Mitigating Anthropocene Influences in Forests in the United States

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Abstract: *Anthropogenic and other climate changes, land use changes, forest structure changes, and introduced organisms are difficult to isolate with respect to their cumulative consequences. Similar changes have occurred before with undesirable effects and the currently high human population could suffer greatly if they happen again. Active forest management can help avoid dramatic, unfavorable changes. We can anticipate some effects from current geographic and weather patterns and forest ownership sizes, species compositions, and age class distributions. Less known are what foreign species might invade and cause trouble; how much forests will be converted to agriculture to replace the drying farm lands; and what wood demands, equipment, and incentives will be directed toward the forests. Many silvicultural activities can mitigate the undesirable effects of climate changes. The silvicultural expertise can be applied if the infrastructure of labor, equipment, and markets and the will of the people exist to support such activities with finances and legislation.*

THE ISSUES AND CONCERNS

Changes to forests during the Anthropocene are difficult to isolate between those generated by human-induced climate changes, land use changes, and movements of species. And, in fact, all three factors may be involved. It is also difficult to separate human-induced changes from those that would happen even if people never existed. Many of the dramatic changes today have been preceded by analogous events:

- About 30 species of large mammals became extinct in North America about 5 to 2 million years ago, destroying the "American Serengeti" presumably as a result of rapid climate change (Flannery 2001);
- Between about 10,000 and 6,000 years ago, species in North America moved northward roughly at a rate of 25 miles per century. A fir species separated into two genera—balsam fir (*Abies balsamea* (L.) Mill.) and Fraser fir (*Abies fraseri* (Pursh) Poir.)—as some individuals moved up the Smokey Mountains and others moved northward to Canada. Undoubtedly,

some species became extinct. And, others remained in topographically cool “refugia” far south of their contiguous ranges.

- Species have been moving to new continents for millions of years, with the raven family now occupying all continents (Flannery 2001), for example.
- Native species have created local epidemics, such as the pine butterfly (*Neophasia menapia menapia* C. Felder & R. Felder) which killed old growth Ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) trees over 150,000 acres in eastern Washington in 1893-1895 (Scott 2012).
- Extreme hurricanes and ice storms have impacted many forests throughout the eastern United States for over 400 years (Oliver and Larson 1996).

People have also dramatically changed North America’s forests for several thousands of years. Many North American mammal species became extinct after people colonized America after the last glacial maximum—the saber-tooth cat, flat-nose bear, North American camel, and others. The eastern United States has undergone extensive forest clearing for agriculture before Europeans arrived, re-expansion of forests when the native populations declined, re-clearing when English colonists occupied the land, and re-expansion of forests in the 19th and 20th century as agriculture moved west (Mann 2005). Such land use changes also cause extinctions. These earlier changes indicate what can happen again. Even if future changes are no worse than previous ones, there is still reason for concern and for action to prevent further human hardship and loss of forest values. The values at risk referred to in this paper include the “Criteria of Sustainability” (Guldin 2008).

This paper will address ways of ensuring that forests of the contiguous United States continue to function and so provide the many values in light of recent and anticipated Anthropocene changes. Fire-prone forests of the interior western United States are also being addressed elsewhere in this general technical report. Vose and others (2012) have also addressed the United States forest changes in detail. The activities targeted to the forest are under the discipline of “silviculture.” However, silviculture can only be done in appropriate coordination with other disciplines. This paper will address:

- Anticipated changes in forest behavior with continued climate and other changes;
- Other human responses to climate change that may affect forests;
- Specific silvicultural activities that can be done to maintain forest values and functioning;
- The importance of other influences needed to ensure the success of silvicultural activities.

ANTICIPATED FOREST BEHAVIOR WITH CLIMATE CHANGE

Based on the past climate warming of about 10,000 years ago, North American plant and animal species can be expected to move to cooler climates both to the north and at higher elevations as the climate warms. Previously, the species’ contiguous ranges moved northward at a rate of about 25 miles per century (Davis 1981) or to higher elevations at the same latitude at about 130 feet per century (Hopkins 1920).

At the same time, the world is already entering a period of drying at lower latitudes caused by more intensive equatorial sunlight, based on orbital patterns (Milankovitch Cycles; Pielou 1991) and has caused the shrinking of forest areas and the change of the Sahara and Arabian grasslands to deserts during the past few thousand years. The earth is expected to re-enter a period of cooling at the poles caused by less intensive sunlight there sometime within the next few thousand years; and Pielou (1991) has suggested that polar species may already be migrating southward. At about the same time, we would ordinarily expect continental glaciers to form and expand over Canada and northern Europe, sea levels to recede, and a cooling of the earth including low latitudes. If/when this glacial expansion occurs, the world's forest and cropland area will shrink to a relatively narrow belt between cold polar temperatures and arid, cool equatorial climates.

It is uncertain if the recent climate changes are the beginning of this broader cycle. And, it is uncertain if the human-induced climate change will prevent the continental glaciers from forming. This paper will consider the northward migration of species in the United States, but not consider the southerly migration of species in Canada—or the overall southerly migration of species if the continental glaciers begin to form. It will be important to monitor the possibility that such changes could occur.

Plant species do not migrate as communities. That is, species found together as a community at one latitude now were probably not together at a lower latitude when the climate was cooler and will probably not be together at a higher latitude in the future (Davis 1981). Instead, a plant community is simply an assemblage of plants that are migrating from and toward different places, but happen to be in the same location when observed. Plant species migrate simply by individual seeds becoming established and outcompeting other species at a given time and place. Plant movement occurs

Figure 1. The unusual mixture of Douglas-firs (*Pseudotsuga menziesii* [Mirb.] Franco), mountain hemlocks (*Tsuga mertensiana* [Bong.] Carriere), and Pacific silver firs (*Abies amabalis* [Douglas ex Loudon] Douglas ex Forbes) growing together at 3,000 feet elevation in the North Cascades of Washington is a result of the different climates when each species became established (from Oliver and others 1985). 1) Foreground Pacific silver fir, 5 ft tall, 110 years old became established at a slightly cooler climate than present. 2) Tree to right of center is mountain hemlock (growing about 1000 ft lower than it usually germinates at present) about 200 years old (established during Little Ice Age). 3) Large Douglas-fir person is leaning on typically becomes established about 1000 feet lower at present and is about 800 years old, established during the Medieval Warming period. (Photo credit. C. Oliver)

primarily after a disturbance, when growing space is available for the plant to become established in the new location. Plant survival during germination and initial growth seems quite sensitive to climate; and, long-lived trees that begin growing under one climate can survive in the same place even after the climate has changed. Many tree species may actually be living in places where they can no longer become established (Brubaker 1986; Figure 1).

Species can become established on favorable slopes—sunny slopes in the cool, northern end of the range and shady, north slopes in the southern end. Species also become established at slightly higher and lower elevations in response to climate changes. The opportunistic nature of plant establishment and migration means a species' range may fragment if some individuals move to higher elevations, others move northward, and some remain as isolated "refugia" on favorable microsites. These fragmented habitats can lead to the isolated groups evolving along such different trajectories that they become different species—the "species pump" concept (Huston 1994).

The current warming of climates tends to force species northwards, especially on gentle terrain and where mountain ranges lie north-south (Figure 2), as in much of North America (Flannery 2001). Here, the species can easily migrate to more amenable locations slightly to the north. Other factors tend to keep species positions more stationary (Figure 2). A mountain range can keep a species nearly stationary as it moves slightly uphill to re-establish in a cooler climate (with 400 feet elevation having a similar climate change to 70 miles of latitude; Hopkins 1920). Some species that move up mountains to cooler climates may eventually become isolated in "Sky Islands" similar to those in the Southwestern United States (Warshall 1995) and possibly in the Smokey Mountains; and, species may be eliminated if the mountain is not tall enough to provide suitably cool climates.

The generally North-South mountain orientation in the United States allows species to move latitudinally quite readily with climate change; however, steep east-west valleys along the Pacific Coast have prevented—and may continue to prevent—species migrations northward (A, Figure 2). The

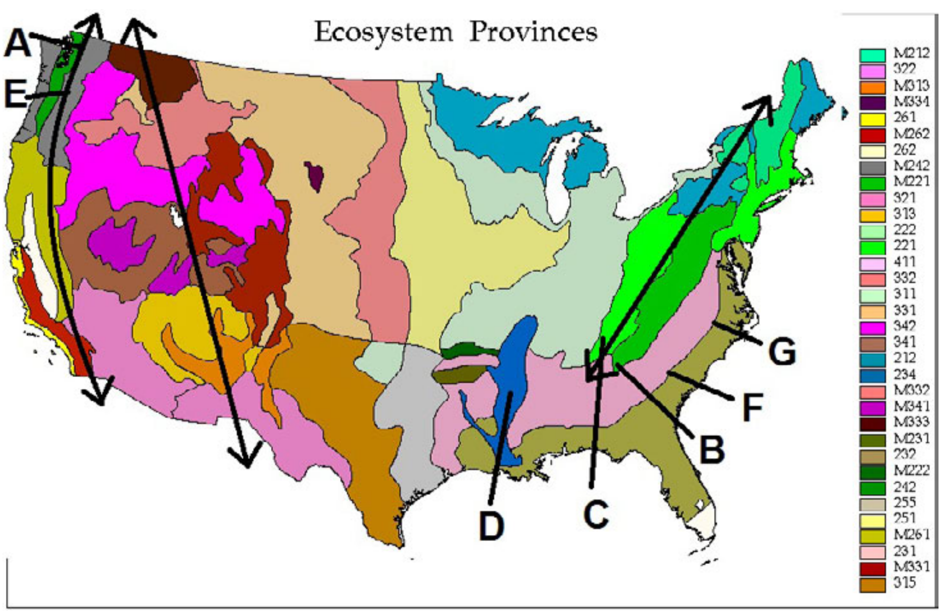


Figure 2. Features affecting species movement and stability in the contiguous United States, overlain on Bailey's Ecosystem Provinces (Bailey 1995). (Letters refer to discussions in text. Arrows show north-south orientations of mountains.)

east-west valleys of the Pacific Coast may explain the region being a "biodiversity hotspot" (Myers 2000) with global concern over the extirpation of species.

Mountain ranges also affect rainfall patterns, cold periods, and ice storms. The orographic precipitation belt at the southeastern base of the Smokey Mountains (B, Figure 2) will probably not move with climate change. And freezing rain storms will probably continue at the Cumberland Plateau (C, Figure 2). Similarly, the Mississippi River and its floodplains may continue to be a barrier to the east-west migration of species (D, Figure 2). And, the crest of the Cascade and Sierra Ranges (E, Figure 2) will probably continue to create a division between humid ecosystems to the west and arid ecosystems to the east.

On the other hand, the freezing rain belt that limits slash pine's (*Pinus elliottii* Engelm.) northern range in southern South Carolina (F, Figure 2) may move northward (Baldwin, 1973). The sandy soils (Sand Hills) of the upper coastal plain (G, Figure 2) in the southeastern United States will not move, and so longleaf pines (*Pinus palustris* Mill.), scrub oaks, and other species well adapted to those soils will probably not move northwestward into the adjacent, clay soils; however, species may move farther north within the Sand Hills. Similarly, species adapted to floodplains may move northward within floodplains, but not move to other soil types very much.

The above description suggests that some species changes can be anticipated; however, it is impossible to predict all changes—especially behaviors of insect and disease pests such as the pine butterfly-bark beetle outbreaks in the Pacific Northwest (Scott 2012), or the native bark beetle outbreaks with warming climate in central British Columbia (Astrup and others 2008).

Ideally, we would monitor the forests and facilitate the migration of each species to more suitable areas; however, the overwhelming numbers of species would make such an endeavor impossible. Alternatively, we can focus on the viability of all ecosystems—the "coarse filter" approach to biodiversity conservation (The Nature Conservancy 1982)—recognizing that they will reorganize with different component species in the future. As they reorganize we can reclassify the ecosystems and concentrate on maintaining their viability. If all current and future ecosystems are viable, it is highly likely that most species will also be viable, although differently arranged. We can also monitor a subset of key species of trees, herbaceous plants, and animals to ensure they are thriving—the "fine filter" approach to biodiversity conservation (The Nature Conservancy 1982).

NON-FORESTRY POSSIBLE HUMAN INFLUENCES

A concern is that a unique ecosystem may become extremely small, resulting in component species become exterminated by chance local events. On a coarse scale, this concern is probably not substantive in the eastern United States. Most ecological provinces in the eastern United States contain over 50% of their areas in forests (Bailey 1995; Figure 3 and Table 1); consequently, much of the issue will be ensuring the forests are in appropriate condition, rather than creating forests. Exceptions are the Eastern Broadleaf Continental Forest and the Lower Mississippi Riverine Forest, both of which have been extensively cleared for agriculture; and the Everglades, which may always have had lesser amounts of forests. The Lower Mississippi Riverine Forest province is of special concern because it is a small area to begin with; and the Ozark Broadleaf Forest-Meadow and Ouachita Mixed Forest-Meadow provinces are also small and, although currently forested, will need attention to avoid their extirpation of species. The Everglades is already receiving attention,

Table 1. Ecosystem province names and abbreviations used in Figure 3 (Bailey 1980).

Ecosystem province name	Abbreviation
Laurentian Mixed Forest Province	212
Adirondack-New England Mixed Forest—Coniferous Forest—Alpine Meadow Province	M212
Eastern Broadleaf Forest (Oceanic) Province	221
Central Appalachian Broadleaf Forest—Coniferous Forest—Meadow Province	M221
Eastern Broadleaf Forest (Continental) Province	222
Ozark Broadleaf Forest—Meadow Province	M222
Southeastern Mixed Forest Province	231
Ouachita Mixed Forest—Meadow Province	M231
Outer Coastal Plain Mixed Forest Province	232
Lower Mississippi Riverine Forest Province	234
Everglades Province	411

and the Eastern Broadleaf Continental Forest and the Lower Mississippi Riverine Forest provinces may be difficult to address because increasing the forests here will shift agriculture to larger areas of less productive soils.

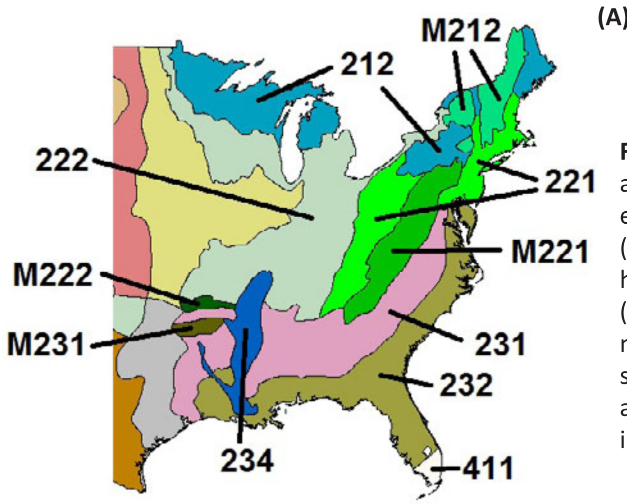
Extensive clearing of some eastern forests for agriculture could occur if the Ogallala aquifer providing irrigation for the "farm belt" in the Great Plains dries up with climate change. Irrigation and modern farming techniques could make eastern forests productive for agriculture, but would create problems maintaining extensive forests and their values.

The eastern forests are already fragmented with highways, cities, and farmlands that make migration difficult for plant and animal species. Such issues as connectivity to allow migration with climate change will need to be addressed (Redondo-Brenes 2007).

Some introduced species become benign parts of the ecosystem, while others are more harmful because they eliminate some native charismatic tree species and restrict the ranges of others. Problems with these harmful introduced species is increasingly creating problems both in the United States and abroad as increased global trade is moving more predators to locations where the hosts are not resistant. As the number of tree species in an area declines, the food diversity of animals also declines. It is uncertain if the overall behaviors of these introduced species will create different kinds of problems as the climate changes. Native species may also exhibit different behaviors with a changed climate (Warren and Bradford 2014; Urban and others 2012), and currently benign species may aggressively displace their long-time neighbors.

SILVICULTURAL ACTIVITIES TO MAINTAIN FOREST VALUES

Two features of the forest are highly important to monitoring, sustaining, and possibly facilitating migration of species: current and future condition of the forest and our ability to manipulate the forest. Figure 4 shows the recent age class and diameter distributions of the U.S. forests in different regions (Smith and others 2009). Figure 4 also shows the mean global temperature when each age class became established (Soon 2005). To the extent that species are most compatible with their climate at the time they initiate as discussed earlier, Figure 4 shows which age classes—and



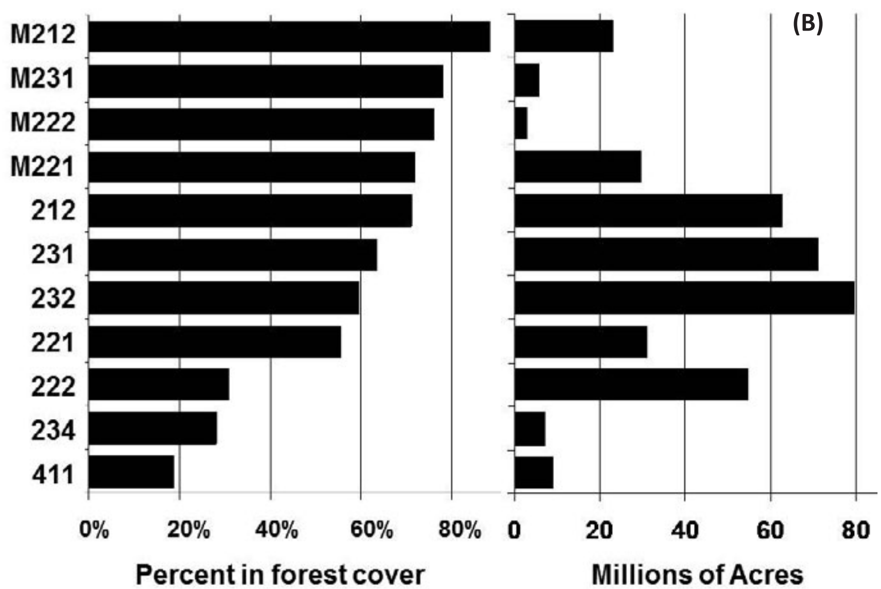


Figure 3. Locations **(A)** of ecosystem provinces and forest proportions and areas **(B)** within each province in the eastern United States (Bailey 1983, 1995). Only a few ecosystems have small proportions or areas of forests. (Unlike eastern forests, western forests are not continuous, but are mixed with natural shrublands, grasslands, deserts, and alpine areas.) (See Table 1 for key to letters/numbers in Figure 3.)

which proportions of each region's forest—are living in compatible and incompatible climates. The 40-to-80 year age classes became established during the warm period in the first half of the 20th century when the climate was somewhat similar to present; consequently, plants in these forests may survive well in the warming climate. Forests less than 40 years old and over 80 years may be more vulnerable to the warming climate because these forests became established when the climate was cooler. Consequently, much of the western forests are growing in climates much warmer than they began in, and so may not be physiologically well adapted. Older forests in the North also may be out of synchrony with their climate, but nearly all forests in the South, being young, began in warm climates similar to the present and anticipated future.

The forests in each region will probably be most resilient to loss of functioning with climate change if they are maintained in a diversity of stand structures (Oliver and Larson 1996; Figure 5). Since each structure supports many, different species (Oliver and O'Hara 2004), the diversity means that large, uniform populations of native hosts or pests are less likely to develop. The variety of structures also makes the forests less susceptible to catastrophic fires and more suitable for water

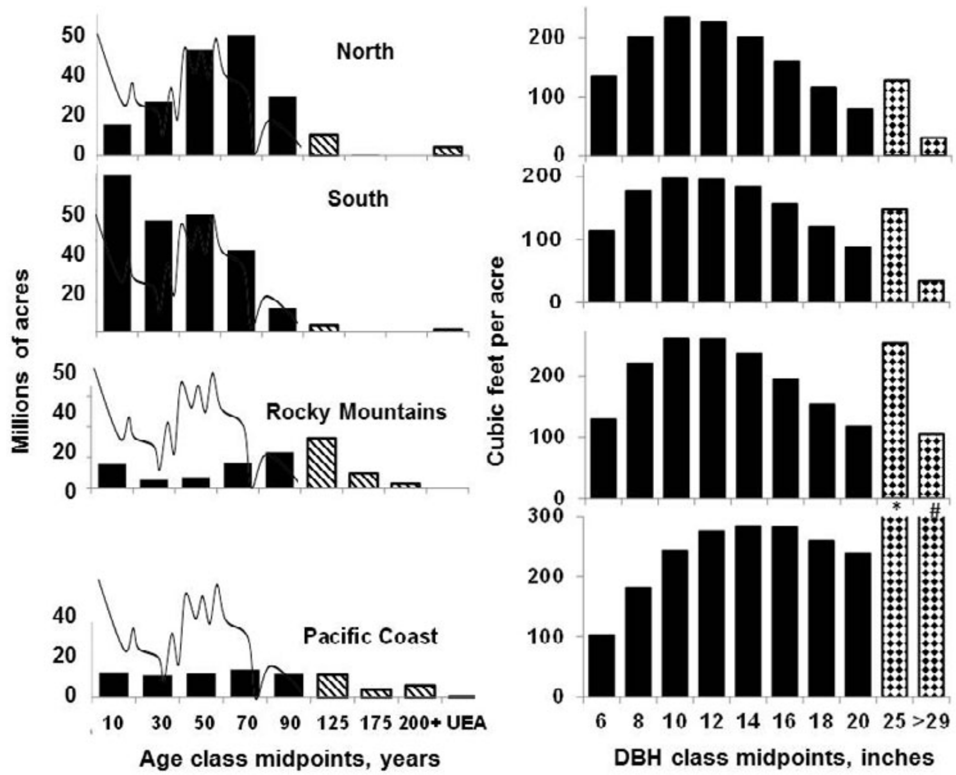


Figure 4. Distributions of forest age and diameter classes in the four major forest regions of the contiguous United States (Smith and others 2009). Line graph (Soon 2005) superimposed on age classes shows relative temperature compared to present (far left) when each age class initiated. ("UEA = uneven-age; "*" and "#" indicate even higher volumes than shown.)

infiltration. Open and savanna structures evapotranspire less water than the other structures that have more leaf area; consequently, more water flows through the soil to aquifers or streams. And, the constant need for "open" and "savanna" structures gives opportunities for available growing space where species can become established and thus migrate to more suitable climates.

Each structure also will have issues that will need silvicultural attention with climate change. The older, understory and complex forests may contain trees that are physiologically weakened by the warmer climate and/or susceptible to associated storm or other weather patterns. On the other hand, these forests are needed by some animals and plants. And, these structures take a long time to replace. It may be appropriate to focus especially on protecting those old forests in cool and moist topographic positions. And, it may be appropriate to remove old forests where their demise may provide a human hazard, such as alongside roads where wind and ice storms can destroy power lines and block roads. It may be appropriate to begin planning areas of future old forests within the cooler parts of the current tree ranges, as permanent "reserves" while the younger forests are managed to respond to climate change (Seymour and Hunter 1999). This planning may give an opportunity to promote understory and complex forests in the Southeast, where relatively few of them currently exist.

All regions contain many crowded stands of small diameter trees in the dense structure (Figure 4; see also Oliver 2002). These crowded stands pose problems of insect and disease infestations and

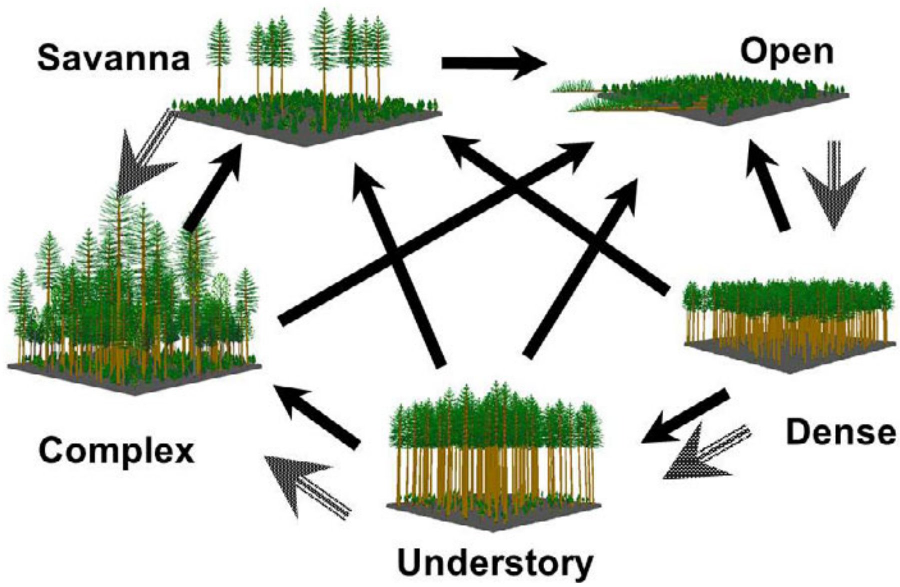


Figure 5. Forests naturally contain stands in a variety of structures that change with growth and disturbances. Each structure provides habitat for some species, so a forest maintains the most diversity—as well as being resilient to catastrophic disturbances and climate change—if all structures are maintained (Oliver and Larson 1996).

subsequent fires, especially in conifer stands. Monitoring and thinning these stands can maintain these stands and avoid the catastrophes.

The savanna and open structures are among the structures that contain the most species (Oliver and O'Hara 2004). Both structures are generally needed for the complete suite of species because some species utilize the large savanna trees and others avoid them. Creating these two structures allows tree and other plant species to invade or be introduced that are suitable for the climate, and so assists in migration. On the other hand, these structures also allow unwanted, introduced and native plants to become established, and so care is needed.

Special measures, such as "assisted migration" of plants to allow them to cross the east-west valleys of the Pacific Coast, may be called for in some areas. Such measures need to be taken with caution and monitoring since the species may not survive or, conversely, become an aggressive pest outside of its current range.

The silvicultural knowledge and techniques exist to manage the forests in ways that maintain its many values during the Anthropocene changes. Silviculture has changed from identifying a single "system" for managing each species and community. It now considers that each stand can develop naturally through any of a large number of possible "pathways" that are the result of both growth and disturbances (Botkin 1991; Oliver and O'Hara 2004). A stand's pathway can be directed by using silvicultural operations that avoid and/or mimic disturbances and regeneration at key times to provide targeted structures and values at later key times. Silviculturalists can mix the many pathways of different stands within a landscape to ensure a diversity of structures and values are continuously provided. Individual structures can be placed and moved on a landscape so they are least susceptible to unwanted disturbances or pests. In the process of implementing the diversity of pathways, various species and species combinations can be regenerated in favorable habitats. In addition, various "protected areas" can be designated not only for endangered species but also for aesthetic (e.g., the "golden spruce"; Vaillant 2005) or scientifically unique species or as parts of corridors that allow species to migrate. Such corridors can be created in managed forests and other landscape features (Redondo-Brenes 2007).

A major issue will continue to be introduced species, especially insect and disease pests (Zavaleta and others 2001). We have seen elimination of the American chestnut (*Castanea dentata* [Marshall] Borkh.) and possibly its return, as will be discussed later. Now, we are seeing the possible elimination of the Carolina hemlock (*Tsuga caroliniana* Engelm.), American ash (*Fraxinus americana* L.), and sugar maple (*Acer saccharum* Marshall). For those pests currently in the United States, we are already undertaking a mixture of quarantining them, developing resistant trees, and introducing analogous species (Oliver 2014). Once developed, resistant and analogous species still need to be reintroduced into the forests, which would be done in the savanna and open structures.

OTHER INFLUENCES TO ENSURE SUCCESSFUL SILVICULTURAL ACTIVITIES

The Need for a Forest Infrastructure

All of the silvicultural knowledge and technology to avoid catastrophic forest problems associated with climate change are insufficient without the financial backing and an infrastructure of appropriate labor and equipment to do the needed operations. And, markets for the wood removed are needed to keep the operations from becoming prohibitively expensive.

Currently, there is a shortage of labor and forest management equipment (Knight 2013) in much of the United States. And, there is little incentive to invest in such equipment because very much more wood is growing than is being utilized in the United States (Figure 6)—and in the rest of the world (Oliver and others 2014). Consequently, wood is a "buyer's market," and most stands are not being treated. In addition, much of the present orientation of forest operators is toward equipment that is too large to do the needed operations such as removing small trees in thinnings or operating on small forest tracts (Cushing and Straka 2011).

The infrastructure could be developed by a concerted effort to harvest and utilize more wood sustainably for wood construction, with the residues used for wood energy. Such greater wood use would also reduce the world's CO_2 (carbon dioxide) emissions and fossil fuel use (MGB 2012; Oliver and others 2014). A paradigm shift toward greater logger skill and smaller, less expensive equipment that can operate more carefully could allow more stands to be managed in an appropriate way (Scott 2013). And, active public incentives and forest management programs similar to tree-planting incentives, the "Land Care" program in Australia, the Florida state forest fire prevention program, and a counter-cyclic program similar to the Civilian Conservation Corps could both provide labor and financing for the needed forest management and help provide productive employment (Oliver 2014).

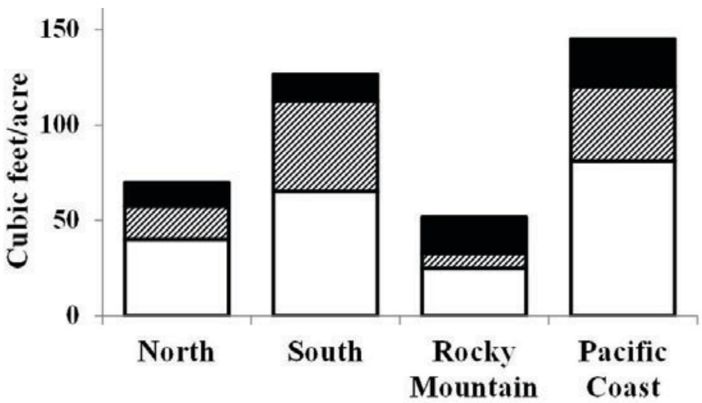


Figure 6. Forests in all regions of the United States are accumulating biomass (Smith and others 2009). (white = net growth), with relatively little harvest (diagonal = harvest), and some mortality (black = mortality).

Broader Issues Needing Adjustment

Silviculture, including the infrastructure, can be important but needs to be done as part of a broader effort rather than as a series of stand-alone mandates. First, the silviculture activities need the "dynamic" perspective described by Botkin (1979, 1991), rather than the now-outdated "steady state" perspective. The "steady state" perspective tended to separate management from some preferred "natural" development that would occur without human intervention (Colwell and others 2012). We now appreciate "natural" trajectories are random and may not protect biodiversity or provide other forest functioning and values. A similar issue is the potential legal liability if a forest fire or other catastrophe occurs following "active management," whereas a fire burning in an unmanaged forest could be considered an "act of God" and so incur no blame. This obstacle could be similar to the issue of a passing medical doctor helping victims of a traffic accident and then being sued for any lingering injury.

Second, we need to reduce the public's confusion between science and advocacy. A sincere debate among scientists is healthy; however, decades ago, legal actions against the tobacco and automobile industries made industry as a whole very disciplined in its statements. A similar discipline needs to be instilled in environmental organizations. Both industry and environmental organizations are important; however, neither should be misinterpreting science.

Third, we need a new, creative economic paradigm for sustaining forests and other natural resources. The "sustained yield" economic paradigm served well (Davis and others 2001), but proved problematic in the long term because the world is dynamic, rather than stable. Critiques of sustained yield defaulted to short-term profitability, such as following price signals, as an alternative (Dowdle 1984). Such short-term management is similar to the cutting of all trees on Easter Island for short-sighted advantage, as described by Diamond (2005). Under the justification of "fudiciary responsibility to the owners," it has probably led to the decline in wood consumption, logging infrastructure, and profits of forest ownership. We need an economic/business paradigm in resource management that bridges the best of both the long term and short term.

Fourth, we need to look at forestry from the landscape level (Oliver 1992; Boyce 1995; Heilig 2001) since single stands only provide parts of the values. For small landownerships, it will be helpful for many owners to work together to provide all values. Such cooperation may also enable marketing and managing benefits through the economies of scale. Each landscape has different properties (Oliver and others 2012), so local knowledge will be needed for appropriate management.

Fifth, introduced aggressive organisms such as those attacking trees are often extremely vigorous at first; however, over time populations of species that prey on them can build and keep their aggressiveness in check. A gradual approach of trying to slow each aggressive species may give time for these predator populations to grow and limit the harm of the aggressive one. This gradual approach may be combined with "Integrated Pest Management" (Kogan 1998), which also combats pests through a combination of monitoring and taking increasingly severe actions only as needed. Together the two approaches may be very effective.

Finally, more stringent measures may need to be taken to prevent new pests from entering North America—or leaving it. Since many regions of the world are facing losses of species and money with these introduced pests, it may be prudent to stop overseas shipping of raw organic materials (Oliver 2014). This action would prevent "hitchhiker" pests on these raw materials, and ensure that secondary manufacture occurs in the region where the organic material is grown. This approach may have an additional benefit of stimulating economies throughout the world by helping them develop value-added products instead of exporting raw materials (Acemoglu and Robinson 2012).

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This paper received peer technical review. The content of the paper reflects the views of the authors, who are responsible for the facts and accuracy of the information herein.