be unintended, or it can result from intentional forest management strategies, such as planting transgenic trees. The outcomes of management strategies involve many stakeholders across spatiotemporal scales. Clarity is needed regarding desired and undesired forest conditions, appropriate strategies for achieving those conditions, the trade-offs created by action and inaction, and relevant uncertainties. Managers must be explicit about communicating these trade-offs and uncertainties to stakeholders. If ecologists want to be successful in communicating with managers, we recommend recasting the somewhat abstract conversation around novelty to focus on concrete issues, such as disease, drought, fire, invasive species, genetics, and succession.

More resources are needed to help forest managers evaluate and communicate the drivers and potential outcomes of their decisions. Research should examine trade-offs among restoration, persistence, and transition-to-novelty in terms of species composition, ecological structure, ecological function, and ecosystem services. Critical questions for policy and management include: how much of the past will we bring into the future? To what extent will we intervene to prevent native species loss and novel species invasions? Will policy makers, managers, and stakeholders support substantive intentional transitions, for instance to plantations of genetically modified trees?

Our review presents a new framework for understanding forest restoration, persistence, and transition-to-novelty choices and the implications of those choices for diverse forest contexts. Moving beyond binary distinctions, we show how a combination of strategies is often more appropriate given a suite of social, policy, and ecological factors. Current management approaches that focus solely on persistence and restoration are unlikely to lead to desired forest conditions if ecosystem change and novelty are not directly addressed but to simply "embrace" novelty instead would ignore social and policy contexts and risk eroding support for forest conservation and management.

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References

Benayas JMR, Bullock JM, and Newton AC. 2008. Creating woodland islets to reconcile ecological restoration, conservation, and agricultural land use. *Front Ecol Environ* **6**: 329–36.

Berkhout F, Hertin J, and Gann DM. 2006. Learning to adapt: organisational adaptation to climate change impacts. *Climatic Change* **78**: 135–56.

Bliss JC, Kelly EC, Abrams J, *et al*. 2010. Disintegration of the US industrial forest estate: dynamics, trajectories, and questions. *Small-scale For* **9**: 53–66.

Brown G, Squirrell TG, and Harris CC. 2010. Growing organizational challenges for the US Forest Service: results of a longitudinal study in a period of major environmental change. *J Forest* **108**: 77–85.

Butler BJ, Hewes JH, Dickinson BJ, *et al*. 2016. Family forest ownerships of the United States, 2013: findings from the USDA Forest Service's National Woodland Owner Survey. *J Forest* **114**: 638–47.

Chiono LA, Fry DL, Collins BM, *et al*. 2017. Landscape-scale fuel treatment and wildfire impacts on carbon stocks and fire hazard in California spotted owl habitat. *Ecosphere* **8**: e01648.

Clewell AF and Aronson J. 2006. Motivations for the restoration of ecosystems. *Conserv Biol* **20**: 420–28.

Craig RK. 2010. "Stationarity is dead" – long live transformation: five principles for climate change adaptation law. *Harvard Environ Law* **34**: 9–73.

Dale VH, Joyce LA, McNulty S, *et al*. 2001. Climate change and forest disturbances. *BioScience* **51**: 723–34.

Ellis EC. 2015. Ecology in an anthropogenic biosphere. *Ecol Monogr* **85**: 287–331.

Fishbein M and Ajzen I. 2010. Predicting and changing behavior: the reasoned action approach. Hove, UK: Psychology Press.

Fisichelli NA, Schuurman GW, and Hoffman CH. 2016. Is "resilience" maladaptive? Towards an accurate lexicon for climate change adaptation. *Environ Manage* **57**: 753–58.

Fralish JS. 2004. The keystone role of oak and hickory in the central hardwood forest. In: Spetich MA (Ed). Upland oak ecology symposium: history, current conditions, and sustainability. Asheville, NC: US Forest Service Southern Research Station.

Grimm NB, Chapin III FS, Bierwagen B, *et al*. 2013. The impacts of climate change on ecosystem structure and function. *Front Ecol Environ* **11**: 474–82.

Harvey BJ, Donato DC, and Turner MG. 2016. High and dry: post-fire tree seedling establishment in subalpine forests decreases with post-fire drought and large stand-replacing burn patches. *Glob Ecol Biogeogr* **25**: 655–69.

Hobbs RJ, Higgs E, and Harris JA. 2009. Novel ecosystems: implications for conservation and restoration. *Trends Ecol Evol* **24**: 599–605.

Hobbs RJ, Higgs E, Hall CM, *et al*. 2014. Managing the whole landscape: historical, hybrid, and novel ecosystems. *Front Ecol Environ* **12**: 557–64.

Holl KD and Aide TM. 2011. When and where to actively restore ecosystems? *Forest Ecol Manag* **261**: 1558–63.

Holling CS and Meffe GK. 1996. Command and control and the pathology of natural resource management. *Conserv Biol* **10**: 328–37.

Iverson L, Knight KS, Prasad A, *et al*. 2016. Potential species replacements for black ash (*Fraxinus nigra*) at the confluence of two threats: emerald ash borer and a changing climate. *Ecosystems* **19**: 248–70.

Janota JJ and Broussard SR. 2008. Examining private forest policy preferences. *Forest Policy Econ* **10**: 89–97.

Joyce LA, Blate GM, McNulty SG, *et al*. 2009. Managing for multiple resources under climate change: national forests. *Environ Manage* **44**: 1022–32.

Kamal S, Grodzińska-Jurczak M, and Brown G. 2015. Conservation on private land: a review of global strategies with a proposed classification system. *J Environ Plann Man* **58**: 576–97.

Kareiva P and Fuller E. 2016. Beyond resilience: how to better prepare for the profound disruption of the Anthropocene. *Glob Policy* **7**: 107–18.

Klenk NL and Larson BMH. 2015. The assisted migration of western larch in British Columbia: a signal of institutional change in forestry in Canada? *Global Environ Chang* **31**: 20–27.

Knoot TG and Rickenbach M. 2014. Forester networks: the intersection of private lands policy and collaborative capacity. *Land Use Policy* **38**: 388–96.

Laatsch J and Ma Z. 2015. Strategies for incorporating climate change into public forest management. *J Forest* **113**: 335–42.

Lenart M and Jones C. 2014. Perceptions on climate change correlate with willingness to undertake some forestry adaptation and mitigation practices. *J Forest* **112**: 553–63.

Looney CE, D'Amato AW, Palik BJ, and Slesak RA. 2015. Overstory treatment and planting season affect survival of replacement tree species in emerald ash borer threatened *Fraxinus nigra* forests in Minnesota, USA. *Can J Forest Res* **45**: 1728–38.

Millar CI and Stephenson NL. 2015. Temperate forest health in an era of emerging megadisturbance. *Science* **349**: 823–26.

Millar CI, Stephenson NL, and Stephens SL. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecol Appl* **17**: 2145–51.

Milward HB and Provan KG. 2000. Governing the hollow state. *J Publ Adm Res Theor* **10**: 359–80.

Moynihan DP and Landuyt N. 2009. How do public organizations learn? Bridging cultural and structural perspectives. *Public Admin Rev* **69**: 1097–105.

Mwangi E, Meinzen-Dick R, and Sun Y. 2011. Gender and sustainable forest management in East Africa and Latin America. *Ecol Soc* **16**: art17.

Oswalt CM, Cooper JA, Brockway DG, *et al*. 2012. History and current condition of longleaf pine in the southern United States. Asheville, NC: US Forest Service Southern Research Station.

Park A, Puettmann K, Wilson E, *et al*. 2014. Can boreal and temperate forest management be adapted to the uncertainties of 21st century climate change? *Crit Rev Plant Sci* **33**: 251–85.

Primmer E and Karppinen H. 2010. Professional judgment in non-industrial private forestry: forester attitudes and social norms influencing biodiversity conservation. *Forest Policy Econ* **12**: 136–46.

Radeloff VC, Williams JW, Bateman BL, *et al*. 2015. The rise of novelty in ecosystems. *Ecol Appl* **25**: 2051–68.

Reid WV, Mooney HA, Cropper A, *et al*. 2005. Ecosystems and human well-being: synthesis. A report of the Millennium Ecosystem Assessment. Washington, DC: Island Press.

Rissman AR, Owley J, Shaw MR, and Thompson B. 2015. Adapting conservation easements to climate change. *Conserv Lett* **8**: 68–76.

Sample VA, Bixler RP, and Miller C (Eds). 2016. Forest conservation in the Anthropocene: science, policy, and practice. Boulder, CO: University Press of Colorado.

Siry J, Cubbage F, Newman D, and Izlar R. 2010. Forest ownership and management outcomes in the US, in global context. *Int For Rev* **12**: 38–48.

Steelman T. 2016. US wildfire governance as social–ecological problem. *Ecol Soc* **21**: art3.

Swanston C and Janowiak M. 2012. Forest adaptation resources: climate change tools and approaches for land managers. Newtown Square, PA: US Forest Service Northern Research Station.

Temperton VM, Higgs E, Choi YD, *et al*. 2014. Flexible and adaptable restoration: an example from South Korea. *Restor Ecol* **22**: 271–78.

Topik C. 2015. Wildfires burn science capacity. *Science* **349**: 1263.

USFS (US Forest Service). 2018a. Responses to climate change: what you need to know. www.fs.usda.gov/ccrc/education/responses-climate-change. Viewed 10 Jul 2018.

USFS (US Forest Service). 2018b. Forest service manual: silvicultural practices. 2474.02. www.fs.fed.us/dirindexhome/dughtml/fsm2000.html. Viewed 10 Jul 2018.

Wagner MR, Block WM, Geils BW, and Wenger KF. 2000. Restoration ecology. *J Forest* **98**: 22–27.

Waller DM, Mudrak EL, Amatangelo KL, *et al*. 2016. Do associations between native and invasive plants provide signals of invasive impacts? *Biol Invasions* **18**: 3465–80.

Wear DN, Dixon E, Abt RC, and Singh N. 2015. Projecting potential adoption of genetically engineered freeze-tolerant *Eucalyptus* in the United States. *Forest Sci* **61**: 466–80.

Wilson JQ. 1989. Bureaucracy: what government agencies do and why they do it. New York, NY: Basic Books.

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