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Silvicultural Decisionmaking in an Uncertain Climate Future: A Workshop-based Exploration of Considerations, Strategies, and Approaches

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Abstract

Land managers across the country face the immense challenge of developing and applying appropriate management strategies as forests respond to climate change. We hosted a workshop to explore silvicultural strategies for addressing the uncertainties surrounding climate change and forest response in the northeastern and north-central United States. Outcomes of this workshop included identification of broad management strategies and approaches for creating forests that can adapt to rapidly changing conditions. Four themes were prevalent in the discussion of coping with climatic change: recognize relationships between site conditions and species vulnerability, maintain and increase diversity, increase discussion about assisted migration, and place a greater emphasis on monitoring. In this paper, we draw on the workshop to outline a process for presenting information and engaging land managers in discussion of forest management challenges in an era of climate uncertainty.

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Increasing information about the magnitude, rate, and causes of global climate change has increased the urgency for managing natural resources in the face of tremendous change. Societal discussion of climate change has undergone a substantial shift from debating whether the scientific evidence for climate change is "real" toward more constructive dialogue about how to cope with shifts in climate and the ensuing effects. A similar transition of thought is occurring among forest managers, including those on national forests, who are seeking guidance on how to incorporate new objectives related to climate change into their management activities (Innes et al. 2009; Joyce et al. 2008, 2009). Although the ability of forest management to create forests that can both adapt to changing conditions and mitigate increases in atmospheric carbon dioxide is well recognized (e.g., Malmsheimer et al. 2008, Millar et al. 2007), the specific approaches to implement these activities at stand or landscape levels remain unclear.

The overarching challenge for coping with climate change, from a forest management perspective, is the great uncertainty regarding the *specifics* of future climatic conditions and how these conditions will influence management decisions at spatial and temporal scales relevant to managers. At the global scale, we have high confidence in certain effects of climate change. For example, global temperatures, sea levels, and rates of ice cap melting have all increased and will continue to rise (Solomon et al. 2007). Although the mean global temperature is projected to increase 1.8 to 4.0°C by the end of the century (Solomon et al. 2007), the magnitude of change that different regions of the globe will experience is less certain and depends on a number of factors. The most important driver of climate change is future anthropogenic greenhouse gas emissions (Solomon et al. 2007), but feedbacks from the global carbon cycle are also of great concern and may exacerbate warming (Cox et al. 2000, Torn and Harte 2006). Importantly, spatial scale and the uncertainty of future climatic conditions are inversely related, and the ability of climate models to make accurate predictions is reduced at smaller scales, such as continents or subcontinental regions (Schiermeier 2010). Although models continue to improve and methods exist to obtain data at finer spatial resolutions, it currently remains impractical, if not irresponsible, to predict future temperature, precipitation, and other climatic changes at scales most relevant to management, e.g., stand, watershed, and forest, without substantial caveats.

Despite the uncertainty of future conditions at finer spatial scales, there is a growing recognition that management decisions at those scales need to consider climate change (Lawler 2010). Climate model projections can at least provide insight into "trajectories" of change. Considering these trajectories along with their uncertainty encourages a deeper and more realistic discussion of the most appropriate management responses across a range of potential changes and interactions. For example, when considering climate trajectories and forest responses, will a given management objective be more likely to place an ecosystem at risk somewhere within the range of possible outcomes? Or, will the objective maintain or enhance ecosystem resilience under many possible outcomes?

Recognizing the need to address the new set of challenges introduced by climate change, we developed a process to (1) help silviculturists and other forest managers incorporate climate change as an additional consideration in silvicultural planning, and (2) explore strategies and approaches for creating forests that can adapt to rapidly changing climatic conditions. A hallmark of this process is acknowledging and embracing uncertainty in future conditions associated with climate change. Here, we present the results of a workshop where this process was deployed and refined and show how this process could be applied to forest management decisionmaking.

A WORKSHOP TO INCORPORATE CLIMATE CHANGE UNCERTAINTY INTO SILVICULTURAL PLANNING

We hosted a workshop to explore silvicultural strategies for addressing the uncertainties surrounding climate change and forest response. Silviculture was chosen as the focus discipline because it integrates forest ecology and management at the spatial scales where forest management decisions are implemented. Additionally, silviculturists are required to apply specific actions within the spatial and temporal scales where climate predictions are most uncertain. The 2-day workshop brought together more than 30 individuals from across the U.S. Most participants were U.S. Forest Service research ecologists and foresters, generally members of the Northern Research Station's Silviculture Working Group with expertise in silviculture. Other participants included silviculturists and ecologists from a number of national forests in the eastern U.S., regional Forest Service silviculturists and specialists, and university partners. The workshop was structured to include presentations on climate change science and potential responses of forests to climate change (Figure 1). These presentations, given by experts in their respective fields, set the stage for the workshop by establishing a common level of knowledge on climate change science for all participants regardless of their prior level of understanding.

The workshop also used a series of exploratory questions and scenarios to address forest management issues in the context of climate change (Figure 1). The process was iterative: a question was posed; participants addressed the question either individually or within small groups; answers were shared with the larger group; and varying levels of discussion and synthesis occurred during different stages of the workshop. Building upon ideas generated at each step, a more complex scenario and set of questions were posed to the groups, furthering the need to integrate both critical thinking and professional skills to solve complex problems at a variety of spatial scales. A final discussion and synthesis session ensured common understanding among the workshop participants about the outcomes of the workshop and helped identify strengths and weaknesses of the process employed.

WORKSHOP METHODS: QUESTIONS TO EXPLORE CONSIDERATIONS, STRATEGIES, AND APPROACHES

Workshop participants were asked three questions to encourage critical examination of potential climate change effects on silvicultural planning and to help focus discussion during each exploratory activity. The questions reflect the thought process a forest manager or planning team might use when embarking on a new project involving silvicultural activities. They begin with broad concepts and narrow to a focus applicable to stand and landscape scales and incorporate a continuum of management responses ranging from broad adaptation options to specific management tactics (Figure 2).

Question 1: What new or altered <u>considerations</u> does climate change bring to the process of making silvicultural decisions and devising strategies?

This question was posed during a short activity in which participants were first asked to create their own list of considerations that have changed as a result of incorporating climate change as a variable in forest management. The participants then presented these considerations to the full group, and all participants helped arrange the list of considerations into broad categories (e.g., disturbance, stress). The resulting list was not meant to be exhaustive, but rather initiated the more complex discussion of applying these considerations.

Question 2: What silvicultural <u>strategies</u> may be helpful or necessary in sustaining our regional forests in the face of climate change?

This activity was used to convey the importance of acknowledging the uncertainty of the future climate and incorporating this uncertainty into silvicultural planning. We asked participants to consider a variety of future climate scenarios selected to highlight the uncertainty in future climatic conditions. The climate scenarios projected different magnitudes of climate change by the end of the century (2070-2099) by using combinations of two different emissions scenarios developed by the Intergovernmental Panel on Climate Change and three different general circulation models (Table 1). Participants were broken into small groups and each

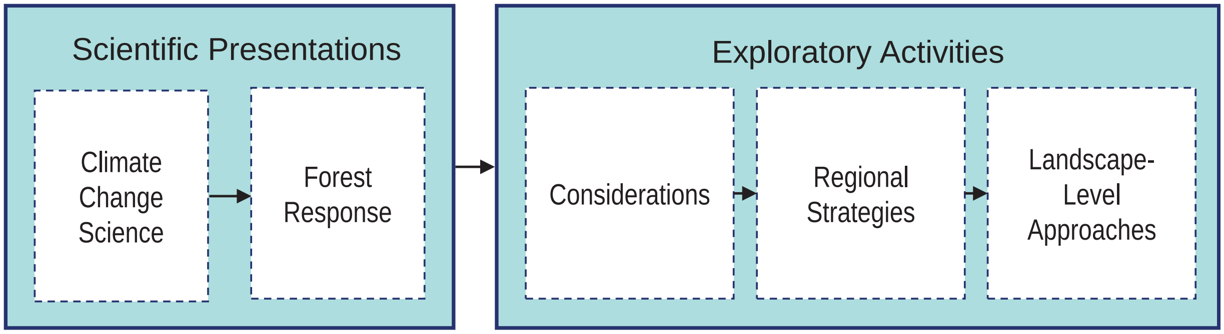

Figure 1.—Components of the silviculture workshop on climate change. The agenda included both scientific presentations about forests in the context of climate change and exploratory activities to determine climate change-related considerations and develop forest management strategies and approaches.

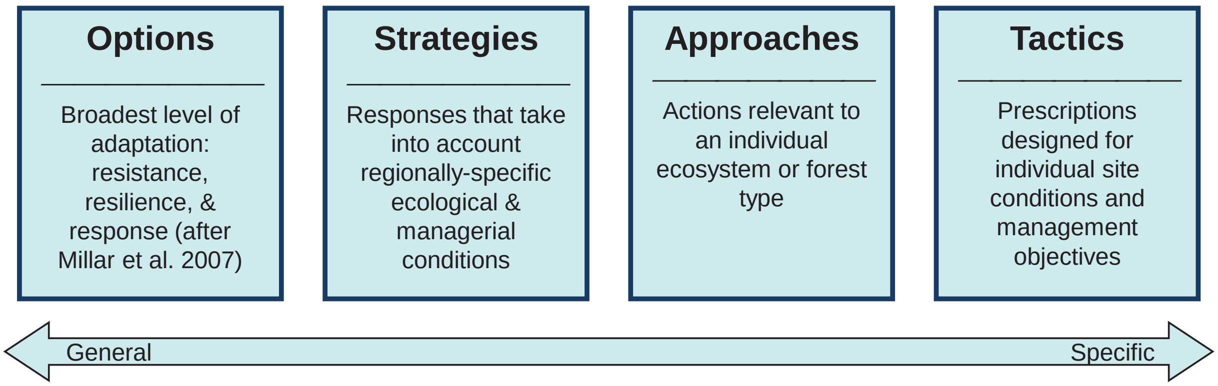

Figure 2.—Adaptation responses are relevant along a continuum of spatial scale and specificity. Adaptation options are the most broadly applicable, whereas tactics are the most specific to individual locations and conditions. Strategies and approaches (center) were the focus of workshop activities.

Table 1.—Materials provided for the exploratory activities of the workshop to develop regional strategies and landscape-level approaches for forest management in the face of climate change.

Exploratory Activity	Materials Provided	General Circulation Models (Emissions Scenarios)	Sources
Regional Strategies	Maps showing projected changes to summer and winter temperature and precipitation at the end of the century (2070-2099) for two climate scenarios (See Figure 3 for an example)	CSIRO (B1) HADCM (A2, B1) MIROC (A2)	R.P. Neilson, unpublished data
Landscape-level Approaches	Description of ecological subregion	--	McNab and Avers 1994
	Map showing ecological subregion	--	Created for workshop using data from USFS and USGS 2002 and USFS 2007
	Maps showing current annual temperature and precipitation	--	Prasad et al. 2007-ongoing
	Maps showing projected changes to annual temperature and precipitation at the end of the century (2070-2099)	PCM (B1) Ensemble of PCM, HADCM3, & GFDL (B1, A1fi) HADCM3 (A1fi)	Prasad et al. 2007-ongoing
	Potential changes in habitat suitability for each ecological subregion	PCM (B1) Ensemble of PCM, HADCM3, & GFDL (B1, A1fi) HADCM3 (A1fi)	L.R. Iverson, unpublished data

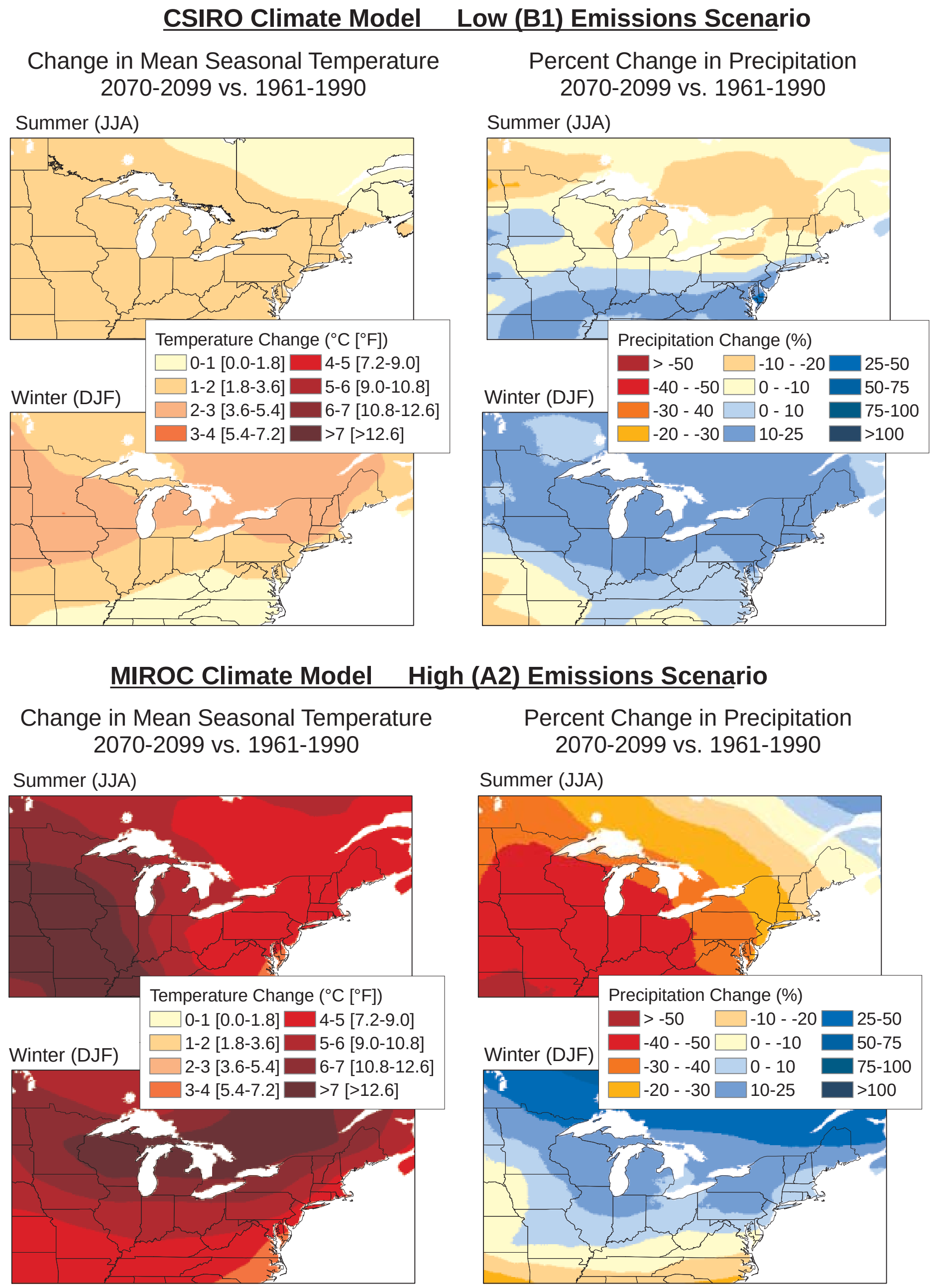

Figure 3.—Example showing two climate scenarios used in the silviculture workshop to develop regional silvicultural strategies for forest management in the context of climate change and uncertainty. These map sets present projected change in temperature and precipitation for the northeastern and north-central U.S. using two climate models and emissions scenarios, and they illustrate a range of uncertainty present among current climate predictions. Top: Projections using the CSIRO general circulation model and low (B1) emissions scenario represent a lesser degree of change in temperature and precipitation at the end of the century. Bottom: Projections using the MIROC general circulation model and high (A2) emissions scenario represent a greater degree of change in temperature and precipitation at the end of the century. Source: R.P. Neilson, unpublished data.

group was given a set of maps showing projected changes in summer and winter temperature and precipitation for two of the models (Figure 3). Groups were then instructed to identify silvicultural strategies that would be applicable across the northeastern and north-central U.S. for the range of uncertainty represented by the differences between the two scenarios. Each group developed four or five strategies and presented these to

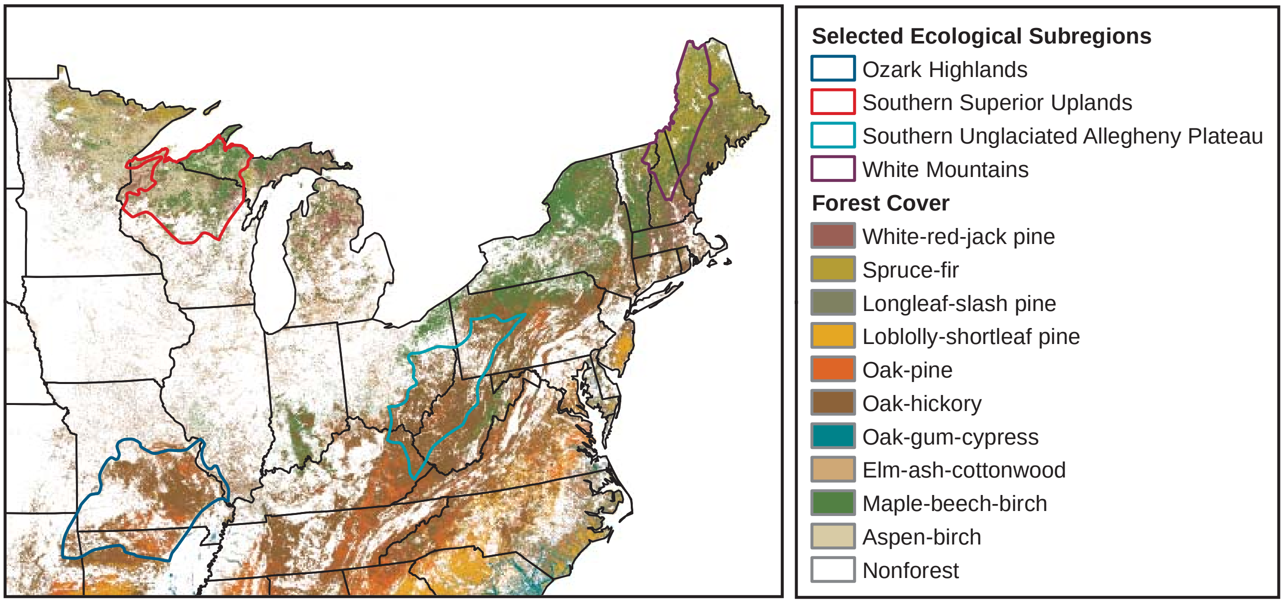

Figure 4.—Four ecological subregions in the northeast and north-central U.S. that were used during the silviculture workshop to develop landscape-level management approaches for forest management in the context of climate change. These ecological subregions are also used in Figure 5. (Data sources: USFS and USGS 2002, USFS 2007)

the full group, allowing ample opportunity for questions and discussion.

Question 3: Given the uncertainty of the future climate, what silvicultural approaches would you use to manage the forests within a specific ecological region?

This more complex activity sought to develop stand- and landscape-level management approaches by looking at specific forest types and conditions. Participants were divided into four groups and assigned an ecological subregion (McNab and Avers 1994; Figure 4). Each group contained a number of individuals with specialized expertise in silviculture and forest management for that ecological subregion, as well as a few generalists that were adept in forest management but did not have expertise in that specific location. Participants were given information on the ecological subregion and projected changes in temperature, precipitation, and potential changes in suitable tree species habitat at the end of the century for a number of climate models and emissions scenarios (Table 1). Information for tree species' habitat was summarized and tabulated for each ecological subregion using a subset of information from the Climate Change Tree Atlas, an online database that characterizes key features for the current distribution of 134 eastern tree species and models future potential habitat of each species under several climate models and emissions scenarios (Iverson et al. 2008, Prasad et al. 2007-ongoing, L.R. Iverson, unpublished data). With this information, participants were asked to select a few forest types common to their area of interest. For each forest type, they then described current conditions and management objectives that would be typical of the forest type in that location, discussed potential changes that could occur as a result of climate change, and developed silvicultural approaches for creating forests that would be able to adapt to the potential changes (Figure 5). Each group selected one example to discuss with the entire group.

WORKSHOP RESULTS: RECURRING THEMES ON FOREST MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE

Several concepts were repeatedly expressed during each of the workshop activities (i.e., considerations, regional strategies, landscape-level approaches) by both individuals and groups despite the spatial and conceptual differences inherent in the activities. During the first step of the workshop process described above, participants

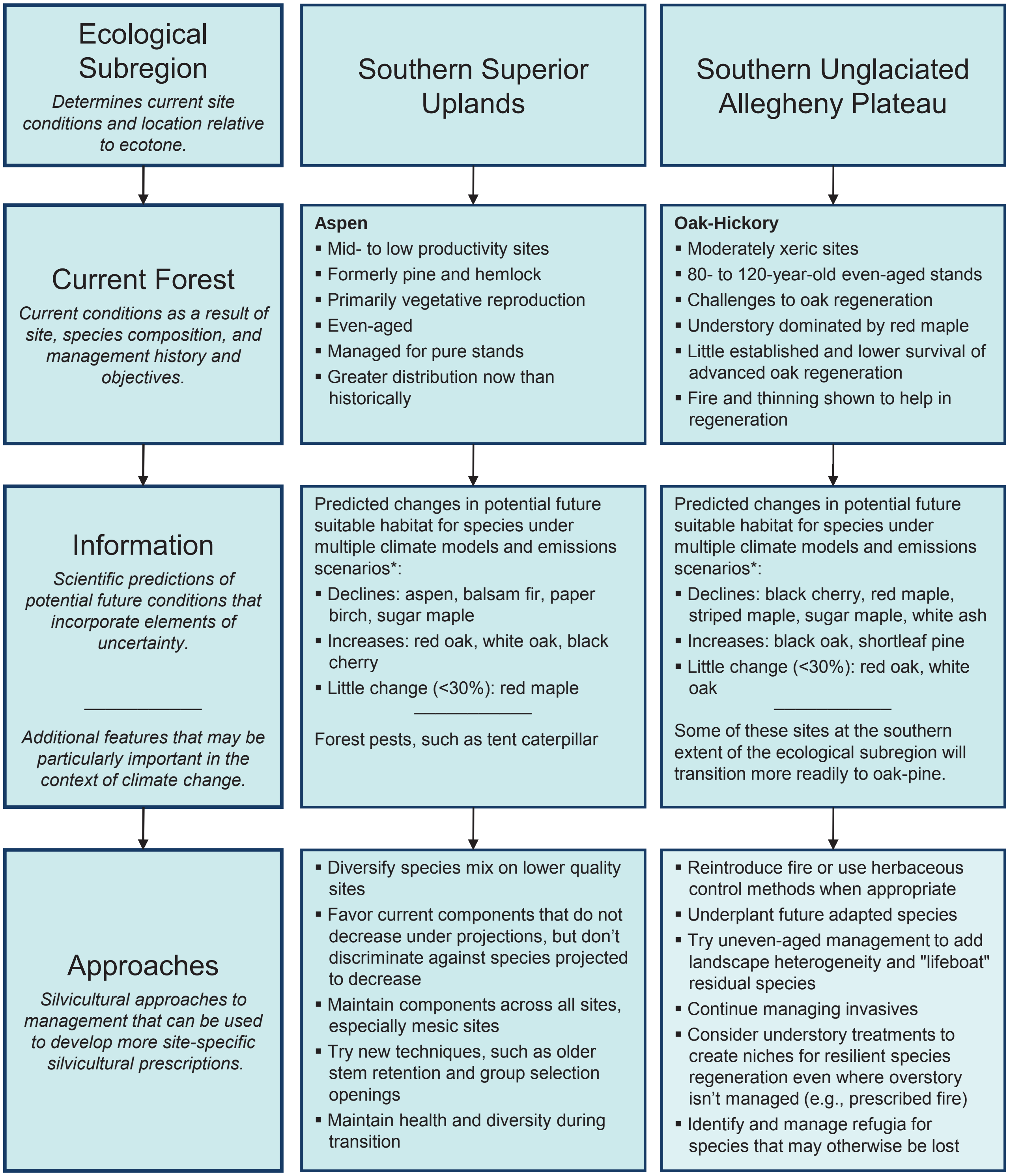

Figure 5.—Illustration of the general process that the silviculture workshop participants used to answer the question "Given the uncertainty of the future climate, what silvicultural approaches would you use to manage the forest that you have selected?" (left column), and two examples of the process using participant responses from the workshop (center and right columns). This process can be applied to developing management responses to climate change for a variety of sites and situations. (*Data used during this step at the workshop were from L.R. Iverson, unpublished data.)

brainstormed on how forest management may change in the face of climate change and grouped their responses into broad categories (Table 2). The resulting list of considerations included both ecological subjects (e.g., stand dynamics, phenology) and management-related issues (e.g., economics, desired future condition). Although the list did not include all possible answers, it did allow the participants to begin envisioning the potential changes that might occur in the future and to relate these changes to realistic management concerns. In the later steps, participants designed appropriate silvicultural strategies for the regional scale, followed by approaches for stand and landscape scales.

The varied backgrounds and levels of expertise of workshop participants elicited a range of responses during the development of silvicultural strategies and approaches. The silviculturists used their expertise of particular forest systems to make direct connections between current site conditions and projections of climate change. This was most evident where the workshop participants developed approaches for management at the stand- and landscape-levels (Figure 5). As a result, many of the responses (e.g., preferential treatment of species, use of thinning or prescribed fire treatments, plantings, invasive species control) were deliberately specific to a given ecological region, forest type, or set of management objectives.

At the same time, there were also many similarities among the proposed strategies and approaches. Four recurring themes emerged during the workshop, based on comments and ideas that were repeatedly expressed during all workshop activities. These themes spanned spatial scales (i.e., region to stand) and levels of management (i.e., strategic to prescriptive). We list these themes below and use them to organize key outcomes from the workshop on forests and climate change.

Recognize relationships between site conditions and species vulnerability. During the workshop, participants discussed the impact of climate change on specific tree species and potential habitats. The climatic, physiographic, biogeochemical, disturbance, and biotic factors that determine suitable habitat for a species are not static. Consideration of the relationships between these factors can help provide forest managers with information about the vulnerability of species to climate change. Extant tree and plant species have persisted through periods of substantial environmental change. Pollen records and other data for the past 20,000 to 50,000 years demonstrate that forest communities have not responded to climatic change as intact groups, but rather individual tree species have migrated independently to form new assemblages (Davis 1983, Webb and Bartlein 1992). However, it is important to note that community-level changes, such as decreases in overall resilience, may also occur (Hansen et al. 2001) and create feedbacks to species vulnerability.

Changes in tree species distribution may be most evident at the edge of a species range or biome where species would generally be expected to move to higher latitudes or elevations as temperatures increase (Hughes 2000, Parmesan and Yohe 2003, Walther et al. 2002). In the eastern U.S., there is already evidence of northward tree migration (Woodall et al. 2009) with projections that this trend will continue (Iverson et al. 2008). However, trees may also be affected well within their geographic range, albeit in specific landscape positions, as site conditions become less suitable due to heat, drought, or other stressors. When widespread, this may result in the decline of a species across a portion of its range, rather than the overall extirpation of the species.

Information on current and projected habitat suitability from the Climate Change Tree Atlas (Prasad et al. 2007-ongoing) and other modeling efforts can be used to examine trends over broad landscapes and determine where particular species may be most at risk. Silviculturists and forest managers in the northeast and north-central U.S. frequently work in forests composed of many tree species that have unique characteristics, including site and management requirements. Identifying potential changes in habitat suitability for tree species in general and even individual trees at specific sites in the future is an approach that could improve management at these locations. Tools such as the Tree Atlas are not designed to tell the manager what will happen, but they can indicate the relative potential for increased stress. By coupling these tools with ground-level assessments of site and stand conditions, managers can better judge the

Table 2.—Grouped responses of workshop participants to the question "What new or altered considerations does climate change bring to the process of making silvicultural decisions and devising strategies?" The short-phrase responses of the participants have been reworded into questions to provide more clarity and detail.

Disturbance

Will natural disturbance regimes be altered?

Will susceptibility to some disturbances increase?

How will fire and/or fire exclusion history affect disturbance susceptibility and frequency?

Migrating climates

Will forests be more vulnerable to increased weather variability?

What are the effects of predicted changes in temperature range and extremes? Water availability and timing?

Is the future trajectory of forest conditions the same or different under climate change?

How long is the lag between the present climate and the future climate?

Diversity

Is more variation needed to increase resiliency to change or disturbance?

Will community composition change in the future, either naturally or through human action?

How can you protect rare components of the ecosystem?

Hoes does the stand contribute to landscape diversity and resilience?

Habitat manipulation

Is the habitat suitability of preferred species changing/likely to change?

Is it possible to create a heterogeneity of habitats for species?

Stress

What stress factors are likely to become more prevalent (e.g., pests, diseases, drought, etc.)?

Competition

How will competitive relationships among species change?

Will there be increased competition from new species (e.g. invasives, off-site species, etc.)?

Can silvicultural practices be used to manage competition throughout the rotation?

Economics

Are there increased costs for needed silvicultural practices?

Are there new product markets that can be used for management?

Distribution

What is the forest's or stand's location relative to an ecotone?

What is the species' location relative to its current range boundaries?

Are there currently or could there be refugia at a specific location?

Management objectives and desired future condition (DFC)

Do the management goals, objectives, or desired future condition need to change?

Is the site prescription compatible with climate change predictions?

How much flexibility is there to change objectives?

Regeneration

Are there or could there be limits on germination and seedling survival?

Should artificial regeneration be considered?

Assisted migration

Is there a new or different species that is currently absent that could better meet DFC goals?

How do we bridge the gap between near-term and long-term adaptation given inherent species resiliencies and lag times?

Age structure

What is the relationship between tree species longevity and the rate of climate change?

Should a different rotation length be considered?

Is there a benefit to even-aged or uneven-aged management?

likelihood of future vulnerability. Management actions can then be implemented to reduce the risk of potential stressors and disturbance effects on the stand. Knowledge of species traits and future climate can also be combined to facilitate the transition of forest communities into new assemblages that are better suited to future climate. For example, foresters could make an effort to favor drought-resistant or heat-tolerant species that are currently present as minor components in stands to increase their occurrence in areas likely to see decreased precipitation and increased temperature with time.

Maintain and increase diversity. Maintaining and increasing diversity emerged as a central theme in the workshop as participants discussed management strategies and approaches for coping with climate change. The cascading pressures and disturbances driven by climate change may result in a loss of biodiversity in many forest ecosystems (Parry et al. 2007). Given these challenges, the participants of the silviculture workshop emphasized the importance of maintaining diversity throughout nearly all workshop questions and activities. This concept became a touchstone that was not limited to the number of species in a stand, but also included species associations, genotypes, stand structures, and ages.

Scale was also identified as a critical element of diversity, looking beyond the value of diversity in a single stand to examine diversity across a greater landscape (Franklin 1993). Increased diversity at all scales may increase the resistance of a forest against change (Noss 2001), and forests can be diversified to buffer systems and develop redundancy to spread the risks of environmental change, rather than concentrate them (Millar et al. 2007). Diversity at multiple scales may also enhance ecological resilience, strengthening the ability of forests to continue providing ecosystem services, such as water filtration and carbon sequestration, while systems are undergoing environmental change (Hooper et al 2005). Fostering this diversity would maintain components of forests for as long as possible, buying valuable time until more is known about how forests respond to climate change and until the adaptive management strategies that prove to be most effective can be implemented.

Increase discussion about assisted migration. Workshop participants elicited a range of thoughts on the use of assisted migration as a strategy for adaptation, emphasizing the need for more discussion on this topic. Overall, assisted migration remains a poorly refined and sometimes contentious issue (Mueller and Hellmann 2007). However, it must be considered as a management option given the potential for increased extinctions as a result of climate change (McLachlan et al. 2007). Natural migration of tree species to new habitats may not be able to keep pace with climate change because the rate of change will likely occur faster than it has in the past and landscapes are more fragmented now than when migrations occurred during previous climate shifts (Davis and Shaw 2001, Iverson et al. 2004).

The planned, active movement of plant species may be a logical solution to this problem, but would require major logistical effort, financial commitment, and social concurrence based upon incomplete information. Current uncertainty in climate and tree species range projections makes it difficult to predict the future habitat of species and decide where new assemblages should be located (McLachlan et al. 2007). Additionally, there are many challenges in trying to determine what effects these new species will have on their new host ecosystems; the great efforts put into detecting and eradicating invasive species in many forests make the idea of intentional introductions unappealing to many (McLachlan et al. 2007).

Even as this discussion continues within the management community, it needs to be broadened to include forestry stakeholders and the general public. People are accustomed to the current species mix present in any given location, whether from a management perspective (species-site relationships) or in a broader aesthetic sense. If undertaken, plans to incorporate assisted migration into management activities will need to be coupled with extensive efforts to educate the public on the role of these new species. The challenge will be to communicate the need to actively introduce new species into some forests, even as we exclude certain invasive species from the same ecosystems.

Lastly, in addition to the ecological, management, and aesthetic components of the discussion, a crucial and potentially insurmountable component will involve the logistics of assisted migration. An enormous investment in infrastructure would be required for this endeavor. In collaboration with climate scientists and ecologists, seed orchards, nurseries and other facilities will need to establish provenance tests, planting trials, and other research to determine which tree species and genotypes can be successfully moved into new locations. This infrastructure will also be required to provide the planting stock for species that are finally chosen for active migration and incorporated into new management plans.

Place a greater emphasis on monitoring. The need for additional forest monitoring to detect the effects of climate change on forests was stressed by many of the workshop participants. Although there are many forest monitoring programs, few have been designed specifically for monitoring climate change response. Existing programs typically occur at spatial or temporal scales that do not provide the resolution for detecting subtle changes in ecosystem function. Further, they may not be measuring the specific variables that are likely to be most responsive to climate change and extreme events. Finally, these established programs are generally designed to detect responses to specific management actions implemented to meet project objectives related to timber, habitat, recreation, water yield and quality, and ecosystem restoration.

Long-term silvicultural studies on experimental forests around the country may provide a particularly valuable and critical resource for understanding the impacts of forest management on natural resources in the context of climate change. Many of these studies include control treatments that allow comparison to responses in managed stands and measurements of at least some key response variables. A potential drawback of these studies is that the frequency of measurement (often at 5- to 10-year intervals) is typically too coarse to relate to annual variation in climate fluctuation or to provide insight into the impact of extreme events on ecosystems.

Focused climate change monitoring is essential for understanding the actual effects of climate change on forests and associated disturbances and impacts (Dale et al. 2001, Spittlehouse 2005). Key climate change response indicators should include measures of demographics (population establishment, growth, mortality), fecundity (cone, fruit, seed production), and phenology (flowering, vegetative development) that integrate information about environmental conditions driven by climate. Understanding and anticipating forest stress also requires information on the effects of extreme weather events, increased pest incidence, and other factors related to forest health and productivity (Dale et al. 2001). Long-term datasets tracking these types of variables are rare, yielding relatively little information on human-induced climate change impacts.

The appropriate monitoring system for detecting climate change response will need to target potentially vulnerable ecosystems, such as those near climatic and edaphic ecotones. Existing multifactor ecological classification systems, in use on most national forests, may provide a framework for selecting at-risk ecosystems and deploying a monitoring network. It will be especially helpful to integrate a combination of approaches into this monitoring system, including long-term silvicultural experiments, phenological data, and ecosystem carbon dioxide fluxes.

DISCUSSION

The climate change and silviculture workshop provided several insights on how to structure a process for developing forest management strategies while embracing the uncertainty of climate change (Figure 5). The uncertainty of climate change and future forest conditions at fine spatial scales can impede forest management planning and decisionmaking. We addressed this by describing the sources of uncertainty, distinguishing between uncertainty and inaction, and then exploring the concept of managing with climate uncertainty. The participants brainstormed using the breadth of their experience and expertise as silviculturists and managers; because there is no single answer or solution, they were able to suggest ideas that might be considered outside the box and too difficult or controversial to implement. Throughout the workshop, we made the point that "training" in the workshop was in both directions: we provided information and expertise on climate change, while we relied on the participants to provide viable management responses.

An additional strength of our approach outlined above is that it allowed us to take a large-scale global issue (climate change) and focus it down to spatial scales (forest and stand levels) most relevant to forest managers (Figure 1). Essentially, we were able to work with an issue that is often perceived as too large to be effectively managed, and break it down into manageable components by building on the participants' inherent localized knowledge and experience. The activity to develop silvicultural approaches for specific ecological subregions characterizes this method. It emphasized the finer spatial scales most frequently used for management, and it structured a process that could be applied to developing management responses to climate change in a variety of sites and situations (Figure 5). The progression of increasing complexity presented in this workshop could be used in additional workshops or meetings to elicit ideas and responses from a larger group of both managers and experts. These would be tailored to help land managers think about the management responses that are most applicable for their location and specific resource issues. For example, an abbreviated version of this process has been used in national silvicultural training for the U.S. Forest Service (Nagel et al. 2010).

SUMMARY

Climate change presents unprecedented challenges to forest managers. Silviculture and forest management are inherently long-view disciplines; managers need to consider the effects of their current actions on forest ecosystems many decades into the future. Including climate change in this decisionmaking process adds tremendously to an already complex task. Now forest managers must make their decisions in a "climate of uncertainty" regarding which species may be competitive and healthy in future decades and under unknown future climatic conditions, long after management actions are implemented. While many current forest management strategies are designed to increase ecosystem resilience and ensure long-term sustainability, climate change will require managers to develop new tactics and to implement techniques in different and possibly unexpected ways.

We have outlined a workshop-based process to explore considerations, strategies, and approaches meant to specifically help managers address the uncertainty of future climates and ecosystem responses. This process acknowledges that climate and ecosystems will change, but that the degree and magnitude of changes are poorly predicted at present. Despite this uncertainty, managers can devise broad strategies that anticipate a changing climate. Indeed, it is more important than ever for managers to consider the interdependence of ecosystem composition, function, and diversity at stand and landscape scales. This will lead to better prediction of ecosystem resistance to change and resiliency in recovering important ecosystem processes and functions in the face of these changes.

Existing frameworks for sustainable forest management in use by many agencies and organizations already acknowledge ecosystem interdependencies, and these also need to be used to provide information for emerging climate change strategies. Sustainable forest management concepts (e.g., promote diversity, encourage landscape connectivity, mitigate the effects of extreme disturbances) still fundamentally apply to managing forests in the context of climate change but will need to be approached somewhat differently. Forest managers do not have the luxury of waiting for explicit, science-based direction for managing forests in every landscape, on every site, and for all management objectives. Existing management techniques are applicable, and existing climate projections provide insight into future trajectories. It is the role of managers to combine these resources with their skills and experience to prepare forests for an uncertain climate future.

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Land managers across the country face the immense challenge of developing and applying appropriate management strategies as forests respond to climate change. We hosted a workshop to explore silvicultural strategies for addressing the uncertainties surrounding climate change and forest response in the northeastern and north-central United States. Outcomes of this workshop included identification of broad management strategies and approaches for creating forests that can adapt to rapidly changing conditions. Four themes were prevalent in the discussion of coping with climatic change: recognize relationships between site conditions and species vulnerability, maintain and increase diversity, increase discussion about assisted migration, and place a greater emphasis on monitoring. In this paper, we draw on the workshop to outline a process for presenting information and engaging land managers in discussion of forest management challenges in an era of climate uncertainty.

KEY WORDS: climate change, forest management, adaptation, silviculture

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