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Drivers of Change in U.S. Forests and Forestry Over the Next 20 Years

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Abstract: Drivers of change are overarching forces that have changed conditions in the past, are influencing the present, and are anticipated to influence the future. For this report, we define drivers of change as influential direct or indirect forces expected to shape the future of U.S. forests and the forest sector over the next 20 years. This report explores eight drivers of change expected to influence forests and forestry in the United States over the next two decades: climate change, economic drivers of change, the forest products sector, technological change, demographic change, society's changing forest values, the exercise of Indigenous rights, and forestry education. Each paper is written by experts on the particular driver or by professional futurists. The set of drivers examined here is not intended to be comprehensive. These papers provide information about important drivers of change for use by policymakers and decision makers and contribute to the USDA Forest Service's comprehensive forest futures research portfolio.

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Seasonal changes in a Wisconsin forest
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Drivers of Change in Forests and Forestry: An Introduction

Michael J. Dockry, David N. Bengston, and Lynne M. Westphal

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A fundamental precept of strategic foresight research is that there are multiple possible futures (Bengston 2017, Bishop 1998, Dator 2002). These futures can be influenced by myriad social, environmental, economic, and technological trends and events. Strategic foresight research often employs horizon scanning methods to identify weak signals of change that have the potential to influence future conditions (see Table 1 for explanations of some key strategic foresight terms [Bengston 2013, Hines et al. 2019]). There are also stronger, more overarching forces that have changed conditions in the past, are influencing the present, and are anticipated to continue to do so in the future. These larger forces are often called drivers of change or, simply, drivers. Drivers of change are direct or indirect forces expected to shape the future in multiple ways (Nelson et al. 2006). The Millennium Ecosystem Assessment defines drivers of change as "any natural or human-induced factor that directly or indirectly causes a change in an ecosystem" (Nelson et al. 2005: 175). In this report we define "drivers of change" as influential direct or indirect forces expected to shape the future of U.S. forests and the forest sector over the next 20 years.

Drivers of change analyses are useful for many strategic foresight projects, including scenario planning and horizon scanning. The concept of drivers of change has been widely used by scholars and practitioners alike and a Google Scholar search for "drivers of change" returns almost 50,000 results. The natural resources fields have applied the concept of drivers of change extensively as well. For example, the Canadian Forest Futures Project of the Sustainable Forest Management Network compiled a series of 13 reports outlining drivers of change that were used as the basis for scenario planning for forest management in Canada: global climate change, global forest products demand and Canadian wood supply, invasive species, geopolitics, global energy, technology, governance, aboriginal empowerment, air pollution, conflict over resources, society's forest values, demographics, and industry profitability (Duinker 2008). The U.S. Federal Emergency Management Agency developed a series of reports outlining nine drivers of change that are anticipated to affect emergency management: changing role of the individual, climate change, critical infrastructure, evolving terrorist threat, global interdependencies and globalization, government budgets, technological innovation and dependency, universal access to and use of information, and U.S. demographic shifts (Federal Emergency Management Act 2012). Similarly, the Millennium Ecosystem Assessment outlines several direct and indirect drivers of ecosystem change that were seen as critical to understand possible global futures (Nelson et al. 2005). In another example, the Great Lakes Futures Project outlined eight drivers of change of the Great Lakes region: economy, energy, geopolitics and governance, water quality, climate change, invasive species, and biological and chemical contaminants (Friedman et al. 2015). In summary, drivers of change form a critical part of many strategic foresight projects. While there may be overlap, specific drivers of change are tailored to the needs of the individual project or topic.

This report explores eight drivers of change expected to influence forests and forestry in the United States over the next 20 years. The drivers were identified through a review of strategic foresight literature and projects, the USDA Forest Service (hereafter, Forest Service) Northern Research Station horizon scanning system (see Hines et al. 2019), and iterative brainstorming by the Forest Service's Northern Research Station Strategic Foresight Group and partners. Thirteen drivers of change were initially identified: Indigenous rights, urbanization, demographic change, technological change, society's changing forest values, economy, forestry education, forest products sector, climate change, increasing

Table 1.—An overview of strategic foresight and the methods used in it, with references for learning more (hyperlinked to open-access publications)

Term or method	Description	Learn more here
Strategic foresight (also called futures)	A transdisciplinary field of inquiry that uses a variety of methods to explore possible, plausible, and preferable futures. The goal is to develop foresight—insight into how and why the future could be different than today—to improve policy, planning, and decision making. The methods employed help people overcome business-as-usual thinking to better prepare for an uncertain future.	Futures Research: A Neglected Dimension in Environmental Planning and Policy Ten Principles for Thinking About the Future Futures Research Methods and Applications in Natural Resources
Strategic foresight projects	Research projects or applied work to help individuals and organizations think more deeply about possible, plausible, and preferable futures.	Environmental Futures Research: Experiences, Approaches, and Opportunities
Scenarios	Data-based stories of a range of potential futures. Scenarios are one of the most widely known techniques used in strategic foresight. They are written in compelling, accessible language, often as if the events have come to pass. There are many approaches to developing scenarios, including the well-used 2 × 2 matrix approach and Aspirational Scenarios. Scenarios offer strengths missing from other tools to extrapolate about the future, such as forecasting. Forecasting takes existing data and trends and calculates from them to a single future. Scenarios, on the other hand, support strategic foresight's focus on the many possible futures by developing alternate possible futures.	Scenarios and Decisionmaking for Complex Environmental Systems Millennium Ecosystem Assessment Aspirational Scenarios
Scenario planning	A specific application of scenarios, used to guide decisions in the near term. Scenario planning aims to achieve the preferable future outcomes identified through the scenario process. Multiple scenarios depicting possible future outcomes are developed to guide planning efforts.	Scenarios to Provide Context for Horizon Scanning: Backcasting North American Forest Futures from 2090 to 2035
Horizon scanning	A process to gather early signals of change—weak or strong—in the area of concern. Horizon scanning is a foundational method in strategic foresight. The signals of change serve as a guide to what the future may hold, can facilitate effective planning, may reduce surprises, and are used as input into other futures methods.	The Forest Futures Horizon Scanning Project Setting up a Horizon Scanning System: A U.S. Federal Agency Example

disturbance, invasive species, fire, and water. The compilers of this report reached out to both technical experts and futurists to write short papers about each driver and to provide broad perspectives on how these drivers may influence forests and forestry in the coming 20 years. This report contains essays on eight drivers. We anticipate continuing this effort with updates and new drivers reports to be produced as Research Notes.

The first driver of change in this report is an environmental driver: climate change. This driver is arguably one of the most important environmental influences expected for forests over the next 20 years (see Intergovernmental Panel on Climate Change 2014). In "Climate as a Driver of Change in U.S. Forests," Leslie Brandt shows how climate change has the potential to cause changes in forest productivity, distribution, composition, and structure. She explains that future climate impacts are anticipated to vary regionally and influence hydrology, flooding, and drought; invasive species; forest insect and disease outbreaks; and fire regimes. She also explains how climate change could affect forest management operations, options, and goals. This paper provides a concise treatment of the complex environmental and management challenges anticipated for forests and the forest management sector and identifies key uncertainties about what climate change could bring in the coming decades.

The next several drivers of change in this report—economic growth, forest products, and emerging changes in technology—can be considered economic drivers. In "An Uncertain Economic Future for the United States," Robert Olson approaches the uncertainties of forecasting economic growth futures by describing four possible economic scenarios: higher growth, slow growth, techno-economic acceleration, and hard times. He describes how these different economic scenarios could influence forest sector employment, natural resource management, research and development, and demand for forest resources. Omar Espinosa explores the importance of the U.S. forest products sector in his paper, "Trends in the U.S. Forest Products Sector, Markets, and Technologies." He first describes the negative trends the forest products sector has exhibited over the past several decades and then describes many promising opportunities for new technologies and products with the potential to transform the industry. This paper contains many useful graphs and charts that illustrate major trends affecting the forest products industry. The paper finishes with a look ahead to how the forest products industry will continue to play a critical role in the economic, social, and environmental development of the United States during the next two decades and beyond. Last in the set of papers that consider economic drivers is George Kubik's "Technology as a Driver of Future Change in the Forest Sector: Projected Roles for Disruptive and Emergent Technologies." Kubik highlights eight technologies that have the potential to influence forestry futures and their implications: artificial intelligence, autonomous vehicles, electronic performance enhancement systems, genomics and synthetic biology, the Internet of Things, materials science, nanotechnology, and robotics.

The next papers focus on social drivers of change and potential implications for forest futures. In "Demographics as a Driver of Change in the U.S. Forest Sector," Robert Olson shows how demographic shifts could require different forest management responses to address land use changes, an aging population, and increasing cultural diversity. He describes how forestry may be more effective through coordination between rural and urban forest management. He examines the potential need for greater accessibility of forest amenities to an aging population and the need for fire management to account for more people living in the wildland-urban interface. Also explored is the need to address how the quickly growing communities of racial and ethnic minorities use forests and how they ascribe values to forests. David Bengston's paper, "Shifting Forest Values as a Driver of Change," provides a framework for understanding the important and unexpected ways that people's values change in relation to forests and natural resources. He sketches out three scenarios for how values could unfold and affect forestry and society in the coming decades: eco-utopia, back to the utilitarian future, and growing apathy and disengagement. In the last paper of this section, "Indigenous Rights and Empowerment in Natural Resource Management and Decision Making as a Driver of Change in U.S. Forestry," Michael Dockry explores how Indigenous communities have been organizing and using their inherent sovereignty to influence major environmental issues such as climate change, fossil fuel extraction and transport, timber harvesting, and water management. The paper concludes with four possible scenarios of how Indigenous empowerment could unfold: increased collaboration and comanagement, increased litigation, increased conflict and protest, or a continuation of the current situation that includes a combination of all three scenarios, each applicable at different places and times.

Finally, in "Education as a Driver of Change in U.S. Forests and the Forest Sector," Terry Sharik and co-authors outline the changing trends in general education and then take a deep look at the specifics of the future of forestry and natural resource education. They show how new educational paradigms will focus more on knowledge generation, interdisciplinary learning, communication technology, student engagement, and lifelong learning. They then explain how these changes could be incorporated into forestry education. Specifically, they illustrate how forestry education will most likely shift to focus on social and environmental sustainability, field-based learning, distance learning for nontraditional students, and broad interdisciplinary undergraduate degrees with disciplinary-specific master's degrees and technically specific associate degrees. They also characterize forestry education as increasing among the public and discuss the importance of increased racial and ethnic diversity among those pursuing this field.

These papers are intended to be a baseline for research by the Forest Service and others working on natural resource foresight. They lay the groundwork for integration of strategic foresight research and practice with the ultimate goal of improved forest management, decision making, and broad interdisciplinary planning for change. The report is not intended to be comprehensive but to provide information about important drivers of change for use by policymakers and decision makers and as part of a comprehensive Forest Service forest futures research portfolio. As the future unfolds, these drivers could be updated with new information, edited to incorporate new ideas, and expanded to include additional drivers. We hope that this collection is useful in raising awareness of some key drivers of change that are likely to influence forests and forestry over the next 20 years. We are thankful for the contributions of the authors, editors, and reviewers, each of whom improved this compilation in substantive ways. Though this report does not cover every possible driver of change for forests and forestry, we believe that it provides a range of papers that will be useful for foresters, land managers, and others interested in the future of forests and natural resource management.

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Climate as a Driver of Change in U.S. Forests

Leslie Brandt

Abstract: Climate exerts a major influence on the productivity, distribution, composition, and structure of forests. Temperatures are increasing globally, and these widespread temperature increases are resulting in local changes in temperature, precipitation, and extreme weather events across the continental United States. Changes have varied by region, and many of these regional differences will continue in the coming decades. The western United States has been experiencing an increase in drought, wildfire, and mountain pine beetle (*Dendroctonus ponderosae*) damage that is leading to losses in productivity. In the Midwest and East, increased heavy rain events and decreased winter severity have altered forest hydrology and induced range shifts for trees and biological stressors. The east coast is experiencing rising sea levels that threaten coastal forests with flooding and increased salinity. This region could also be subject to more severe hurricanes and other tropical storms in the coming decades. Climate change impacts may affect forest management operations, reduce windows of opportunity to conduct prescribed burns and harvest, or necessitate changes in timing of those activities. Direct and indirect effects of climate change on the Nation's forests will influence the benefits that they provide, such as timber and nontimber forest products, recreation opportunities, clean water, and cultural values, in the coming decades. Climate change also presents opportunities to manage forests for increased carbon sequestration and develop strategies to adapt to change, which can help reduce the magnitude of some of these impacts.

KEY WORDS: climate change, precipitation changes, temperature changes, extreme weather, forest productivity, range shifts, forest management

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Introduction

Climate is a major factor in determining the distribution of forests world-wide. Climate has influenced the distribution, competitive dynamics, and assemblages of vegetation as global temperatures have cooled and warmed significantly over millions of years. Temperatures have been rising over the past century, and these increases are linked to rising concentrations of carbon dioxide and other greenhouse gases in the atmosphere (Intergovernmental Panel on Climate Change [IPCC] 2014). Global climate models project increases in temperature globally and across the United States over the next century as greenhouse gas emissions continue to rise (U.S. Global Change Research Project [USGCRP] 2017). Forests in the continental United States are likely to undergo many direct and indirect effects from these changes (Vose et al. 2012). This paper summarizes trends over the historical record and projections over the next century for key climate drivers of forests across the continental United States. It also summarizes implications for forests and the forest sector.

Trends and Projections in Physical Drivers

Carbon Dioxide

Levels of atmospheric carbon dioxide (CO_2) have been increasing since the beginning of the industrial era and now exceed 405 parts per million on average (Tans and Keeling 2018). By 2050, CO_2 concentrations could potentially reach levels of 500 to 600 parts per million (USGCRP 2017). Studies that have experimentally increased CO_2 levels in forests have shown higher CO_2 concentrations can increase photosynthetic rates, increase carbon storage, alter nutrient cycling, and improve water use efficiency (Ainsworth and Long 2005, Farrior et al. 2015). It is unclear whether these responses will continue in magnitude and direction as CO_2 levels continue to rise, and how responses may interact with or be offset by other stressors.

Temperature

Average temperature in the United States increased about 0.68 °C (1.23 °F) between 1986 and 2016 compared to the first 60 years of the 20th century (USGCRP 2017). Increases have been more dramatic in some parts of the country than others. The Southeast has experienced less than half as much warming as the rest of the United States, and Alaska, the northern Great Plains, and the Southwest have experienced the most warming. Average annual temperatures are projected to increase another 1.4 °C (2.5 °F) for the years 2021 through 2050 compared to 1976 through 2005 as greenhouse gases such as CO_2, methane, and nitrous oxide continue to rise (USGCRP 2017). Temperature increases can have direct and indirect effects on forests as described in the following sections.

Heavy Rain Events

Heavy precipitation events have increased in both frequency and intensity over the historical record across the United States (USGCRP 2017). Increases have been most pronounced in the Northeast, where the frequency of extreme rain events has increased by 74 percent (Easterling et al. 2017). Model projections suggest that heavy rain events will continue to increase over the next century, and will increase even in areas where total precipitation is projected to decrease (USGCRP 2017). This increase in heavy rain events could lead to greater surface runoff, erosion, and flooding and subsequently loss of topsoil, lower water quality, damage to recreation sites, and changes in nutrient cycling in forests.

Drought

Drought can lead to stress and mortality of trees and make forests more vulnerable to fire and insect pests. Recent trends in drought vary regionally (Vose et al. 2016). The West has been experiencing an increase in drought in recent decades, which has been attributed to declining snowpack and winter precipitation (Wehner et al. 2017). Observed trends in the

East are more variable and complex; small pockets have had more drought and most of the land area has shown either no change or decreased drought frequency, especially compared to the Dust Bowl era of the 1930s (Ficklin et al. 2015). There is currently a low degree of confidence in drought projections across the United States (USGCRP 2017). One exception is the Southwest, which is generally projected to experience an increase in drought. It is likely, however, that warmer temperatures will lead to reductions in soil moisture through increased evapotranspiration in other parts of the continental United States (Wehner et al. 2017).

Tropical Storms and Hurricanes

Hurricanes and other tropical storms can lead to widespread tree mortality and breakage from wind as well as flood-induced stress and mortality in coastal forests. The observational record has limitations, including a lack of satellite-detected hurricane records before the last few decades and a lower density of ships making on-the-ground observations. Consequently, it is difficult to conclude whether the frequency or severity of hurricanes and other tropical storms has changed over the past 100 years due to warming global temperatures (Geophysical Fluid Dynamics Laboratory 2017, Kossin et al. 2017). Despite considerable uncertainty in future projections, models project an increase in the number of the strongest (Category 4 and 5) hurricanes by the end of the century, with increases in precipitation rates and intensity (Kossin et al. 2017).

Changes in Winter Severity

Winter severity, determined by cold temperatures as well as snow, can have a strong direct and indirect influence on forests in the United States. In the last few decades, snow cover across much of the United States has decreased in depth, extends over a smaller area, and melts sooner in the spring, leading to wide-ranging effects on forests (Vose et al. 2012). Less snowpack combined with earlier melting provides less insulation for plants and soil, exposing roots to frosts and freezing temperatures. Early snowmelt also alters the timing of runoff into streams; large flows occur earlier, followed by diminished flows late in the growing season. Current and projected increases in winter minimum temperature can exacerbate forest disturbance by reducing winter mortality of insect pests and increasing their range northward, such as mountain pine beetle (*Dendroctonus ponderosae*), southern pine beetle (*D. frontalis*), and hemlock woolly adelgid (*Adelges tsugae*) (Lesk et al. 2017, Paradis et al. 2008, Safranyik et al. 2010). Winter recreation in forests, such as skiing and snowmobiling, may be reduced in many areas as temperatures continue to increase (Wobus et al. 2017). However, some recent research suggests that some areas may experience increases in extreme cold events due to a weakened polar vortex (a large area of low pressure and cold air surrounding the Earth's poles) in the northern hemisphere (Kretschmer et al. 2017).

Sea Level Rise

Sea level has been rising and is expected to continue to rise due to thermal expansion and melting of polar ice caps (IPCC 2014). Global sea levels have risen 20 centimeters (8 inches) since the 1880s. Sea level changes have been variable by location. Sea level did not rise as much as the global average along the Pacific coast until recently. Along the Atlantic coast sea level rise was below the global average in the Southeast and exceeded the global average in the Northeast. By the end of the century, global sea level is projected to rise by 0.3 to 2.4 meters (1 to 8 feet) (Sweet et al. 2017). Sea level rise is projected to be greater in parts of the Gulf coast and the northeastern Atlantic coast than other parts of the coastal United States. This rise, along with potentially more coastal storms, will increase the risk for erosion, storm surge, and flooding events, affecting coastal ecosystems and infrastructure. Sea level rise may also result in saltwater intrusion into coastal forests, which may lead to widespread stress, reduced seedling recruitment, and mortality (Saha et al. 2011).

Growing Season Length

The frost-free season, often used to define the length of the growing season, has lengthened across the United States since temperature records began; the largest increase—more than 17 days—has been observed in the West (Hibbard et al. 2017). The first freeze is happening later in the fall, and the first thaw is happening earlier in the spring. The increase in length of the frost-free and growing seasons is expected to continue in this century. Earlier snowmelt and springtime have led to earlier emergence of leaves and earlier flowering in some plants, which may increase the productivity of forests if adequate water and nutrients are available later in the growing season. However, there may also be some negative aspects to a longer growing season, such as asynchrony in plant and pollinator timing or more insect life cycles. In addition, many plants have specific requirements for chilling during winter that may limit their ability to respond to warmer spring temperatures (Zhang et al. 2007). Changes in growing season length may also affect the length of the recreation season (Brice et al. 2017) and reduce opportunities for management during the dormant season (Rittenhouse and Rissman 2015, Scott et al. 2004).

Wildfire

Climate is an important driver of wildfire in forest ecosystems. Warming temperatures are generally expected to increase fire risk, although this relationship varies by forest type, region, and fire regime (McKenzie et al. 2011). As a result of longer growing seasons and altered precipitation, the length of the fire season and the annual area burned have been increasing in the West and are expected to continue to increase in the future (Abatzoglou and Williams 2016, Wehner et al. 2017). There is insufficient information regarding trends or projections for other parts of the United States (Wehner et al. 2017). However, it is expected that rising temperatures combined with seasonal dry periods and more insect outbreaks will trigger more wildfires by the end of the century, even in the East.

Key Impacts to Forests

Biological Stressors

Changes in climate can influence biological disturbance agents in forests. The mountain pine beetle has had dramatic impacts on western forests in part due to milder winter temperatures (Raffa et al. 2015). In the upper Midwest, the native larch beetle (*D. simplex*) appears to be benefiting from warmer temperatures, leading to increased larch (*Larix* species) mortality (Raffa et al. 2015). Along the east coast, the native southern pine beetle and the invasive hemlock woolly adelgid have both expanded their ranges northward (Lesk et al. 2017, Paradis et al. 2008). Forest pathogens may also be affected by changes in climate. For example, bur oak blight (caused by the fungus *Tubakia iowensis*) may be increasing in severity, partly because of wetter spring conditions (Harrington et al. 2012). Invasive plant species may also benefit directly from warmer temperatures. For example, kudzu (*Pueraria montana*), which has caused dramatic economic losses in the South, could migrate to the Midwest and Northeast (Bradley et al. 2010).

Altered Productivity

Increases in temperature and higher levels of CO_2 in the atmosphere can both lead to increased photosynthesis and growth. In areas where forest productivity is currently limited by temperature and growing season length, productivity may increase with warming temperatures (IPCC 2014). In the West, increased wildfire, bark beetle disturbance, and drought have decreased productivity and are likely to further decrease productivity in the coming decades (Vose et al. 2012). In the eastern United States, elevated CO_2 and temperature may increase forest growth and potentially carbon storage, at least in the short term if sufficient water is available. Mortality from increased disturbances combined with higher soil respiration rates may outweigh the gains in productivity from longer growing seasons and higher photosynthetic rates over the long term, however (Rustad et al. 2012).

Species Range Shifts

As temperature increases and precipitation changes, the range of suitable habitats for many forest species will also change. The suitable habitat range of some tree species may shift northward or upslope to higher elevations to align with cooler temperatures, or may shift in other directions to track changes in moisture. Species outside their suitable habitat ranges may experience more stress, reductions in productivity, difficulty regenerating, or reduced seedling establishment. Forest fragmentation is already slowing natural rates of migration, and it is unlikely that species will be able to migrate as fast as their suitable habitat is shifting even in the absence of fragmentation. In the Pacific Northwest, climate is projected to become unfavorable for Douglas-fir (*Pseudotsuga menziesii*) and many other conifer species in the area (Vose et al. 2012). Northern and boreal tree species at the southern edge of their current range in the Midwest and Northeast will decrease in abundance as habitat suitability for oak (*Quercus*) and hickory (*Carya*) species increases (Iverson et al. 2019). In the Southeast, red spruce (*Picea rubens*) and eastern hemlock (*Tsuga canadensis*), already declining in some areas, are projected to be extirpated from the region by 2100 as a result of the combined stresses of warming, air pollution, and insects.

Implications for the Forest Sector

Changes in climate are likely to have substantial implications for the U.S. forest sector and forest ecosystem goods and services in the coming decades. Changes in productivity are expected to vary regionally, with some timber-producing areas experiencing gains and others losses. Habitat suitability for southern pines (*Pinus* species), which are the main source of the Nation's pulp and paper, may shift northward, leading to reductions in production and economic loss in some areas (Vose et al. 2012). As growing seasons lengthen, production could expand in the Northeast and Midwest (Kirilenko and Sedjo 2007). In the West, fire, drought, and mountain pine beetle outbreaks could reduce productivity (Kurz et al. 2008).

Other goods and services provided by forests may also be affected. Opportunities for forest-based winter recreation activities such as snowmobiling and skiing may decrease as snow decreases and winters become milder (Bowker at al. 2012, Wobus et al. 2017). Summers may become too hot for outdoor recreation across much of the country, and more recreation may shift to cooler seasons in the South (Brice et al. 2017, Scott et al. 2004). Nontimber forest products may also be affected. Changing conditions, such as increased temperatures and altered freeze-thaw cycles, may have negative impacts on sugar maples (*Acer saccharum*) in some parts of the United States, reducing sugar maple health (Houle et al. 2015, Hufkens et al. 2012) and syrup quantity and quality (Matthews and Iverson 2017). Maple syrup production may move to the far Northeast and parts of Canada (Skinner et al. 2010). Additionally, increasing temperatures are projected to change the timing and duration of fall foliage colors (Archetti et al. 2013) and shift habitats and migratory patterns for birds and other wildlife (Langham et al. 2015). Such changes have implications for tourism-related economies (Thomas et al. 2013).

Climate change may also alter the timing and intensity of forest management. For example, in response to longer and more intense fire seasons, more resources will be diverted to fire fighting and suppression, resulting in fewer resources available for other management activities (USDA Forest Service 2015). Prescribed fire seasons may also need to shift in some areas if conditions become too wet or dry. More resources may be required to detect and treat invasive species, forest pests, and pathogens if these species benefit from warmer climates. Timber harvesting opportunities on frozen ground may also be reduced, and harvesting may need to switch to periods when soils are dry instead of frozen (Rittenhouse and Rissman 2015).

A changing climate may provide incentives for efforts to partially offset fossil fuel emissions and increase carbon storage in forests and wood products (Janowiak et al. 2017). Forest management strategies include land use change to increase forest area (afforestation) or to avoid deforestation (or both), and optimizing carbon management in existing forests. Strategies for forest product use include using wood wherever possible as a structural substitute for materials such as steel and concrete that have a large carbon footprint, and using wood as biofuel. If wood-based biofuel becomes an attractive strategy for emissions reduction, it could drive up demand for wood products.

As climate change impacts become apparent, managers are beginning to take action to adapt their forests to climate change (Ontl et al. 2017). Management strategies can be employed to protect existing species and ecosystems, such as identifying areas that may serve as refugia (Morelli et al. 2016) or reducing stocking to reduce competition for water during drought (D'Amato et al. 2013). Other adaptation actions may focus on enhancing species or genetic diversity to increase the probability that some species or individuals may be able to withstand current stressors. Finally, actions may be taken to assist the migration of species or populations to newly suitable areas because of conservation or economic concerns (Williams and Dumroese 2013). Adaptation actions that are not effective or yield unintended consequences could have additional negative impacts on forests.

Conclusions

Climate will continue to be a major driver influencing the distribution, species composition, and structure of forests. Climate-driven disturbances, such as storms, droughts, floods, wildfire, and pest outbreaks will have a strong influence on the productivity and composition of forests in the United States over the coming decades. These disturbances will influence the availability of forest products and other forest-derived services. Forest managers will be faced with the challenge of adapting to these changes while also ensuring that forests continue to provide important ecosystem services.

Acknowledgments

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An Uncertain Economic Future for the United States

Robert L. Olson

Abstract: There is extraordinary uncertainty about how the U.S. economy will perform over the next two decades because so many of the variables that affect the economy are in flux. As a result, 20-year forecasts are highly problematic and a more responsible approach is to consider alternative forecasts of how economic conditions could evolve. This essay sets out scenarios that represent some of the main views held by economists and other informed professionals and leaders. Each view is plausible and there is no "right" view on which to base decisions. The better approach is to be prepared to make the best of whatever circumstances emerge by thinking in advance about what actions would be appropriate in each of them—and what actions would make sense no matter what the future holds.

KEY WORDS: economy, growth, technology, scenarios

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Introduction

This essay sets out alternative views, expressed as scenarios, of how the U.S. economy may perform over the next 20 years and gives examples of implications that these different economic conditions could have for the forest products sector and forest management in the United States. Scenarios "contain the stories of … multiple futures, from the expected to the wildcard, in forms that are analytically coherent and imaginatively engaging" (Bishop et al. 2007: 5). The measure most widely used for assessing a Nation's economic performance is growth in the gross domestic product (GDP). GDP is a measure of the market value of all the goods and services produced in a period of time, typically quarterly and yearly. The views explored here differ primarily in their expectations regarding GDP growth.

Past Trends

Gross domestic product has grown steadily in the United States over the entire past century despite periodic recessions and one major depression (U.S. Bureau of Economic Analysis 2019). The rate of the economy's growth has varied considerably over this time, going on average from very rapid (above 4 percent per year) between World War II and the 1960s to somewhat slower from 1970 to 2000 (around 3 percent) and still slower since the beginning of the 21st century (nearer 2 percent) (Fig. 1).

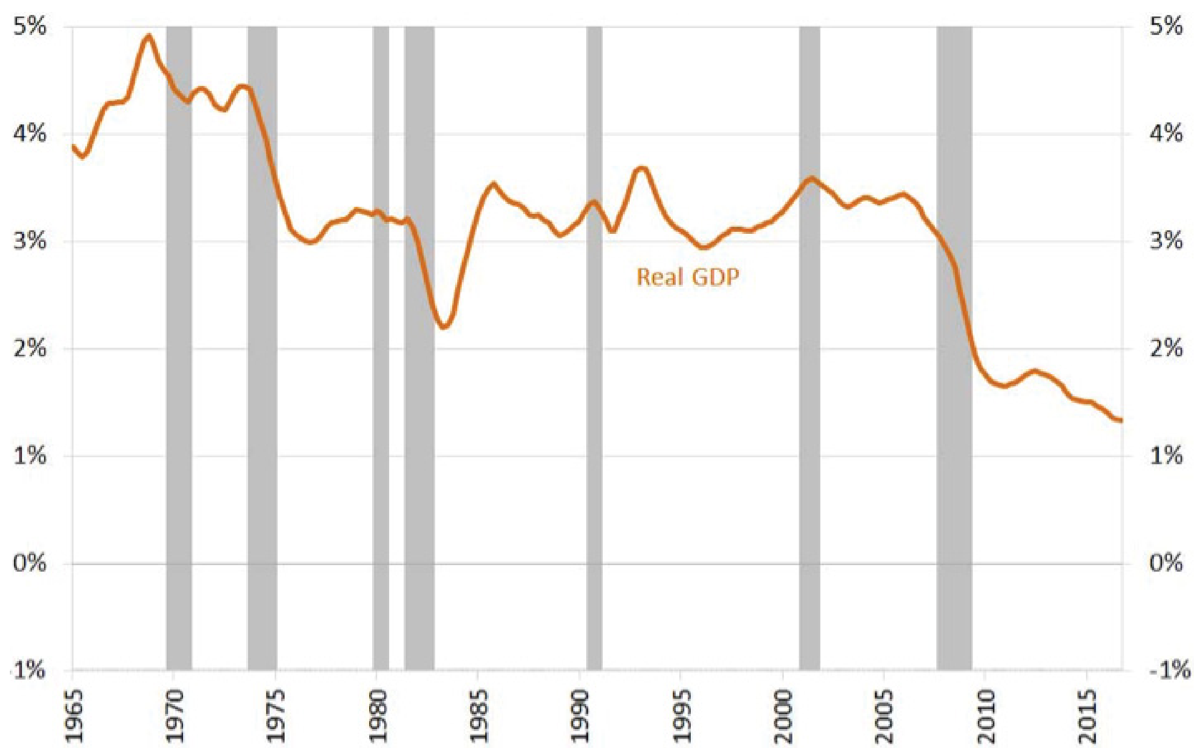

Figure 1.—Rolling 10-year averages of annual growth in real gross domestic product in the United States. Periods between official start and end dates for recessions are shaded. Source: Martin (2017a).

A Look Ahead

Twenty-year forecasts of U.S. economic performance are highly problematic because of considerable uncertainty about how technological change, productivity growth, public policy, debt, inflation, interest rates, international trade rules, and many other factors will play out over the years ahead. Rather than 20-year predictions, a more responsible approach is to consider scenarios that set out alternative views held by economists, corporate leaders, public officials, and technology visionaries.

Two scenarios that capture the most widely held views about how economic conditions could evolve are labeled Higher Growth and Slow Growth (see, for example, Bengston et al. 2016, Laitner et al. 2016, Panayotou 2016, Wilkinson 2016). Higher Growth reflects the view that it is possible to return to the higher growth rates more typical of the 1960s or at least the period from 1970 to 2000. Slow Growth represents the view that the recent uptick in growth is temporary and we are likely to return soon to the slower post-2000 rate of growth.

Two other scenarios labeled Techno-Economic Acceleration and Hard Times represent views that are less widely held but deserve consideration (Laitner et al. 2016). Techno-Economic Acceleration explores the ideas of visionaries who believe emerging technologies could trigger an unprecedented surge of U.S. and global growth (Brown 2011, Perez 2010). Hard Times examines the risks that some experts believe could seriously undermine economic performance. The following descriptions make the case for the plausibility of each of these viewpoints.

Scenario 1: Higher Growth

The economy will grow rapidly over the next few years and there are major forces likely to drive continuing strong growth, with only minor interruptions, over the next 20 years. Goldman Sachs' "Macroeconomic Outlook 2018" states that the current global economic outlook is "as good as it gets," buoyed by a synchronized expansion across both developed and developing markets with every major economy on Earth expanding at the same time (Goldman Sachs 2017). The World Bank report "Global Economic Prospects" is nearly as optimistic (World Bank 2018).

As of the time of writing, unemployment is low, consumer confidence is robust, and business investment is expanding in the United States. Tax cuts and regulatory reforms are expected to stimulate further investment and, despite inevitable corrections, the stock market is at near-record levels. The International Monetary Fund has lifted expectations for U.S. expansion in 2018 to 2.7 percent from 2.3 percent because of the tax cuts (Goodman 2018). The current administration's stated goal for the years ahead is a growth rate of 4 percent or higher (Bach 2017).

There are fundamental forces that could sustain strong growth over the next two decades. For example, information technology may be able to do much more to support growth. A recent report by the Technology CEO Council argues that roughly 70 percent of U.S. business sectors, including some of the largest, such as manufacturing, health care, and transportation, have underinvested in digital technologies, but the level of commitment is changing rapidly (Mandell and Swanson 2017). Dramatic improvements in business operations are anticipated as artificial intelligence applications are developed and implemented (Brynjolfsson and McCafee 2017).

Energy is another area that could help to sustain U.S. economic growth. The United States is on the verge of dethroning Saudi Arabia as the world's largest oil producer due to the success of hydraulic fracturing (fracking) technology. Plans to open vast ocean areas to offshore exploration and open the Arctic National Wildlife Refuge (ANWR) for drilling could assure that the United States remains an energy superpower for years to come (Blas 2018).

People who hold this view do not expect the economy to be trouble-free for the next generation. But they believe that an overall growth rate of 3 percent or higher is both desirable and likely.

Scenario 2: Slow Growth

The projection by the Congressional Budget Office (2017) that growth will be near 2 percent per year over the decade ahead is more plausible than the growth rates of 3 to 4 percent—or better—that the current administration is promising. There are also major forces likely to prevent growth from accelerating into the 2030s (Congressional Budget Office 2017).

Consumer spending is the primary driver of growth in the United States, but the middle class is becoming too weak to support historical levels of spending. While the top 1 percent of income earners has been taking home well over 90 percent of the growth in income, households in the middle have lower incomes, adjusted for inflation, than they did 20 years ago (Stiglitz 2013). Middle-income households have been attempting to sustain their buying power through the use of credit, but average household credit card debt has reached $5,700 and average balance-carrying credit card debt is $16,048 (ValuePenguin 2017). This debt burden makes it difficult over the long term to continue spending at past rates (ValuePenguin 2017). Age is another factor affecting spending. A 40-percent decline in consumer spending occurs from age 45 to 74, so the aging baby boom generation will be spending less over time (Alkin 2018).

More people working and contributing to the economy also drives growth. But as former chair of the Federal Reserve Alan Greenspan points out, with unemployment down to nearly 4 percent, the economy cannot continue creating as many jobs as it has in recent years (Summers 2017). The retirement of baby boomers is also causing the labor force to expand more slowly, and immigration restrictions would do the same (Samuelson 2016).

In light of the constraints on consumer spending and labor force expansion, the rate of growth depends mainly on improvements in productivity (output per unit of labor input). But productivity gains have significantly declined since 1970 (Samuelson 2016). Many reasons have been suggested for this phenomenon, including rising energy prices and a structural shift in the economy from high to low productivity sectors (e.g., from manufacturing to services). Developments like these are not easily or quickly reversible.

Technological progress has been the largest contributor to productivity over generations past, but its influence is also declining. Economic historian Robert Gordon demonstrates in statistical detail that productivity and living standards increased during the "special century" from 1870 to 1970 more rapidly than at any time before or after. He argues that we have exhausted a broad range of "can only happen once" inventions and have little prospect of soon finding another set of inventions of such breadth and impact. Going from no aircraft to global jet travel can only happen once, for example, and further progress to supersonic or hypersonic transportation will have small impacts by comparison. The same is true for electric motors in manufacturing, automobiles, television, central heating and air conditioning, lighting, and many other areas. Despite the hype about information technology, Gordon shows it has had very little impact on productivity to date (Gordon 2016, Nordhaus 2016).

People who hold the Slow Growth view admit there are developments that could lead to faster growth. Among these forces are technical progress that lowers energy costs, policies that boost the buying power of middle-income families, or possible productivity increases from the utilization of artificial intelligence.

Scenario 3: Techno-Economic Acceleration

A recent McKinsey & Company report highlights the beginning of what the authors call a "new era" of major industry disruption by emerging technologies: "We're not just being invaded by a few technologies … but rather are experiencing a *combinatorial technology explosion*" (Greenberg et al. 2017: 2). Even some environmentalists concerned about the environmental impacts of emerging technologies believe that we are at a "critical point in history, where technical changes even larger than those that produced the industrial revolution are converging" (Olson and Rejeski 2005: 2).

Some analysts are highly optimistic about what a convergence of major technical developments could make possible. Peter Diamandis, the founder of the X Prize Foundation, believes it can lift the whole world. He argues that "new transformational technologies—computational systems, networks and sensors, artificial intelligence, biotechnology, bioinformatics, 3-D printing, nanotechnology, human-machine interfaces, and biomedical engineering—will soon enable the vast majority of humanity to experience what only the affluent have access to today" (Diamandis and Kotler 2012).

This forecast is tame compared to those of computer scientist, inventor, and futurist Ray Kurzweil, who argues that because technological progress is increasing at an exponential rate we seriously underestimate what will soon be possible. In "The Singularity Is Near," Kurzweil (2005) forecasts that by the 2030s nanotechnology-based molecular manufacturing will be in widespread use. Molecular manufacturing would manipulate materials at the atomic level, allowing products of all kinds to be produced quickly at a miniscule fraction of the cost of traditional manufacturing and with no atoms wasted or out of place (i.e., perfect efficiency, zero pollution). He believes this will lead very quickly to a world of high-level universal affluence (Kurzweil 2005).

Forecasts like this strike many people as optimistic to the point of being out of touch with reality, but Kurzweil is, in fact, the director of engineering at Google. One does not have to give credence to views this extreme, however, to appreciate the possibility that accelerating technological change could have substantial economic impacts.

Scenario 4: Hard Times

Some economic analysts are concerned about potential risks that could bring hard times or even an economic collapse. The largest risk for the global economy is probably the high level of private and public sector debt in major economies. The United States has unprecedented and unsustainable debt—projected at 144 percent of GDP or higher by 2050 (up from 78 percent; Congressional Budget Office 2019), driven upward rapidly by both tax cuts and spending increases. But economists are even more concerned about China. A recent report by the International Monetary Fund warned that the current trajectory of China's debt is "unsustainable" and therefore "dangerous" (Martin 2017c). Research published in December 2017 by analysts at Deutsche Bank estimate the probability of a crisis in the Chinese economy at as high as 13 percent (Martin 2017b).

Conflict and instability are another source of risk. The World Economic Forum's 2018 annual assessment of risk factors based on a survey of 1,000 experts found that 93 percent of respondents worry there is an increasing likelihood of political or economic confrontations. Some 79 percent are concerned about a heightened likelihood of military conflict and 73 percent see rising risks of an erosion of world trading rules (World Economic Forum 2018). Developments like a major conflict in the Middle East, a military engagement with North Korea, or a trade war with China might deal serious blows to the global economy.

Much larger risks than we commonly appreciate may also come from things we are not even aware of or do not understand. Such events are what Nassim Taleb has called black swans, events that are highly improbable (Taleb 2010). As the Great Recession got underway in 2007, some honest economists admitted that they knew hardly anything about credit-default swaps, auction-rate securities, collateralized debt obligations, and other high-risk new financial instruments being invented for valid or disreputable purposes. Risky unknowns and black swans may emerge from practices such as China's "shadow banking" system and the decrease in regulation of the U.S. financial system (Shen 2019, Sun 2019, Zhang 2017).

Implications for the Forest Products Sector and Forest Management in the United States

These four scenarios have multiple implications for forest, forest products, and natural resource management institutions. The following examples illustrate how strongly the forest products sector of the economy and forest resources themselves could be influenced—positively and negatively—by these alternative economic conditions.

The Slow Growth scenario could continue the current situation of lost economic capacity with declines in research and innovation. Slow growth, combined with a steady increase in entitlement costs, would put continuing pressure on Federal agency budgets. Combined with ecosystem change and increased wildfire, the USDA Forest Service could increasingly become the "Fire Service." Forest Service funding priorities could shift almost entirely to fire management (see North et al. 2015). On the other hand, although slower economic growth would probably put continuing downward pressure on Federal budgets, it would also be likely to reduce the pressure of housing development and result in less fragmented forests in the long run.

The Hard Times scenario could cause a further decline in employment and natural resource management, possibly even a sharp decline, with some capacity returning to local control. This would be a scenario where Federal budgets are cut back sharply, hindering land management and possibly undermining the capacity to deal with worsening wildfires. Tighter Federal budgets could lead to different organizational models, such as greater State-level support for firefighting operations and the kind of public-private research and development partnership that is currently used in New Zealand (Hall et al. 2017). In a different vein, the Hard Times scenario might create high demand for public land as a focal point for creating jobs, spurring economic growth, and restoring natural resources, as was done in Great Depression programs like the Civilian Conservation Corps (Alexander 2018). A severe and long-term economic decline could also significantly increase the demand for wood as fuel, as homeowners in many areas turn to wood as a low-cost means to heat their homes and cook. This would in turn have implications for air quality and human health, and would also result in increased release of carbon dioxide (CO_2) into the atmosphere.

The Higher Growth scenario could increase consumer demand and put pressure on forest ecosystems. This could drive sprawling development patterns in the future, resulting in increased forest fragmentation and loss of biodiversity. Radeloff and co-authors (2010) estimate that another 17 million housing units will be built within 30 miles (48 km) of protected areas (national parks, national forests, and Federally designated wilderness areas) by 2030 if long-term trends continue. This construction would greatly diminish the conservation value of these lands and make land management more complex. The Higher Growth scenario could also increase economic resources that would enable the Forest Service and other forest managers to restore or even expand their full range of operations. The Forest Service might be able to take on a major role in removing built-up fuel in fire-prone areas.

A Techno-Economic Acceleration scenario with very high innovation might generate a huge range of new wood-based products. Research is already underway on innovations such as wood-based nanomaterials, cellulosic material from wood pulp for 3-D printing (additive manufacturing), fabrics made of wood, transparent wood substitutes for glass, electronics using graphene conductors made from wood, and densified "superwood" so strong and durable it might compete with steel or even titanium for many uses (Bengston 2017). Accelerated development of technologies such as artificial intelligence and advanced robotics could also have profound implications for future employment in forestry, forest products, and Federal agencies such as the Forest Service. Experts are deeply divided about the net employment effects of automation (Winick 2018), but it is possible that the number of forestry-related jobs, from arborists to wildland fire fighters, could decrease significantly. Additionally, advances in wood material science could figuratively turn every twig into an electronic device, creating an urgent need to learn how to handle the soaring demand sustainably (Bengston et al. 2016). Alternatively, technical innovation might lead to new processes and materials that make wood obsolete for many functions. For land management institutions, a Techno-Economic Acceleration scenario might provide major new capabilities in areas ranging from forest condition monitoring and invasive species control to precision fire management.

Conclusions

Annual planning and conventional strategic planning require making assumptions about the most likely ecological, social, technological, and economic conditions over the next few years. Even in these short timeframes there is more uncertainty about these conditions than planners typically acknowledge. Over still longer periods the level of uncertainty becomes much higher. Each of the very different 20-year scenarios presented here is plausible and there is no clear "most likely" or "right" scenario for the Forest Service and others in the natural resource management arena to use exclusively as a basis for decision making. Rather than put all their eggs into the basket of a single set of assumptions about the future, institutions can adopt a futures approach to help them prepare for whatever circumstances emerge.

One of the ways to develop this flexibility is to think in advance about what actions would be appropriate in different future circumstances—and what actions would make sense no matter what the future holds. One way for futures methods to stimulate that thinking is through periodic strategic conversations about alternative futures focused through scenario planning (Peterson et al. 2003, Schoemaker 1995). Scenarios can create a framework and a vocabulary for continuing conversations about assumptions, emerging developments, potential surprises, alternative perspectives, and long-term goals and strategies. Holding these conversations at different levels within the organization as well as with stakeholders makes it possible to gather and combine the best ideas from people with different backgrounds and perspectives. As appropriate, these ideas can be used in decision making and planning.

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Trends in the U.S. Forest Products Sector, Markets, and Technologies

Omar Espinoza

Abstract: The forest products sector plays a critical role in the economic and social well-being of the United States. The country is the top producer and consumer of forest products, and it has the highest per capita industrial wood consumption. Nevertheless, the country's forest area has not changed in over a century, owing in part to sound forest management practices and a strong tradition of wood utilization. Cyclical and long-term trends, such as the Great Recession of 2007 to 2009, changing consumer demand, globalization of manufacturing, and emergence of substitute materials, have had negative impacts on the U.S. forest products industry in the last two decades. Sustainable management of U.S. forests has in turn been negatively affected, as strong forest products markets are vital to the health and resilience of U.S. forest lands and forest-dependent communities. However, there are promising opportunities for the forest products sector, including increased interest in renewable materials and energy, increasing demand for wood-based energy products, expanding nanotechnology applications, the emergence of mass timber, and increased use of wood in large-scale construction. This paper presents the major market trends affecting the U.S. forest products sector and discusses potential scenarios over the next 20 years.

KEY WORDS: forest products, market trends, wood consumption, nanotechnology, cross-laminated timber, CLT

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Introduction

Over the long term, few industries have contributed more to the development of the United States as a nation than the forest products industry, and it is no exaggeration to say that wood was the foundation of American society (Youngquist and Fleischer 1977). Wood has played a central role in all aspects of the U.S. economy, from transportation to construction and from energy to communications. The forest products industry is one of the most dynamic sectors of the U.S. economy. Although the United States accounts for only 7.5 percent of total global forest area, it produces close to one-fifth of all the industrial roundwood (Food and Agriculture Organization [FAO] 2018), and Americans use five times more timber per capita than the global average (FAO 2011). However, the country's forested area has not changed significantly in more than 100 years (Oswalt et al. 2014). These trends can be attributed to several factors, including sound forest management practices, a strong wood culture, the abandonment of marginal farmlands that reverted to forest, and effective fire suppression, which all contribute to offset the loss of forest land to urbanization (Alvarez 2007). According to the American Forest and Paper Association [AF&PA], the forest products industry (excluding logging) is among the top 10 employers in 45 states, generating 4 percent of the manufacturing output (AF&PA 2017). This industry provides direct employment to over 1 million people (Golden et al. 2015). It is also the leader in biomass-based renewable energy generation, producing more than one-fifth of the renewable energy consumed in the country (Energy Information Administration [EIA] 2015).

However, the U.S. forest products industry has been facing substantial challenges, both cyclical, such as the Great Recession of 2007 to 2009, and structural, such as globalization and the decline of printed media. Employment in the industry has not fully recovered from the last economic recession and the associated decline in the housing market, which prompted thousands of layoffs and plant closings (Buehlmann et al. 2007). Domestic manufacturers have lost market share to low-cost imports, where sectors like household furniture were particularly affected (Buehlmann and Schuler 2009, Quesada and Gazo 2006). Products traditionally made with wood, such as windows, siding, framing, and decking, are losing market share to substitute materials. In addition, considerable decrease in paper consumption has reduced the demand for fiber (Belz 2012) and caused many pulp and paper mills to close. Partly as a result of these developments, employment in the forest products industry declined considerably between 1996 and 2016 (Fig. 1). The U.S. share of global roundwood production decreased from 27 percent in 1996 to 19 percent in 2016 (FAO 2018).

This paper presents major market trends within the U.S. forest products sector that stand as key drivers of change for forestry and the forest sector. Most data presented correspond to the 1996–2016 period, but exceptions occurred when data for that period were unavailable.

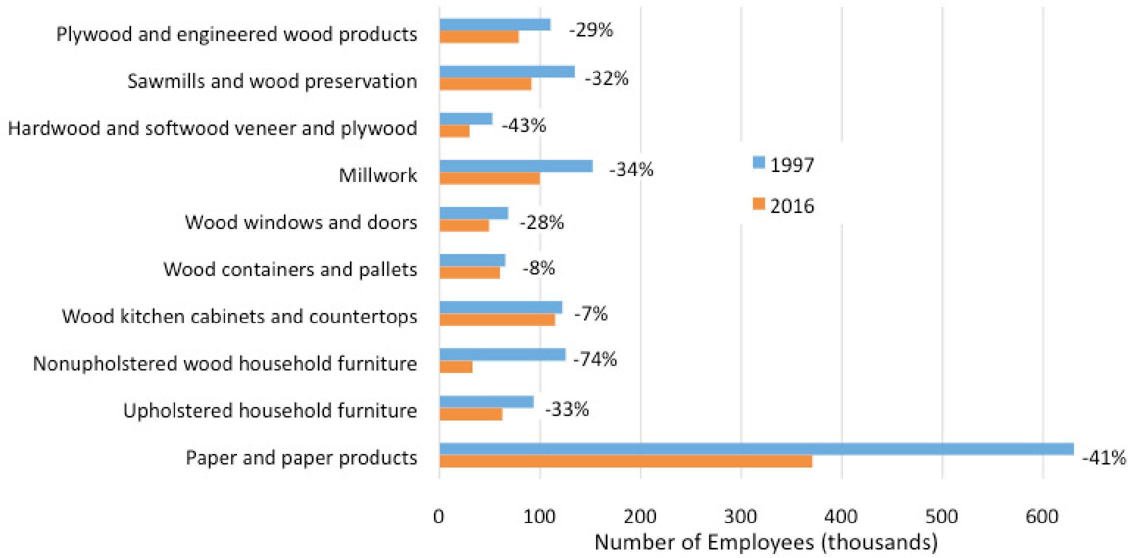

Figure 1.—U.S. employment in selected industry subsectors, by year. Numbers to the right of the bars denote the percent change between 1997 and 2016 (Bureau of Labor Statistics 2017).

Current Trends

Wood Consumption in the United States

Per capita annual wood consumption in the United States was 1.24 m^3 (530 board feet) in 2013 (Howard and Jones 2016), the last year of available data (Fig. 2). U.S. consumption is higher than the world's average of approximately 0.5 m^3 (200 board feet) (FAO 2011). The distribution of this consumption is also markedly different; close to 90 percent of U.S. consumption is in industrial wood products, while in developing countries over 80 percent of wood consumption is for fuel for cooking and heating (Bruinsma 2003). U.S. consumption declined sharply from a peak in 2005 to its lowest point in over four decades in 2009, corresponding to the U.S. recession and the associated decline in the construction industry.

Trends in Raw Materials

One important trend in raw materials of recent decades that affects demand for wood fiber is the growth of substitute materials. Substitute materials continue to reduce the market share of wood as raw material for several product categories. For example, siding, which was once overwhelmingly made of wood (usually naturally durable species), now has a market share of 5 percent in the single-family residential market, with vinyl and fiber cement overtaking this segment (Fig. 3). Regional differences do exist; for example, vinyl is prevalent in the Northeast and Midwest (71 percent and 60 percent of homes in 2016, respectively) while brick and stucco have a considerable market share in the South (35 percent and 22 percent, respectively). Stucco and fiber cement have a large presence in the West (52 percent and 37 percent, respectively) (U.S. Census Bureau 2017b).

Other industries where substitutes have taken significant market share from wood-based products are outdoor decking and windows. In decking products, wood had a comfortable 97 percent share of the market in 1995 (Ganguly et al. 2010), which dropped to 62 percent in 2016 (Biobased News 2017), largely due to losses to wood-plastic composites and plastic decking (32 percent and 6 percent of the market in 2016, respectively). Wood windows, once dominant, are now limited to the traditional and luxury segments, and vinyl is the market

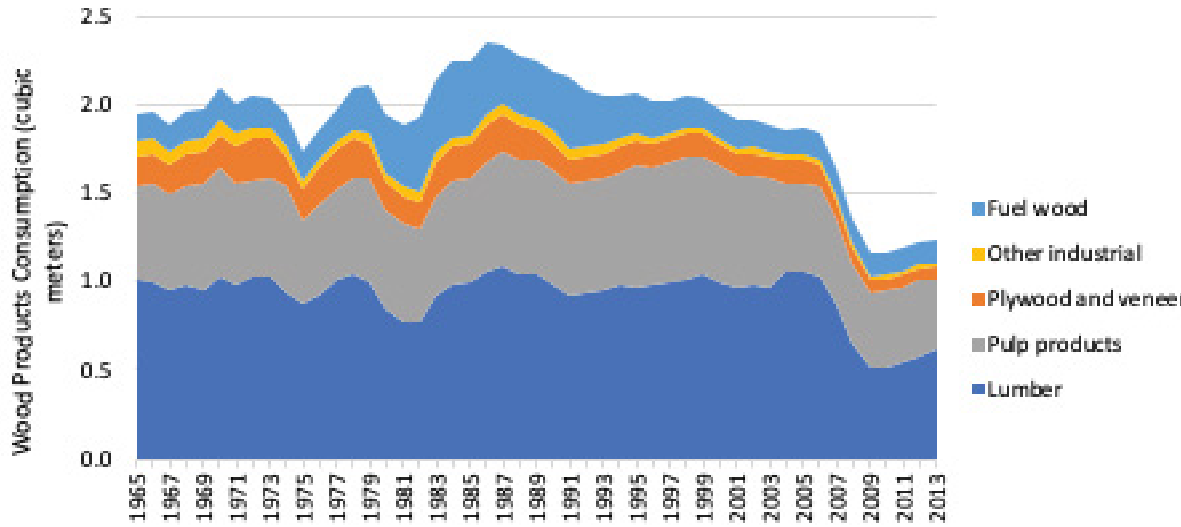

Figure 2.—U.S. per capita wood consumption, by year (Howard and Jones 2016). Data for 2013 are the latest available.

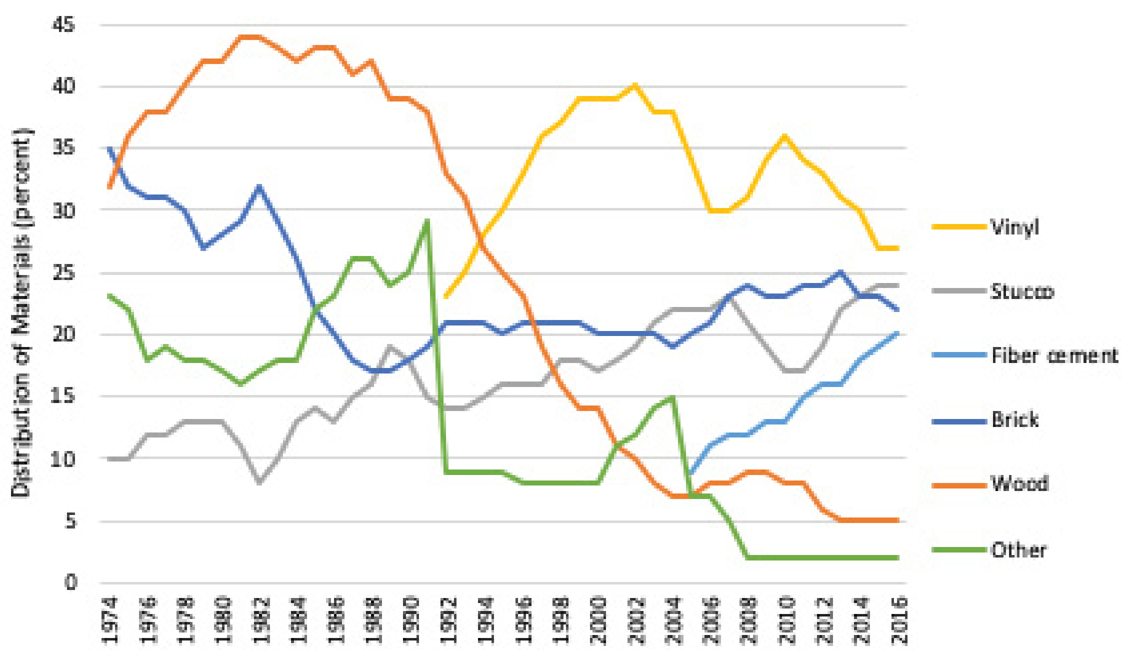

Figure 3.—Distribution of primary type of exterior wall material of new single-family houses completed in the United States, by year (U.S. Census Bureau 2017b). "Other" includes concrete block, stone, aluminum siding, and other minor types. "Other" included fiber cement before 2005 and vinyl siding before 1992 (thus the large drops in those years).

leader (Thompson 2017). Wood has held its own against substitute materials in markets such as pallets, residential construction, and kitchen cabinets. Wood framing is still used in more than 90 percent of single-family construction (U.S. Census Bureau 2017a), and it was estimated that more than 90 percent of pallet units are made of wood (National Wooden Pallet and Container Association 2018, Trebilcock 2013).

Lumber

From 1996 through 2016, about 75 percent of lumber produced was in softwood species and 25 percent, hardwoods (Fig. 4). Production of both softwood and hardwood lumber reached all-time highs in 2005: 69.2 million m^3 (29.3 billion board feet) and 27.8 million m^3 (11.8 billion board feet), respectively. Lumber production dropped during the Great Recession to its lowest level in 2009, and as of 2016, it had not yet recovered to the levels of the 1990s and early 2000s.

Hardwood Lumber

During the last two decades, there has been a considerable change in U.S. hardwood lumber markets. Industrial and export markets have grown in importance, while the participation of high value-added uses, such as furniture and cabinets, decreased between 1999 and 2015, particularly in furniture markets (Fig. 5). If only "grade" hardwood lumber is considered (excluding industrial uses such as pallets; crane mats, which are large wood platforms that provide ground stabilization for heavy machinery in several industries, such as oil drilling and exploration operations; railroad ties; and others), participation of exports is even larger, growing from 14 percent in 1999 to 41 percent in 2014 (Snow 2016). China's share of total U.S. hardwood lumber export shipments by volume jumped from 8 percent of exports in 1999 to 46 percent in 2014. It is estimated that one in five grade lumber boards sawn in the United States was shipped to China as of 2016 (Snow 2016). Canada, the second largest export market for U.S. hardwood, decreased its market share from 34 percent to 16 percent in the same period. China also shifted from primarily a manufacturer of hardwood products (using imported lumber and logs to manufacture goods for export) to a consumer of those goods, as its middle and upper classes grow. Another important trend has been some decoupling of housing construction activity and hardwood lumber prices. Historically lumber prices traced the trends in housing starts closely; however, starting shortly after the Great Recession, hardwood lumber prices have been increasing at a higher rate than housing starts, and exports have become a major driver of price (Snow 2016).

The United States has been historically the leading hardwood lumber exporting country in the temperate region, and the importance of export markets has been growing in the last two decades (Fig. 6). However, its market share declined from 34 percent in 1990 to 23 percent in 2011 (Bumgardner et al. 2014).

Softwood Lumber

The United States has historically led the world in softwood lumber consumption. In 2016, the United States consumed 81.7 million m^3 (34.6 billion board feet) of softwood, followed by China with 56.3 million m^3 (23.9 billion board feet) (FAO 2018).

The primary driver for softwood lumber consumption is residential and nonresidential construction, which has been trending upward during the last few years (Fig. 7). It is expected that new applications, such as engineered wood products, mass timber, and increased share in some markets (e.g., commercial construction, mid- and high-rise construction, pallets, and containers) will boost demand for softwood lumber. Softwood lumber has remained competitive with substitute materials, such as steel and plastic, in markets like dimension lumber, doors, and windows.

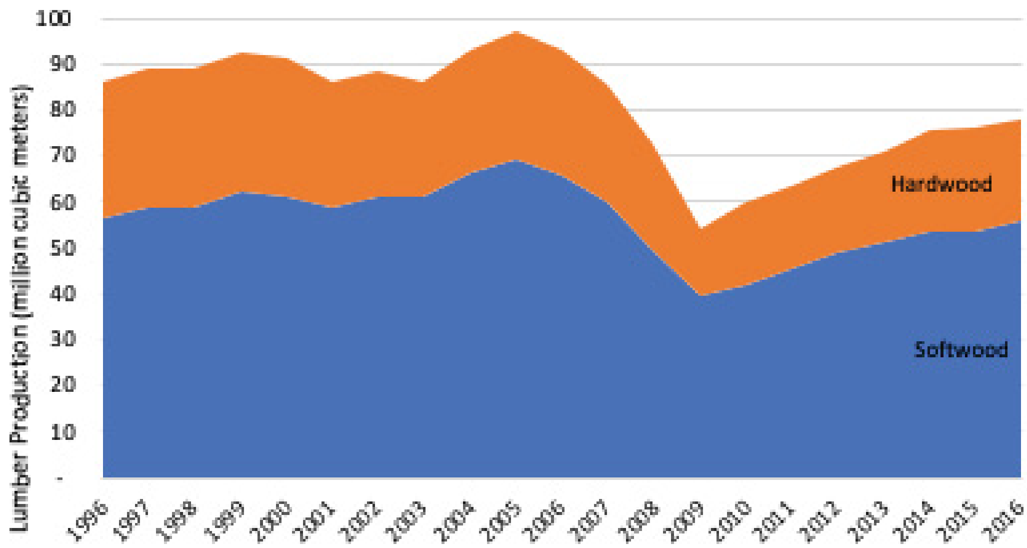

Figure 4.—U.S. softwood and hardwood lumber production, by year (FAO 2018).

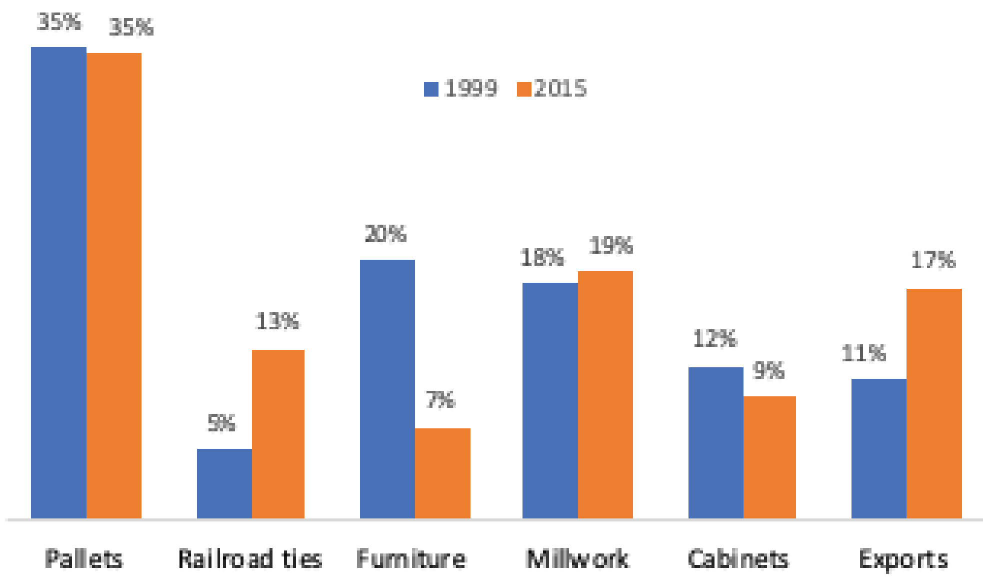

Figure 5.—Distribution of markets for U.S. hardwood lumber by volume, by year (Bumgardner 2016).

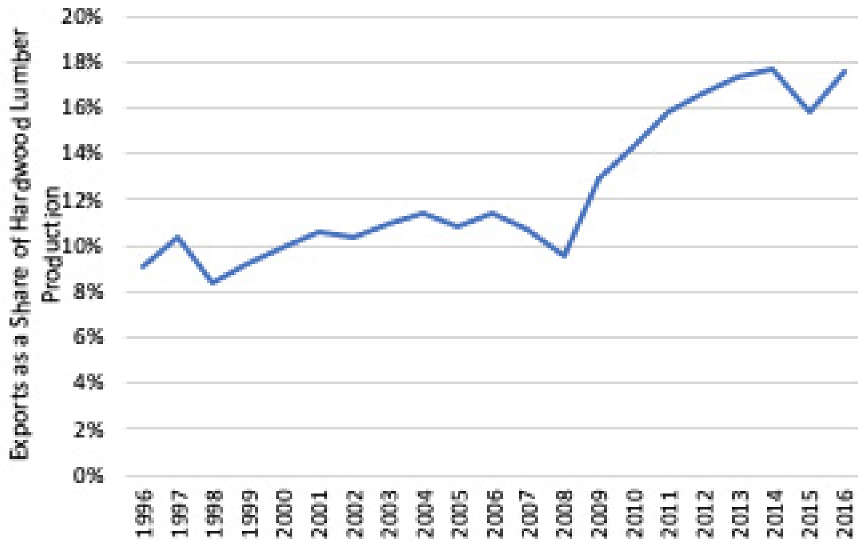

Figure 6.—Exports as a percentage of production for U.S. hardwood lumber, by year (FAO 2018).

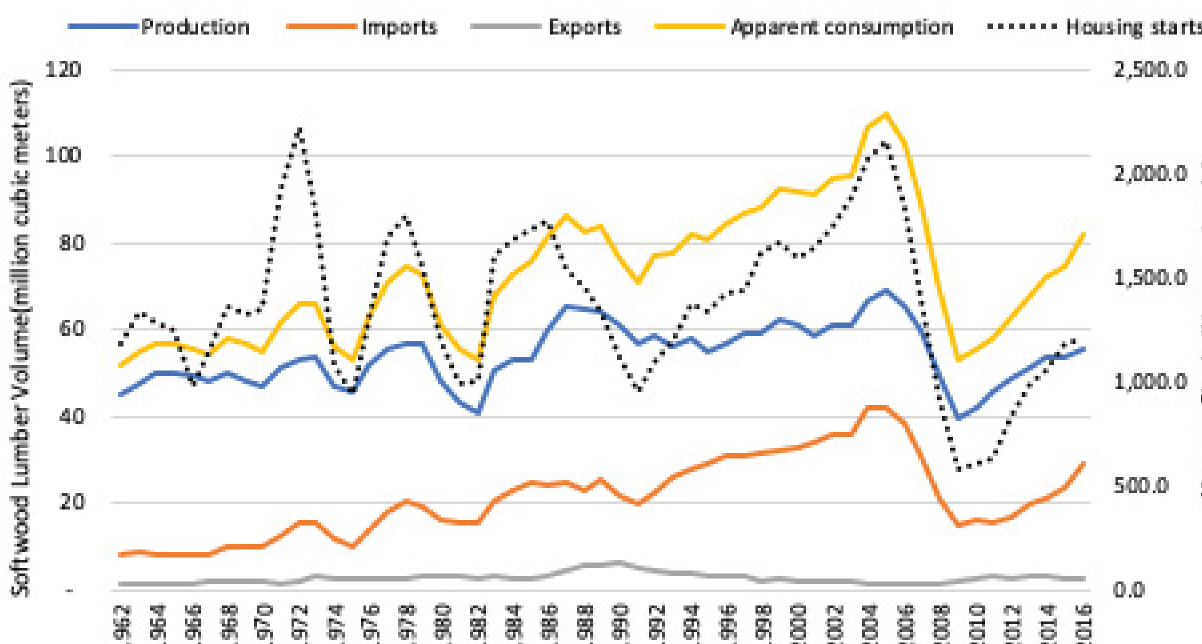

Figure 7.—U.S. softwood lumber production, imports, exports, and apparent consumption (FAO 2018). Housing starts are also represented (U.S. Census Bureau 2018b). Apparent consumption is calculated as production plus imports minus exports.

Moreover, improvements in process efficiency, such as the use of small diameter logs as raw material, will contribute to maintaining the competitive position of softwood lumber over substitute materials.

Industrial Wood Products

Industrial wood products support transportation and logistics operations as well as communications and energy infrastructure. Major industrial wood products are pallets and containers, railroad ties, wood utility poles, mining supplies, crane mats, and road construction products (e.g., sound barriers, guardrail posts, retaining walls, signposts, and trail and road bridges). These products are gaining importance as logistics operations become more global, U.S. oil and gas industries prosper, and outlets for lower-grade hardwoods shrink.

Pallets are a critical component of logistics infrastructure, as they reduce material handling time and costs. More than 90 percent of pallets are made of wood, primarily hardwood species (Sanchez Gomez 2011). However, there are continued efforts to use competing materials (metal, plastic) to capture market share from wood. Pallets and containers, as well as railroad ties, are important for hardwood timber utilization, as they provide an outlet for the lower-grade material from lumber manufacturing. Pallets are the single most important outlet for low-grade hardwood, and their production consumes over 40 percent of all hardwood produced in the United States (Hardwood Market Report 2014). Some pallet industry trends include the steady growth of pallet recycling, an increasing market share of pallet rental systems, phytosanitation requirements for invasive species and exports, and increased use of softwoods for pallet manufacturing. Pallet production has grown steadily during the last four decades but had a notable downturn in 2007 through 2008, associated with the Great Recession (Fig. 8). Wood railroad ties are an important outlet for wood; in 2016, more than 19 million new wood crossties were installed in the United States (Railway Tie Association 2018).

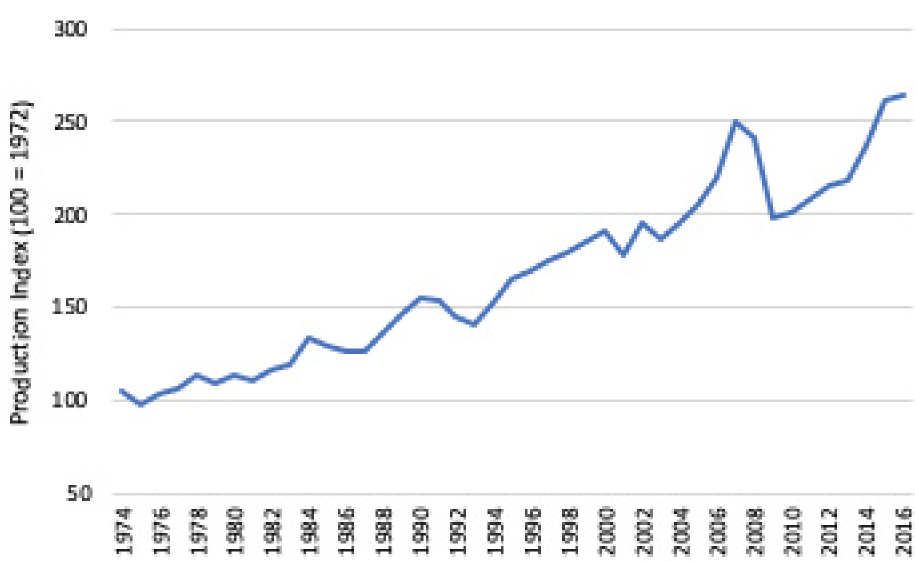

Figure 8.—U.S. wood pallet and container production index, scaled to an index of 100 in 1972, by year (Federal Reserve Bank of St. Louis 2017).

Value-added Products

Value-added wood products are manufactured by using the outputs such as lumber, veneer, and wood-based panels obtained from primary processing operations. Value-added products include furniture, kitchen cabinets, millwork, wood flooring, decking, railings, windows, and doors. Production of value-added wood products has declined in the United States over the past three decades because of the Great Recession, increased competition from imports, market penetration from substitute materials, and other factors. For example, more than 70 percent of the nonupholstered furniture consumed in the United States is now imported (Fig. 9). There have been changes in the sourcing of those imports as distributors look for lower-cost suppliers. For example, in 2015 China accounted for 59 percent of total imports of household and institutional furniture and cabinets, by value, down from 61 percent in 2010. Meanwhile, Vietnam has been steadily increasing in market share (Bumgardner 2016), mostly due to Vietnam's lower costs. Imports from China grew only 3 percent in 2016, while those from Vietnam grew 30 percent in the same period (American Plywood Association 2017). The decline in U.S. manufacturing of value-added products has led to a decrease in domestic demand for grade lumber (Fig. 5). Other market segments, such as flooring and millwork, have shown similar trends.

Engineered Wood Products

Engineered wood products (EWPs) are generally made by breaking down wood into smaller pieces or particles, which are then bonded with adhesive. These products reduce wood product variability and help to utilize the raw material more efficiently. They are designed to meet precise standards and specifications (Fig. 10).

In general, trends of engineered wood products follow those of the housing market (Fig. 11). After a large drop during the Great Recession, production of laminated veneer lumber (LVL), I-joists, and glulam has increased steadily.

One engineered wood product that has received considerable attention during the last decade is cross-laminated timber (CLT), a relatively new engineered wood product made of multiple layers of wood boards oriented perpendicularly to the adjacent layers (Karacabeyli and Douglas 2013). These panels are manufactured in large dimensions to form entire wall and floor systems. The cross-laminated configuration of CLT (Fig. 10) results in excellent mechanical properties, and the prefabricated nature of CLT allows for high precision and a construction process characterized by faster completion and little disruption to the neighboring areas. In the United States, CLT panels for structural use are certified by the American National Standards Institute (2018), which specifies requirements and test procedures for quality assurance. One early study estimated that a CLT market in North America could generate need for 1.2 million to 3.6 million m^3 (0.51 billion to 1.5 billion board feet) of wood, depending on market penetration (Crespell and Gaston 2011). In the United States, as of the time of this writing, two firms manufacture CLT panels approved for structural use (American Plywood Association 2018), two firms produce noncertified panels, and the construction of four plants has been announced (Dalheim 2017, Esler 2017).

Wood-based Panels

Wood-based panels can be structural or nonstructural. Structural wood-based panels are used in construction as sheathing for roofs, floors, and walls. The two basic types of structural panels are plywood and oriented strand board (OSB). Structural plywood is made mostly from softwood species. Nonstructural wood-based panels have countless applications, such as furniture and kitchen cabinets, laminated flooring, millwork, doors, wall paneling, car parts, and

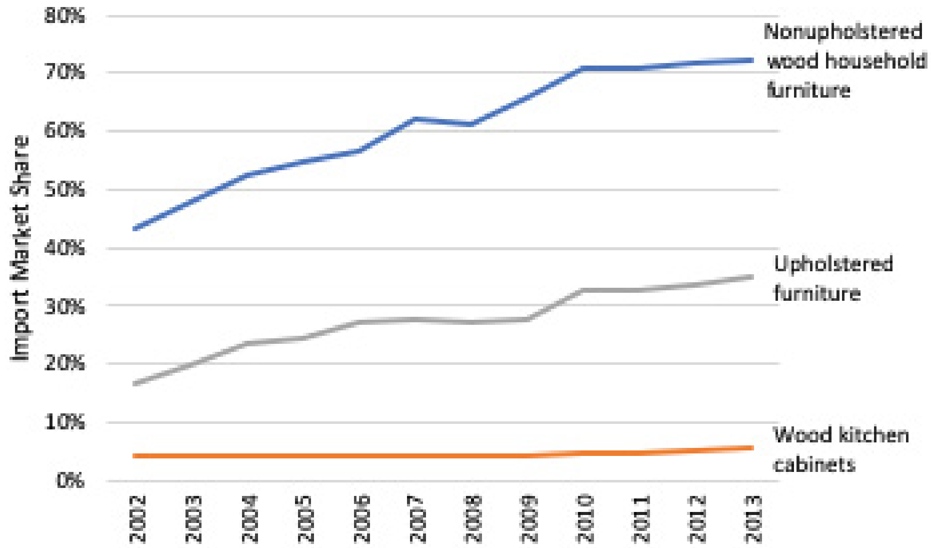

Figure 9.—Market share estimates of imports of kitchen cabinets and furniture in the United States (Nicholls and Bumgardner 2018).

Figure 10.—Examples of engineered wood products. From left: parallel strand lumber, I-joists, and cross-laminated timber (Photo credit: Maria Fernanda Laguarda Mallo, University of Minnesota, used with permission).

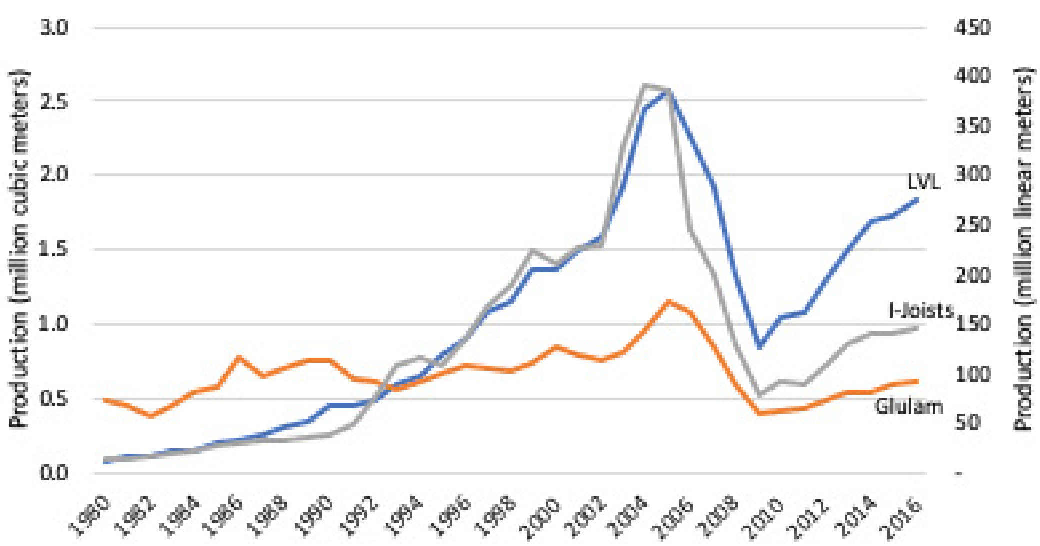

Figure 11.—U.S. production of laminated veneer lumber (LVL), I-joists, and glulam, by year (American Plywood Association 2017, Howard and Jones 2016).

siding. Common nonstructural wood-based panels are plywood (often hardwood plywood), particleboard, medium density fiberboard (MDF), and hardboard. During the last few decades U.S. production of wood-based panels has shown a sustained shift from plywood to other panel products (Fig. 12). In residential construction, OSB has overtaken a large part of the plywood market share. Plywood's largest market is now in the industrial sector (United Nations European Forestry Commission/Food and Agriculture Organization 2017). Oriented strand board is also used for siding, and about 600 million square feet (3/8 inch basis) (56 million m^2; 1 centimeter basis) was produced on average from 2012 through 2016 (American Plywood Association 2018).

In secondary wood products manufacturing, the use of composites, such as particleboard and MDF, has increased. However, an increasing percentage of consumption has been covered by imports, while domestic production has decreased. For example, the average production volume of MDF between 1996 and 2016 decreased at an average annual rate of 3 percent, while imports grew 19 percent annually (calculated with data from FAO 2018). U.S. imports of OSB panels, almost exclusively from Canada, grew by more than 11 percent from 2010 to 2017 (calculated with data from American Plywood Association 2017), while plywood imports came primarily from China and Canada.

Pulp and Paper Products

Pulp and paper products include a wide variety of goods, such as communication papers (e.g., printing paper, newsprint), packaging and paperboard products, and tissue. There is also high diversification in terms of raw materials, channels of distribution, and final uses. Many of the pulp and paper industry's outputs are raw materials for other industries. Important structural changes have affected the global paper industry during the last three decades. Electronic communications have greatly reduced consumption of newsprint, writing paper, and printing paper, especially in developed countries. The sharp growth in electronic commerce has increased parcel shipping, reflected in increased demand for paperboard and wrapping and packaging paper—a trend that is expected to continue in the United States (Fig. 13) and elsewhere. Consumption of household and sanitary paper products has kept pace with population growth, but an emerging trend is a shift in consumption; people in lower income countries are rapidly increasing their use of household paper goods. Low-income countries were projected to surpass higher income countries in the use of household and sanitary paper products in 2014 (Hansen et al. 2014). Last, there has been a considerable increase in the share of recovered paper as input to paper production in the United States; recovery rates almost doubled, from 34 percent in 1990 to 66 percent in 2017 (AF&PA 2018).

In the United States, the pulp and paper industry has experienced consolidation and plant closings. The number of establishments decreased from just under 7,000 in 2001 to 5,500 in 2016, and employment fell from 630,000 to 368,000 between 1997 and 2016 (Bureau of Labor Statistics 2017). Likewise, there was a decline in capacity, from 62.0 million metric tons (air dry; 68.3 million tons) to 53.5 million metric tons (air dry; 59.0 million tons) between 1997 and 2016 (FAO 2017). Consumption and production of paper and paperboard are expected to continue to decline in North America. According to at least one projection, consumption in 2030 may be half of what it was in 2000 (Hansen et al. 2014). These changes have profound implications for wood fiber demand.

Another important development in the pulp and paper industry is the diversification toward new products, such as biorefining and bioenergy. Research and development efforts in the industry are focused on innovations in biochemicals, biofuels, biocomposites,

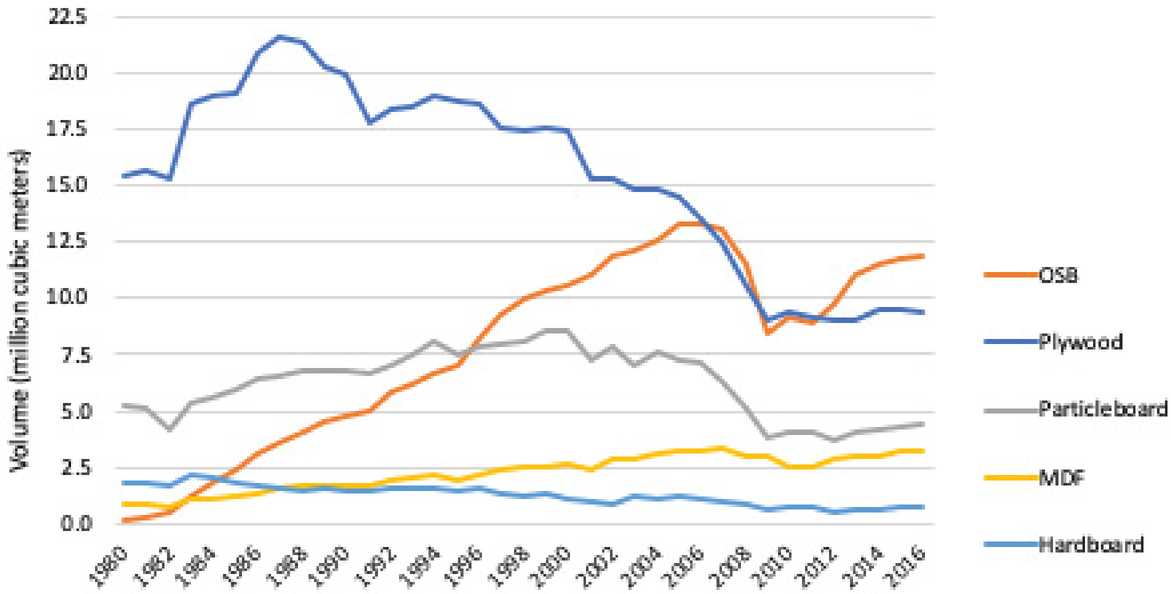

Figure 12.—Wood-based panel production in the United States, by year (FAO 2018, Howard and Jones 2016, Howard and McKeever 2016, Howard et al. 2017). Values for 2016 are estimates. OSB: oriented strand board; MDF: medium density fiberboard. Plywood figures include hardwood and softwood plywood.

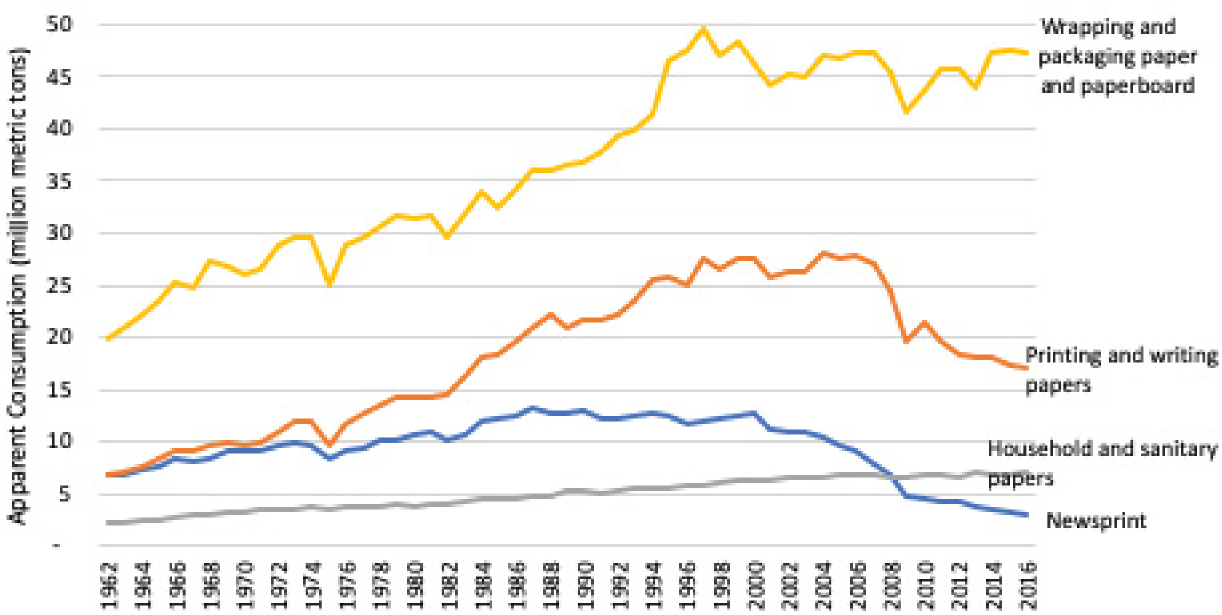

Figure 13.—Apparent consumption of paper and paper products in the United States, by year (FAO 2018). Some data for 2016 are estimates.

nanotechnology, and others. Industry and research communities have proposed the concept of "biorefinery," which is a production facility that can use different raw materials (forest or agricultural biomass, or municipal and industrial solid wastes) to produce a wide variety of outputs. These products include biofuels, electricity, chemicals, and conventional products like paper, lumber, and composites (Hansen et al. 2014). Biorefineries will take years to become an economically viable option, but they can have an important effect on demand for fiber.

Wood Energy

Markets for heat and electricity generation from wood biomass have grown during the last decade. In 2016, wood represented over 40 percent of the total biomass energy consumed in the United States and 20 percent of the total renewable energy (EIA 2017). Wood-based energy represented 2 percent of total U.S. energy consumption and 10 percent of industrial energy consumption as of July 2018 (EIA 2018b). The major use of wood biomass is for heat and electric energy generation (combined heat and power, or cogeneration) by the forest products industry, mostly pulp and paper.

A bioenergy application of wood that has grown rapidly is wood pellets (Fig. 14). As of July 2018, there were 83 facilities producing densified biomass in the United States, with a production capacity of 12 million metric tons (13 million tons) per year (EIA 2018a). Although pellet production started in the Northeast and Northwest, most of the growth in pellet production capacity has been in the Southeast (Dale et al. 2017). The major raw material sources for wood pellet manufacturing in the United States are mill residues and pulpwood (both softwood and hardwood).

Exports of wood pellets account for 80 percent of total sales, with close to 100 percent going to Europe (80 percent to the United Kingdom) to replace coal for power generation (EIA 2018a). European targets to reduce greenhouse

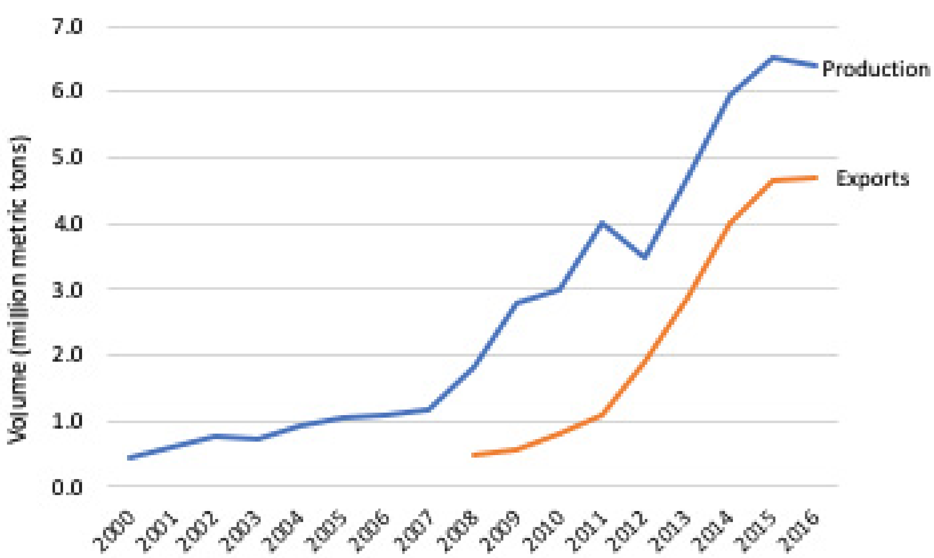

Figure 14.—U.S. wood pellet production and exports, by year (Lamers et al. 2012, Thrän et al. 2017, United Nations European Forestry Commission/Food and Agriculture Organization 2017).

gas emissions drive this demand in great part as Europe strives to meet 20 percent of its energy needs from renewable sources by 2020 (European Commission 2018b). Demand for wood pellets is likely to increase as countries in Europe and other regions move away from coal for power generation (Beeler and Morrison 2018).

The major driver for U.S. domestic consumption of wood pellets has been the competitiveness of wood biomass with heating oil and propane, coupled with very little industrial demand for pellets (Thrän et al. 2017). In the United States, wind and solar are the preferred renewable energy sources (Motyka et al. 2018). Growth of wood pellet production in the United States also responded to declines in the pulp and paper industry. However, wood biomass for pellets accounts for a small percentage of removals (e.g., only 2 percent of 2014 removals in the Southeast) (Dale et al. 2017). Currency exchange rates will greatly influence the future of U.S. pellet exports; a strong dollar will benefit suppliers in other countries. New environmental policies in the United Kingdom may negatively affect imports of U.S. wood pellets. However, new subsidies in the Netherlands may offset such losses (Tovey-Fall 2016). The European Commission publishes European and national biomass action plans (European Commission 2018a).

An emerging wood energy application is torrefaction, where wood biomass (as chips or pellets) is "roasted" in a low oxygen environment, increasing its energy density (Fosnacht 2018). Torrefied wood can be co-fired with coal in power generation, increasing renewable energy output and reducing emissions. Recent tests in several power plants yielded promising results (Fosnacht 2018, HM3 Energy 2018).

Other Products and Trends

Nanotechnology

Nanotechnology is the manipulation of materials at dimensions of less than 100 nanometers (Atalla et al. 2005). For perspective, 100 nanometers is approximately one-thousandth the thickness of a sheet of paper. At this scale, material properties change significantly from those of materials at a macroscale, allowing for new and unique applications. For example, some forms of nanocellulose exhibit high strength, transparency, and electroactive behavior (Hansen et al. 2014). It is believed that nanotechnology will be an important driver of economic growth, and it is expected to transform the forest products industry by opening new and commercially important areas for innovation. Significant investments are being made on nanoscience and nanotechnology research, such as the P3Nano Public-Private partnership (U.S. Endowment for Forestry and Communities 2018), the nanocellulose pilot plants at the USDA Forest Service's Forest Products Laboratory (Forest Products Laboratory 2018), and the University of Maine's nanomaterial pilot plant (University of Maine 2018). Some potential applications of nanocellulose technologies that are being investigated are in mining and drilling rheology agents, concrete additives, wood preservation, energy efficiency, drug delivery, tissue engineering and scaffolding, automobile parts manufacturing, food packaging, self-sterilizing surfaces, coatings, bioremediation, and computer chips (Bowyer et al. 2016, Laks and Heiden 2004, Moon et al. 2006, Wei et al. 2014).

Wood-based Chemicals and Biofuels

Deriving chemicals from wood is not a new industry. Exudates from pine (*Pinus* species) trees were used to obtain turpentine and rosin in North America beginning in the early 1700s, and these products had many applications in the "naval stores" industry

(Williams 1992). Wood hydrolysis, which converts wood polymers into simple sugars, has been understood for well over a century and has been used to create commercial quantities of rayon and cellophane since the early 1900s (Goldstein 1978). There is renewed interest in using wood biomass as raw material for chemicals traditionally derived from petroleum and other commodity compounds, as the chemical industry explores a transition from hydrocarbon-based products to carbohydrate-based products. Processes such as gasification, extraction, and fermentation seem promising for the commercial production of chemicals from wood biomass. For example, lactic acid, a very versatile platform chemical, is industrially derived from starch crops, but it is possible to use sugars from wood as raw material (Abdel-Rahman et al. 2011, Parajo et al. 1996). Other chemicals from wood with commercial application are acetic acid, furfural, succinic acid, methanol, itaconic acid, and hydrogen (MacKay et al. 2009).

Wood biochar, a product of thermal decomposition under conditions of low oxygen and low temperature, is commonly used as a soil conditioner (Lehmann and Joseph 2009) but has potential for carbon sequestration, for energy generation, and as a low-cost alternative to activated carbon (Groot et al. 2016). There are about 135 producers of biochar in the United States, with estimated production between 35,000 and 70,000 tons (32 to 64 teragrams; 1 Tg = 1 billion grams) per year (U.S. Biochar Initiative 2018). Future "forest biorefineries" could produce fuels and chemicals from wood biomass derived from a number of sources, including roundwood, short-rotation woody crops, harvest residues, small diameter thinnings, wood residues from manufacturing operations, demolition debris, or black liquor from pulp mills (Golden et al. 2018, MacKay et al. 2009).

Second-generation biofuels, based on cellulosic feedstock, were highly anticipated. Wood biomass is considered an attractive feedstock, due to its abundance (making up four-fifths of the total global biomass [Badger 2002]), relatively low cost, greater energy balance than starch-based ethanol (Morey et al. 2006), long storage life, high bulk density, high sugar content, and established collection systems (Roberts 2008). When harvested sustainably, forest biomass can be a source for renewable energy with low greenhouse emissions, minimum impacts on biodiversity, and carbon mitigation benefits (Bowyer et al. 2011a, 2011b; FAO 2010). However, cellulosic biofuels markets today have fallen short of the expectations. The 2016 Renewable Fuel Standard anticipated 17.0 billion liters (4.5 billion gallons) of cellulosic biofuel produced, and the actual production was only 0.6 billion liters (0.16 billion gallons) (most of it biogas) (Lynd 2017). Some of the causes are technological readiness, underinvestment, the large amounts of biomass and land required, balance between economies of scale and logistics, and the fall in oil prices. As investment in biofuels has dwindled, most of it has been directed toward biochemicals development (Lynd 2017).

Wood Composites

Many research and development efforts have been carried out to enhance wood properties by combining components of wood with other substances. For example, in fiber cement siding, cellulose fibers were incorporated into cement as a safer alternative to asbestos. This product has had market success since its introduction in the early 1980s, doubling its market share in the residential housing market during the last decade (see Figure 3). Wood-plastic composites (WPCs), which incorporate wood fiber into thermoplastics, are another successful alternative to solid wood, especially in market segments such as outdoor decking, siding, molding, and window manufacturing. Further development of WPCs may include the incorporation of nanomaterials, such as nanotubes, to enhance performance (Omar and Matuana 2008) and the advancement of structural applications, for example, by extruding WPC on solid wood.

Wood Modification Treatments

Some of the same forces driving the development of chemicals and composites derived from wood explain the expanding interest in chemical-free treatments to enhance wood's durability for both residential and industrial uses. Interest in treatments with lower impacts on the environment and human health has encouraged researchers and industries to develop treatments such as thermal and chemical modification of wood. In thermal modification, wood is heated to very high temperatures (Kocaefe et al. 2008), thus altering its chemical and physical properties (Esteves and Pereira 2009). As a result, dimensional stability and resistance to rot and decay are improved (International ThermoWood Association 2003, Leitch 2009, Rapp and Sailer 2000).

Thermally modified wood has been successfully marketed for nonstructural exterior applications, such as decking and siding (International ThermoWood Association 2003). Although it is still in its early stage of adoption in the United States, it is believed to have market potential as a high-end substitute for tropical tree species and WPCs (Gamache et al. 2017). In chemical modification, the basic chemistry of the cell wall polymers is changed to obtain the desired improved properties, often to reduce the hydrophilic nature of the cell wall or to improve dimensional stability. One chemical treatment that has had some market success is acetylation, where wood is treated with acetic anhydride, resulting in the esterification of the hydroxyl groups in the cell wall (Rowell 2013). Acetylated wood has shown improved dimensional stability and decay resistance (Ohkoshi et al. 1999, Rowell et al. 2009).

Chemicals-based Wood Preservation

A more traditional way to enhance the durability of wood has been to treat it with chemical preservatives. There are many preservative formulations, with the choice depending on the required protection, exposure, health and safety, and expected service life of the structure (Ross 2010). Wood preservatives are broadly classified in two groups: oil-borne preservatives and waterborne preservatives. Examples of oil-borne preservatives are creosote, copper naphthenate, and pentachlorophenol; and in the waterborne group commonly used preservatives are ACQ (alkaline copper quaternary), CCA (chromated copper arsenate), and ACC (acid copper chromate) (Vlosky 2009). In 2016, the wood preservation industry employed 10,600 and had a total value of shipments of $7.8 billion (U.S. Census Bureau 2018a). Currently heavy-duty preservatives, namely creosote, pentachlorophenol, and heavy metal systems, have the largest share of the wood preservation market for industrial uses. For the residential market, CCA, which was the predominant chemical, was discontinued due to environmental and health concerns and replaced by alkaline copper systems; more recently, micronized copper options have dominated residential applications (Morrell 2017). In the future, it is expected that the use of metal-free options, nonbiocidal treatments, coatings, and barriers will be expanded, after technical and economic limitations are overcome.

The Environmental Movement

Concern for the sustainability of natural resources and human health has given rise to market-based initiatives such as forest certification and green building rating systems (Espinoza and Dockry 2014, Espinoza et al. 2012). These systems are aimed at creating a market incentive for forest managers and companies to adopt sustainable construction standards. In the United States at the time of this writing, there are currently 14 million hectares (35 million acres) of forest certified under the Forest Stewardship Council system (Forest Stewardship Council 2018) and 33 million hectares (82 million acres) under the Programme for the Endorsement of Forest Certification (which, in turn, includes the Sustainable Forest Initiative and the American Tree Farm System) (Programme for the Endorsement of Forest Certification 2018). Green building systems promote the use of environmentally preferable materials in buildings, for example, by favoring the use of environmentally certified wood products (Espinoza et al. 2012). More than 63,000 projects achieved LEED (Leadership in Energy and Environmental Design) certification, the leading green building system in the United States, by 2018 (U.S. Green Building Council 2018). Other green building systems include Green Globe (Green Globe Ltd. 2018) and the Living Building Challenge (International Living Future Institute 2018).

Changing Demographics of the Labor Force

Demographic trends are likely to affect the forest products industry in the next two decades. An aging workforce and difficulty attracting new employees in some sectors can have negative effects on the industry. For example, the logging industry has been particularly affected; the median age of workers in the industry was approaching 50 years in 2017 and a workforce contraction of 13 percent is projected over the next decade (Bureau of Labor Statistics 2017). Added to the growing driver shortage in the trucking industry (Raphelson 2018), this shrinking of the labor force will make timber harvesting the most fragile link in the forest products supply chain. Innovations in timber harvesting technology such as automation, robotics, and precision forestry (Goulding 2016) are unlikely to offset labor shortages in this sector for the next two decades. Similar trends can be observed in other sectors, which makes it important to update recruitment and educational efforts (Espinoza 2015, Sharik and Bal 2018).

A Look 20 Years Ahead and Implications for the Forest Sector

The forest products industry will continue to play a critical role in the economic, social, and environmental development of the United States during the next two decades and beyond. However, several trends will affect the structure of the industry and the nature of its contributions to the economy and forest health. These trends include the globalization of the economy, export opportunities in fast-growing economies, increased interest in renewable materials and energy, changing demographics in the population, and technological developments. Some of these changes will increase the demand for wood fiber or shift its use to new applications, while others will reduce the need for wood. Potential scenarios are discussed next.

- Sustainability concerns, architectural and engineering considerations, and changes to building codes may lead to the increased use of timber in commercial and mid- and tall-rise building construction, including an increased use of prefabrication of building elements.
- The increased use of engineered wood products could lead to further improvements in wood utilization, particularly the use of small diameter and low-value trees.
- Production of wood-based energy products (e.g., biofuels, pellets) could increase, driven, in part, by demand in European and Asian countries. Increased production would benefit mostly producers in coastal areas. Greater demand for wood-based energy products could intensify competition for wood feedstocks with other sectors, such as wood-based panels and pulp and paper, potentially leading to higher fiber prices. A

growing wood energy industry could benefit forest landowners, but it could diminish profits in the manufacturing sector. However, small or no increases in wood energy consumption are likely in the United States in the medium term.

- Use of wood biomass as raw material for industrial chemicals and pharmaceuticals may increase. The concept of "forest biorefineries" could turn into an important source of demand for wood fiber. At the same time, nanotechnology applications of wood biomass may become available at a commercial scale.
- Demand for newsprint, printing, and writing paper is likely to continue to decline, while the use of recycled fiber in paper manufacturing is likely to increase further, resulting in reduced demand for wood fiber. The increasing demand for paperboard and packaging materials will offset part of the declining demand for communication paper.
- The expanding purchasing power in fast-growing economies could increase demand for forest products. As the gap between forest harvest and growth widens in these regions, greater imports will probably be needed to help meet growing demand in those countries. As a result, U.S. exports of logs, lumber, and some value-added products may increase during the next two decades.

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Technology as a Driver of Future Change in the Forest Sector: Projected Roles for Disruptive and Emergent Technologies

George H. Kubik

Abstract: This paper examines emergent and disruptive technologies as potential drivers of change in forest sector futures. Two questions are addressed: (1) Which emergent and disruptive technologies can be projected to substantively impact forestry futures? (2) What are the possible implications of emergent and disruptive technologies for decision makers, policymakers, and other stakeholders involved in forest sector futures? A 20-year timeframe is used for this explorative paper. A cross-disciplinary review of futures literature was implemented to identify and investigate leading emergent and disruptive technologies. A list of candidate technologies was developed from the literature review and eight technologies were selected: artificial intelligence, autonomous vehicles, electronic performance enhancement systems, genomics and synthetic biology, the Internet of Things, materials science, nanotechnology, and robotics. Each of the eight technologies was then defined and three representative forecasts were projected for each technology.

The goal is to provide decision makers, policymakers, and other stakeholders in the forest sector with an awareness of emergent and potentially disruptive technologies and how they might disrupt forest sector futures. The purpose of this paper is not to predict the future in detail, but to (1) promote awareness and informed thinking about the relationship between potentially disruptive technologies and forest sector futures and (2) stimulate a research agenda based on the study of these projected futures.

KEY WORDS: emergent technology, disruptive technology, artificial intelligence, autonomous vehicles, electronic performance enhancement systems, genomics and synthetic biology, Internet of Things, materials science, nanotechnology and robotics

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Introduction

The future is uncertain and it is not known how emergent and disruptive technologies will impact the future of the forest sector. What is known is that disruptive and emergent technologies are both volatile and unpredictable (Kaku 2011). Their potential impacts are largely unforeseen and frequently upset established norms of order by challenging traditionally accepted ideas, models and practices, and perceptions of what is possible in the future. Fortunately, foresight provides tools for anticipating many of these technologies and exploring their potential impacts.

There are several categories of technologies: disruptive, emergent, sustaining, and convergent. Disruptive technologies are new or enhanced technologies that rapidly and unexpectedly overturn established assumptions, models, and practices and radically redefine the competitive landscape in terms of unanticipated products or services. Disruptive technologies often supplant existing technologies and quickly render them obsolete (Armstrong 2017, Christensen 2016). Emergent technologies are new technologies that exhibit relatively fast growth, persistence, and the potential for substantial but uncertain impacts in the future (Rotolo et al. 2015). Emergent technologies are often unexpected. However, not all emergent technologies produce major disruption. Sustaining technologies are technologies that improve an existing product or service (Christensen and Raynor 2003). Finally, technological convergence is the synergistic combination of two or more different technologies in a single device or system (Roco and Bainbridge 2003). Technological convergence creates (1) artifacts or systems with new or improved features or applications and (2) a combined effect greater than the sum of individual technologies acting alone.

The emergence of new technologies encourages the development of innovative forest sector strategies. New technologies foster innovation by (1) expanding the range of opportunities and choices available to decision makers, policymakers, and stakeholders and (2) instigating the creative destruction of existing norms and modes of business. Because emergent and disruptive technologies are moving targets, they continuously surprise and challenge leaders and stakeholders through their sudden appearance and accelerated rates of adoption. They frequently develop in a nonlinear fashion that precludes prediction or detailed projections (Kurzweil 1999, 2005, 2006).

Surprise and disorientation often occur when legacy strategies fail to keep pace with emergent and disruptive technologies. This is especially true when the technologies are evolving at internet speed. It is within this rapid change framework that forest sector leaders and policymakers are constantly challenged to develop well-informed and continuously updated views of technology futures. This is not an easy task and leaders must be ready to experiment, invest, and disrupt their organizations (Christensen and Raynor 2003).

It is not the intention of this paper to predict which technologies will become the most disruptive or to determine the exact scope and consequences of their impacts. Rather, the goal is to provide decision makers, policymakers, and other stakeholders in the forest sector with an informed awareness of the importance of emergent technologies and their potential for future disruption.

Purpose

The purpose of this paper is threefold: (1) identify emergent and potentially disruptive technologies that are likely to exert significant impacts on forest sector futures, (2) examine a range of plausible consequences that can be attributed to these technologies, and (3) encourage informed thinking about alternative forest sector futures. The information developed through these questions will provide valuable information and insight for decision makers, policymakers, and others involved in influencing the future of the forest sector. It is also anticipated that the outcomes presented in this paper will produce new ways of thinking about forest sector strategies and generate further research into forestry futures.

Importance

Disruptive and emergent technologies are important because they redefine what is possible, probable, plausible, and preferable in the future of forestry. Importantly, they accomplish this while retaining human choice in the determination of alternative futures. The premise of this paper is the basic assumption that decision makers and policymakers can benefit from an improved knowledge of projected futures and the options presented by emergent and disruptive technologies.

Approach

A cross-disciplinary literature review was conducted to identify and investigate emergent and disruptive technologies. Eight leading technologies were selected based on their prevalence in the literature and their potential to redefine or disrupt forest sector futures.

A 20-year timeframe was established to evaluate future impact potentials. This framework was used for two reasons: (1) a 20-year projection was determined to be sufficiently advanced in time to preclude many of the biases exerted by current assumptions and existing trends and (2) two decades was sufficiently near in time that the current literature base provided a credible basis for identifying emergent and disruptive technologies and projecting their possible impacts. A time horizon greater than 20 years was determined to be too far-reaching due to the increased probability of radical technical change and other unforeseeable developments (Makridakis 1990). Millett (2006) has noted that while extended timeframes stimulate creativity and improve strategy development, overly prolonged timeframes may produce a loss of relevance for decision making in the present.

Books, periodicals, and journal articles that address emergent and potentially disruptive technologies were reviewed. Futures literature was emphasized in the review. The literature survey identified 15 candidate technologies that were evaluated for their prevalence in the literature and their potential for future emergent and disruptive impacts in the forest sector within the specified 20-year framework. The candidate technologies were artificial intelligence, autonomous vehicles, big data, computers, electronic performance enhancement systems, energy generation and storage, genomics and synthetic biology, the internet, the Internet of Things, materials science, nanotechnology, networks and connectivity, robotics, 3D printing, and virtual reality (VR) and augmented reality (AR). Although numerous other technologies were reviewed during the development of this paper, they did not appear to represent the same potential for major disruption in the forest sector within the 20-year framework. More extensive studies are needed to explore those alternatives.

Eight technologies were then selected for further study. The selected technologies were artificial intelligence, autonomous vehicles, electronic performance enhancement systems, genomics and synthetic biology, the Internet of Things, materials science, nanotechnology, and robotics. They were listed in alphabetical order and were not ranked by probability of occurrence, preferability, or impact potential. Their selection for inclusion in this paper was based primarily on their prevalence in the literature examined and their assessed potential as emergent and disruptive technologies within the 20-year forecasting timeframe. Each technology was defined and three representative forecasts were projected for each technology.

Current Trends and Impacts

There is an explosion of technological invention, innovation, and dissemination (Amidon 1997, 2003). Thus, the rate at which emergent and disruptive technologies occur is increasing and the rate of their development, diffusion, and adoption is accelerating. The traditional interactions among invention, innovation, and application are rapidly collapsing (Kelly 2010).

This rapid technology development and implementation cycle precludes the ability to predict the future of disruptive technologies and the ways in which they will be applied in any detail (Martino 1978). It also renders it increasingly difficult to project the links between extravagant claims and realistic potential. In this milieu there are numerous, and often unforeseen, cultural, economic, structural, and institutional barriers to the adoption of technology and varying lag times between their introduction and adoption (Rogers 1983).

Potentially Disruptive Technologies

This paper identifies eight technologies that exhibit the potential to substantively disrupt the forest sector. The eight technologies are defined, and their potential future impacts are identified. The projected timing of their introduction and their future diffusion rates are not addressed.

Artificial Intelligence

Definition

Artificial intelligence includes computer software systems that mimic or characterize cognitive functions that are commonly associated with human decision making, learning, problem solving, or general reasoning (Russell and Norvig 2016). Artificial intelligence is a general-purpose technology that drives an increasing number of smart, or intelligent, technologies using neural networks, expert systems, and smart agents (Denning and Metcalfe 1997).

Potential Future Impacts

- Expert avatar foresters and administrators-on-a-chip; artificial personas that convivially interface with stakeholders
- Machine learning for tapping big data to develop and analyze complex forest sector planning and projections including real-time climate projections, fire modeling, and forest condition
- Design and conduct of forest research by machine intelligence; real-time automatic language translation for global forest sector stakeholders

Autonomous Vehicles

Definition

Autonomous vehicles are computer-enhanced mobile systems that operate with limited or no human intervention in a wide range of environments and conditions using computer intelligence, sensors and actuators, and automated navigation systems (Gonzalez-Aguilera and Rodriguez-Gonzalvez 2017, Singer 2009). Autonomous vehicles employ artificial intelligence to independently operate in a wide variety of environments (air, water, on or beneath ground surfaces) at a variety of scales (macro, meso, micro, and nano levels) (López et al. 2017).

Potential Future Impacts

- Autonomous aerial, aquatic, and terrestrial vehicles for inventorying, monitoring, harvesting, and treating forest resources
- Autonomous aerial, water, and ground transport service for employees and visitors, transportation of law enforcement and emergency firefighting personnel and equipment, and rescue and evacuation
- Autonomous micro- and nano-sized drones that support multifaceted forest sector functions

Electronic Performance Enhancement Systems

Definition

Electronic performance enhancement systems (EPES) are a class of rapidly evolving computer software systems designed to enhance human ability to learn and perform work (Gery 1991, Rosenberg 2001). According to Winslow and Bramer (1994) and Bastiaens and others (1997), EPES promote real-time learning at points of performance and allow new workers to perform as world-class experts. They are networked and continuously updated systems that employ embedded smart or intelligent components that act together wherever and whenever needed to inform, guide, or assist in real-time learning and performance experiences (Dickelman 2000, Gery 1991).

Potential Future Impacts

- Multidisciplinary forest, administrative, and legal expert systems that provide the latest, leading-edge technical advice and assistance
- Performance enhancement systems that enable volunteers to perform as forest or administrative experts (across all disciplines and work assignments)
- Expert knowledge representation and reasoning systems that assist researchers

Genomics and Synthetic Biology

Definition

Genomics is the modification of the genes or genetic material (genomes) of organisms using one or more biotechnologies. Its purpose is to create new traits or capabilities in organisms (Lesk 2012). Synthetic biology involves the interaction of biology and engineering to design and construct, or redesign, new biological parts, devices, or systems; its purpose is to create new biosystems or new biosystem properties (or both) (Church and Regis 2012).

Potential Future Impacts

- Forest energy farms capable of generating power using genetically engineered foliage for solar energy biocollectors; genetically engineered forests that employ artificial photosynthesis to capture and store the energy of sunlight in chemical form for use in fuel cells
- Biological systems reprogrammed genetically for different properties (e.g., existing tree species genetically engineered for rapid growth, premium wood stock, drought and insect resistance, or climate change accommodation; trees designed for optimized carbon sequestration, fuel generation, or pharmaceutical production (Kaku 2011)
- Revival of extinct flora and fauna and creation of entirely new species

Internet of Things

Definition

The Internet of Things includes networked objects and environments that contain embedded electronics, computer software, sensors, actuators, and data communication technologies (Greengard 2015, Rose 2014). The Internet of Things is built into objects and environments to form connected, and increasingly self-adapting, systems that learn and modify their behaviors. They are projected to operate across a variety of scales (from macro-level to nano-level devices submolecular in size), operate in increasing densities, and function with increasing degrees of autonomy. The technology corporation Cisco has estimated that Internet of Things devices reached 20 billion in 2015 and will double to 50 billion connected devices by 2020 (Bates 2015). Constellation Research estimates that the Internet of Things will consist of over 80 billion sensors by 2020 (Bates 2015).

Potential Future Impacts

- Real-time inventorying of forest resources using organisms genetically engineered with smart bio-barcodes (operating at nano levels and equipped with networked active transmitters); continuous networked micro- or nano-level sensor monitoring of all protected organisms, sites, restricted areas, and sensitive zones
- Smart delivery of targeted microdrip fertilizer and pesticide applications
- Continuous (24 hours a day, 7 days a week) intelligent forest fire detection and suppression systems, building automation and energy management, predictive maintenance, and visitor scheduling and routing

Materials Science

Definition

Materials science addresses the design and production of new materials that exhibit unique physical properties and structures (Ball 1997). Materials science enables the creation of products with new or greatly improved properties (e.g., nano cellulose-based foam fire suppressants, load-bearing construction glass, ultralight and ultrastrong building materials, frictionless bearings, self-cleaning coatings, and programmable matter).

Potential Future Impacts

- Polymorphic infrastructure materials such as variable opacity smart glass that is stronger than steel, rust-proof, self-cleaning, and energy generating (e.g., no more graffiti or corrosion)
- Macroexpanding, environmentally friendly, nano cellulose fire-retardant aerogels that can be seeded by aircraft and computer controlled to degrade as soil nutrients
- Programmable matter that produces metamaterial-based invisibility cloaks for use by field researchers and visitors

Nanotechnology

Definition

Nanotechnology is based on the manipulation of matter at the molecular, submolecular, and atomic level (i.e., approximately 1 to 100 nanometers in at least one dimension) (Drexler 1986). Nanotechnology uses molecular disassemblers and assemblers to create new devices and materials involved in carbon nanotubes, nano medicine, nano solar cells, new building materials with extreme properties, and nano-scale machines (including nanocomputers and nanorobotics capable of self-repair and, in some instances, self-reproduction) (Drexler 2013, Drexler et al. 1991, Mulhall 2002).

Potential Future Impacts

- Nanoremediation of contaminated sites (e.g., remediation of contaminated soil and water on localized farm or industrial sites, large-scale pollution spills, and expansive super-sites) through nano conversion and nano filtration of toxic materials into valuable commodities
- Engineered nanoparticles that act as nano carriers to deliver ultra-low volumes of chemicals, herbicides, or genes to targeted plants or animals
- Real-time monitoring and analysis of entire biomes from submolecular levels to global systems using self-reproducing, self-repairing, nano-level biosensor networks and pocket-scale supercomputers (Petersen 1994)

Robotics

Definition

Robots are machines with computer systems that commonly employ mechanical body structures with sensors, appendages that can be manipulated (actuators), locomotive or moving subsystems (or both), electronic controls, and one or more power sources and software instruction systems (Bekey 2005, Singer 2009). They may be autonomous (e.g., using artificial intelligence or swarming systems), remotely controlled, or a combination. Robots are commonly used for a wide range of applications such as agriculture, domestic services, food service, health care, manufacturing, medical care (including surgery), and law enforcement applications (Kurzweil 2005, Miller 2010). Future robots will operate at an increasing range of scales (e.g., nanorobots operating at submolecular levels and megaconstruction robots operating at massive scales) and in a variety of environments (e.g., airborne, marine, terrestrial, and subterrestrial [Singer 2009]).

Potential Future Impacts

- Self-reconfiguring mobile modular robots conducting a wide range of physical labor in the forest sector (e.g., timber inventory, treatment, pruning, thinning, and removal) with minimal environmental intrusion
- On-demand robo-fire fighters and robo-emergency responders; animatronic robots for visitor assistance; robo-law enforcement agents; and robots for construction and infrastructure maintenance
- Nano- and micro-level robots operating sub-surface for soil aeration or amendment; aquatic robots for water quality sampling and treatment; and airborne robots for surveillance, inventorying, or cloud seeding

What is the value of this exercise? The value lies in promoting an awareness of the future, the opportunities that it presents, and the need to prepare for future unknowns (Johansen 2007). Each of the technologies presented in this paper represents the potential to produce sudden and largely unforeseen changes in forestry. It is an exercise that invites anticipatory governance, the capacity to manage emerging technologies in advance (Guston 2014).

Implications for Forestry and the Forest Sector

Over the next 20 years people will witness changes in the forest sector on an unprecedented scale. Emergent and disruptive technologies will continue to be among the major drivers of those changes and will continue to surprise, disorient, and misdirect (Johansen 2012, Schwartz 2003). However, while surprise may be inevitable, the element of surprise does not undermine the value of preparation (Lombardo 2006).

The literature of technology forecasting documents the value of how forward-looking, anticipatory stances can enhance decision making, policy formulation, and stakeholder understanding of future alternatives (Amstéus 2011, Lustig 2015). It confirms how well-conducted futures studies, using established methodologies, can (1) promote the development of robust and resilient options for the future and (2) identify scenarios that permit the exploration of potential primary, secondary, and tertiary impacts (Bell 1997, Hines and Bishop 2006, Ringland 1998). A major goal of this paper is to identify a range of emergent and disruptive technologies that might serve as valuable candidates for future forest-related horizon scanning efforts.

Conclusions

This paper addresses emergent and disruptive technologies that have the potential to change the game for forest leadership, forest policymakers, and forest sector stakeholders. It is probable that these technologies will create entirely new ranges of forest products, services, and capabilities in the future. It is equally probable that they will also create a spectrum of legal, social, and regulatory challenges that have not existed before. The challenge for forest sector decision makers , policy formulators, and stakeholders today is to develop an awareness of (1) future technological possibilities, (2) how future game-changing technologies have the potential for disruption, and (3) how to turn future disruptive technologies into opportunities. The challenge is awesome!

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Demographics as a Driver of Change in the U.S. Forest Sector

Robert L. Olson

Abstract: Demographic trends such as rapid population growth, urban expansion, regional population shifts, amenity migration, an "elder boom," and increasing ethnic and cultural diversity will require adaptive responses by planners and forest managers. Urban forestry will become more important and doing it well will require better integration of forest management with urban planning and better coordination across organizations and fields of knowledge. Fostering fire resilience will need to become a major focus of effort as more people and structures are located in fire-prone wildland areas. More accessible infrastructure will be needed for an aging population. Better understanding of how ethnic and racial minorities view and use forest resources will be useful as they become an ever-larger proportion of the population. The sooner the scale of these challenges is appreciated, the more likely they are to be met well.

KEY WORDS: population growth, urban expansion, regional population shifts, amenity migration, aging population, diversity, wildland-urban interface, accessible infrastructure

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Introduction

We may not be demographers, but all of us are regularly exposed to the language and concepts of demography. We have a good idea of what terms like "urban sprawl," "millennials," and "diversity" mean and we know that changes in where people live and the character of our Nation's population can affect our lives. These same demographic factors will be important in shaping the future of America's forests.

This paper examines some key areas of demographic change that will influence U.S. forests over the next two decades. It begins by reviewing current trends; then it looks at forecasts for the next 20 years and explores potential implications of these trends for forestry and the forest sector.

Demography is an area where projections of the future are well developed and generally more reliable than forecasts of other aspects of change. However, it is important to keep in mind that there are still significant uncertainties. For example, projections of urban sprawl could be derailed by greater adoption of Smart Growth policies and increasingly severe forest fires and storms could influence where people choose to live. This paper presents both standard projections and uncertainties for consideration by forest planners and managers.

Current Trends

Population

The U.S. population grew by 11.5 percent between 2000 and 2017, from 282,896,000 to 326,922,000 (Worldometer 2017). This is the fastest rate of population growth of any developed nation.

Urban Land Use

Incorporated places or "cities" are home to 62.7 percent of the U.S. population and cover 3.5 percent of the U.S. land area (U.S. Census Bureau 2015). By a broader definition, 81 percent of the U.S. population lives in "urban areas," up from 75 percent in 1990 (Center for Sustainable Systems 2019). Low-density housing developments in suburban and exurban areas have been the major factor in increasing urban land use over the past 50 years. Areas settled at suburban and exurban densities (6 to 250 houses per 100 hectares, or 1 house per 1 to 40 acres, on average) cover more than 15 times the land area settled at urban densities (1 house per 250 km^2 or less) and covered 5 times more land area in 2000 than in 1950 (U.S. Census Bureau 2012).

Regional Shifts

A regional shift of population to the Sun Belt has been underway for several decades. The Great Recession of 2007 to 2009, and the economic sluggishness that followed, interrupted growth in the South and West, but growth has now resumed.

Amenity Migration

Growth has also been occurring in rural areas with attractive scenery and cultural amenities, including the Rocky Mountain and Pacific Coast regions, along the southern Atlantic coast and Gulf of Mexico, and in the Ozark Mountains and southern Appalachia. This movement was first documented in the 1950s (Ullman 1954) and it has been accelerating ever since. Recreational opportunities, forests, lakes, seashores, and mountains attract both part-time and full-time residents, retirees, and professionals able to telecommute.

Elder Boom

The United States reached a new milestone in 2017: There are now 50 million people over the age of 65, up from 20 million in 1970 and 35 million in 2000. During the decade 2000 to 2010 the population of older people began growing faster than the Nation's population as a whole, and the rate of growth increased further after 2011 when the first of the approximately

76 million persons who were born during the "baby boom" between 1946 and 1964 reached age 65 (SeniorCare.com 2017).

Growing Diversity

Whites made up about 85 percent of the U.S. population in 1965, with most of the remaining 15 percent African American. Since then, the white majority has shrunk to just over 60 percent, Hispanics make up about 18 percent, and Asians make up about 6 percent. The percentage of African Americans has stayed roughly constant.

This dramatic change in the Nation's racial and ethnic makeup over the past 50 years is the result of high rates of immigration. Nearly 59 million immigrants have arrived in the United States over this period, mostly from Latin America and Asia. Contrary to popular imagery, Asia has now replaced Latin America (including Mexico) as the largest source of new immigrants (Cohn and Caumont 2016). As a sign of things to come, there are now more students of color than white students in U.S. public schools (Carr 2016).

A Look 20 Years Ahead

Population

The U.S. population is expected to grow from 327 million today to 383 million by 2040 and to nearly 400 million by 2050 (Sen 2016). This projection means that between 2013 and 2050, the U.S. population could grow more than the population of all the other 19 largest "more developed" countries combined, a development made possible because the populations of several of those countries will actually decrease (Table 1). Immigration is expected to drive most of this anticipated growth, so major

Table 1.—Actual and projected population in the 20 largest "more developed" countries (Source: Sen 2016)

Country	Mid-2013 population	Projected 2050 population	Change from 2013 to 2050
	(millions)		
United States	316.2	399.8	83.6
Russia	143.5	132.4	-11.1
Japan	127.3	97.1	-30.2
Germany	80.6	76.2	-4.4
United Kingdom	64.1	78.8	14.7
France	63.9	72.3	8.4
Italy	59.8	62.2	2.4
South Korea	50.2	48.1	-2.1
Spain	46.6	42.3	-4.3
Ukraine	45.5	33.9	-11.6
Poland	38.5	34.3	-4.2
Canada	35.3	48.4	13.1
Australia	23.1	34.2	11.1
Romania	21.3	18.5	-2.8
Netherlands	16.8	17.9	1.1
Belgium	11.2	13.1	1.9
Greece	11.1	9.7	-1.4
Portugal	10.5	8.7	-1.8
Czech Republic	10.5	10.6	0.1
Hungary	9.9	9.1	-0.8

changes in U.S. immigration policy could affect the growth rate.

Urban Land Use

There is much uncertainty about how far urban growth will penetrate into forest and agricultural land over the decades ahead. A classic study of urban growth and its estimated impact on the U.S. forest resource made projections based on the assumption that the rate of urban growth that occurred between 1990 and 2000 would continue out to 2050. By this supposition, urban land in the conterminous United States would increase from 3.1 percent of the Nation's land area in 2000 to 8.1 percent in 2050 (Nowak and Walton 2005). A more recent study estimates that urban land in the lower 48 states will increase to between 10 percent and 12 percent of the U.S. land area by 2050 (Wear 2011).

Population growth is the single largest factor in these estimates, but there are clearly other dynamics involved because urban areas have been spreading at about twice the rate that population has been growing (U.S. Department of Housing and Urban Development 2000).

Research stretching back over several decades shows that the other largest driver of urban expansion is public policy that subsidizes urban sprawl in the form of new water and sewer lines, roads, schools, emergency services, and incentives to new businesses and industries to locate in low-density areas (Transit Research Board 1998). Wider use of Smart Growth policies could have a large restraining effect on urban sprawl (American Planning Association 2012). Adequate Public Facilities Ordinances (APFOs) are an example of a Smart Growth policy; they make low-density development pay its own way by requiring that infrastructure like roads and sewer lines be fully paid for before new development takes place.

Economic conditions can strongly affect urban expansion. People flocked to ever more-distant suburbs and exurbs in the early 2000s as easy mortgages fueled a housing bubble. But when the bubble burst, these distant places took the biggest hit. Growth stalled and the news media carried pictures of abandoned or never lived-in houses in "ghost subdivisions" (Roth 2008).

The cost of gasoline could emerge over the next decades as another factor influencing urban expansion. Suburban and exurban development has been made possible by low-cost energy. Adjusted for inflation, the cost of gasoline today is lower than it was in 1931. Most energy analysts believe that oil will remain available over the decades ahead but will become more expensive due to both policy—putting a price on carbon to mitigate climate change—and the increasing cost of extracting oil from more challenging and remote sites. While the shale oil and gas boom through hydraulic fracturing (fracking) has decreased U.S. prices for natural gas, it has had limited impact on gasoline prices (Kilian 2016). A small set of analysts believes that we are near "peak oil." This condition is the point where global production will begin a steep decline while demand continues to increase, sending oil prices soaring; suburbia would soon be harshly devalued and exurbia abandoned (Kunstler 2006). Even if such a dark future is unlikely, if not impossible, it does seem plausible that gasoline prices will increase over the next years. But whether the increase will be enough to have an impact on urban sprawl is uncertain. Progress in the development of electric vehicles and batteries and the rate at which electric vehicles penetrate the transportation system are additional sources of uncertainty.

Urban expansion could also be influenced by changes in people's preferences about where and how they want to live. Surveys suggest that growing numbers of people say they prefer walkable communities over car-dependent ones (National Association of Realtors 2015). A segment of millennials appears to prefer city to suburban living, at least for their present stage of life. For a few years starting in 2011, dense counties at the center of large metropolitan areas actually grew faster than the exurbs. Updated Census Bureau county population estimates, though, show that the exurbs have again begun growing faster than more urban places (Badger 2015).

Demographers are unsure about what is happening largely because it is hard to untangle people's preferences from economic conditions. Does the so-called "return to the city" reflect lasting changes in preferences among some population groups? Will urban expansion be slower than earlier estimates suggest? Demographers are waiting for more data to give more definitive answers.

Regional Shifts

If current trends in regional population distribution continue, the U.S. population will be even more concentrated in the South and West. Recent projections by the Demographics Research Group at the University of Virginia foresee the most rapid population growth over the next 25 years occurring in Texas, Colorado, Utah, and Florida, with rapid growth also in California, Georgia, North Carolina, and Virginia. Nearly a dozen states in the Northeast and Midwest are projected to lose population between 2030 and 2040; the largest percentage losses would take place in West Virginia, Vermont, Maine, Illinois, and Michigan (Sen 2016).

On a 20- to 30-year time scale, however, it is possible that drought and related water shortages, wildfire, extreme heat, extreme precipitation, hurricanes, storm surge flooding, and other impacts of climate change could disrupt current trends. A recent analysis of locations likely to be most attractive for minimizing impacts of climate change highlights Maine and states around the Great Lakes that standard projections assume will lose population (Bromwich 2016).

Amenity Migration

The U.S. population is likely to continue moving to scenic rural areas over the next two decades. Researchers have identified a wide range of factors driving this trend, including tax laws, industrial restructuring that has taken away previous rural jobs but made areas more attractive to migrants, the decline of commercial forest operations, retirement of baby boomers, the decreasing real cost of transportation, growth of the digital economy and telecommuting, a value shift from consumption of things to consumption of experiences, and the pursuit of a rural or small town "idyll" away from the congestion and pressures of big city life (Gosnell and Abrams 2011). When a trend is driven by so many determinants, it is likely to be robust.

Elder Boom

As the baby boom generation ages, the percentage of the U.S. population 65 and over is estimated to nearly double, from 12 percent of the total population in 2000 to 21 percent in 2050. The population of older people is projected to reach 80 million by 2040 and nearly 100 million by 2060 (Mather 2015).

Diversity

The United States will become much more diverse over the decades ahead. The Census Bureau projects that minority groups will collectively represent a majority of the U.S. population by 2044. Other researchers believe it will take until 2055 or even longer to reach this point (Horowitz 2016), but there seems little doubt that we will become a minority-majority nation sometime within the next 30 to 40 years (Fig. 1).

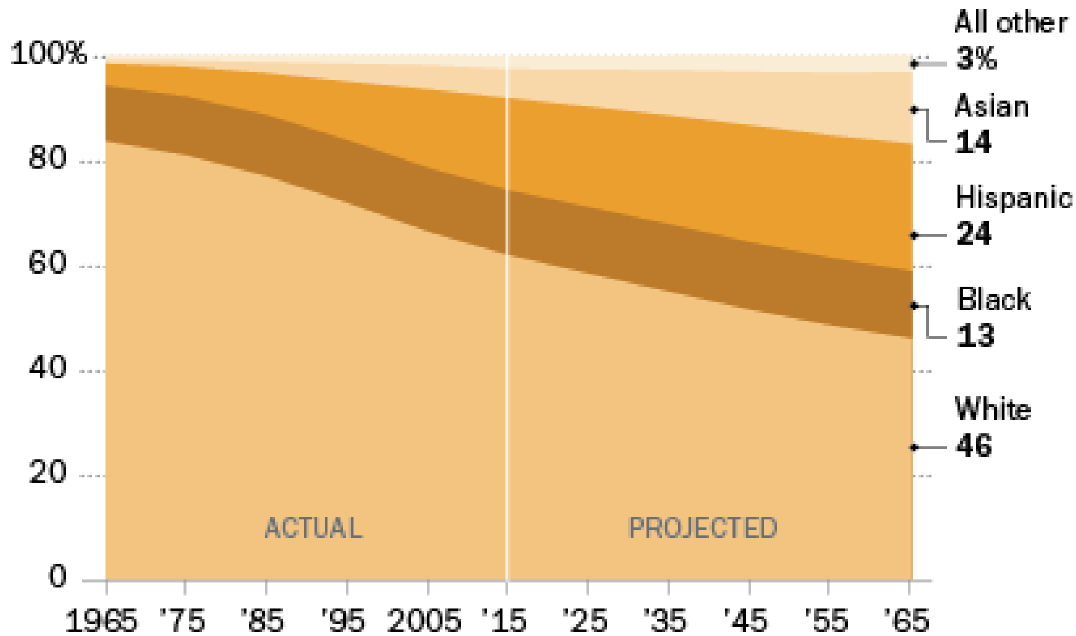

Figure 1.—The changing face of America, by year (reproduced from Pew Research Center 2015). Note: Whites, Blacks, and Asians include only single-race non-Hispanics; Asians include Pacific Islanders. Hispanics can be any race.

Implications for Forestry and the Forest Sector

Population growth and other factors are likely to cause over 5 percent of existing forest land outside of urban areas to be subsumed by urban growth between 2000 and 2050 (Nowak and Walton 2005). Southern states—especially Georgia, North Carolina, and Texas—are projected to have the highest total amount of forest area subsumed. Rhode Island, New Jersey, Massachusetts, Connecticut, and Delaware are likely to have the largest percentage of currently nonurban forest land transformed by urban growth.

As more forested land is impacted by urbanization, forest management objectives may need to continue shifting from commodity-based management toward management for a wide range of ecosystem functions and services, such as stormwater retention, water quality, shading and cooling, recreation, and health benefits (Daniel et al. 2012, Delphin et al. 2016, Li et al. 2017, Pickard et al. 2017).

Wise management for ecosystem services will require better integration of forest management with urban planning and better coordination across organizations and fields of knowledge (Bengston et al. 2004). The ideal to move toward is planning that begins with an understanding of the structure and function of ecosystems. Better management would also require effective public outreach and civic engagement using nontechnical language, engaging storytelling, and compelling visual imagery of urban landscapes that promote both human well-being and ecological health.

Growing amenity migration means more and more people and structures will live in the path of wildland fires—the wildland-urban interface (WUI). Governance of these areas can be difficult because it involves multiple scales, societal values, and institutions (Abrams et al. 2015, Paveglio et al. 2009, Steelman 2016). Forest management could shift to focus more on encouraging communities to become fire-resilient, fostering measures such as codes to make buildings more fire-resistant, and protection zone standards for eliminating flammable vegetation adjacent to structures (Olson et al. 2015).

As the Elder Boom continues across several decades, forest managers and outdoor recreation planners will need to provide more accessible infrastructure to enable older people to continue engaging in outdoor recreation. Members of the baby boom generation typically think of themselves as younger than their chronological age and are likely to stay involved in outdoor activities longer than previous generations. Rapidly growing cultural diversity means that planners and managers with a nuanced understanding of how ethnic and racial minorities view and use forest areas are more likely to meet the needs of these outdoor recreationists (Bengston et al. 2008, Roberts et al. 2009).

Conclusions

Many demographic developments important for the future of forestry are highly likely if not quite certain. Population growth will continue in the United States at a faster rate than in any other developed nation. Ongoing expansion of urban areas will transform large areas of contiguous forest to a parcelized urban forest made up of parks, yards, and street trees amid impervious surfaces. Population will grow most rapidly in areas of the South and West. Migration to scenic rural and forested areas will continue to accelerate. The over-65 population will grow rapidly and what have been considered minority groups will become the majority. These developments will pose challenges for urban forestry and the entire profession of forest management. The sooner the scale of these challenges is appreciated, the more likely they are to be met well.

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Shifting Forest Values as a Driver of Change

David N. Bengston

Abstract: Forest values are significant drivers of change in the relationship between people and forests. Our forest values shape our attitudes, beliefs, and behaviors toward forests and guide forestry policy and management. Forest values have shifted and evolved significantly in the past and will continue to change in important and unexpected ways in the future. This paper presents a simple framework for understanding the forest values that people hold, briefly reviews historical and current trends in forest values, and sketches out three plausible alternative scenarios for how values could unfold and affect forestry and society.

KEY WORDS: forest values, scenarios, drivers of change, trends

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Introduction

Forest values are significant drivers of change in the relationship between people and forests. More (1995: 22) observed: "We stand linked to the world by our values. The same values determine not only how we respond to change, but how we act upon it as well."

Values occupy a central place in current and future forest management and policy because they shape and guide every decision, plan, and policy. Forest values have shifted and evolved in the past (Hays 1988, Xu and Bengston 1997) and will continue to change in unexpected ways in the future.

Values have been defined many different ways across academic disciplines. A thorough review of the many disciplinary conceptions of value is beyond the scope of this paper, but a fundamental and widespread distinction made in defining values is between held and assigned values (Brown 1984). "Held values" are ideals or conceptions of "the good," such as desirable modes of conduct (e.g., courage, honesty), end-states of existence (e.g., equality, sustainability), or qualities (beauty, uniqueness). "Assigned value" is the relative importance or worth of an object, often measured in monetary terms. The focus in this paper is on the changing "held values" of forests and their implications for the future of forests and forestry. Held forest values are defined as concepts of the good related to forests and forest ecosystems. Simply stated, forest values are "the various ways in which forests are important to people" (Duinker 2008: 1).

Many categories of held forest values have been distinguished (Fig. 1). Instrumental value is a concept of the good that focuses on what is useful as a means to some desirable human end. The instrumental value of the environment arises from the fact that "nature benefits us. Nature is useful: it serves a purpose, satisfies a preference, or meets a need" (Sagoff 1991: 32).

The instrumental value of a forest ecosystem stems from its utility as a means to a specific end or the realization of other values. For example, sawtimber is prized not for its own sake, but rather for its usefulness in building things that increase human well-being.

Economic or, more broadly, utilitarian value, is a type of instrumental value. Like instrumental value in general, the economic or utilitarian value of a forest ecosystem stems from its utility for achieving human ends,

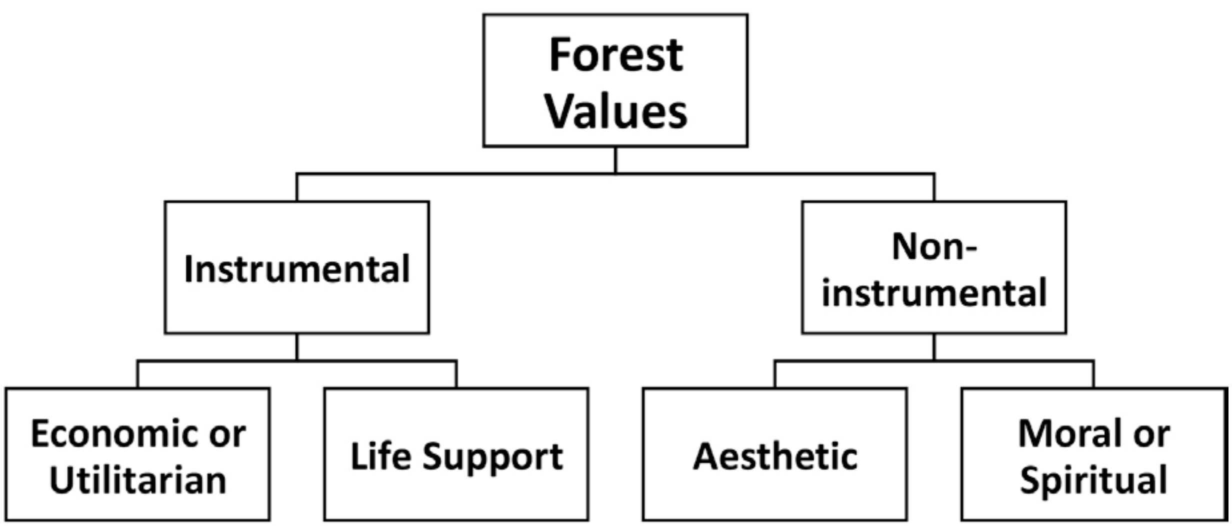

Figure 1.—Broad conceptual categories of held forest values (adapted from Xu and Bengston 1997).

where the ultimate end or goal is maximizing preference satisfaction (Bengston 1994). The economic conception of the value of nature focuses on the usefulness of nature as expressed in individual preferences or an aggregation of individual preferences.

Life support or ecological value is another broad concept of what is instrumentally good about forest ecosystems (Bengston 1994). Life-supporting ecological functions and services are good because human well-being depends on them. Unlike economic value, life support value is not adequately measured by an aggregation of people's preferences for environmental functions and services. Many people are unaware of the life-supporting benefits that ecosystems provide, so aggregating preferences or willingness to pay for life-supporting environmental services does not produce a meaningful measure of their importance.

Noninstrumental value focuses on the worth of something as an end in itself, rather than a means to some end (Bengston 1994). We value family members and other people in this way, in addition to valuing them instrumentally for the benefits we receive from them. They have "a good of their own"; they cannot be substituted for or replaced. Many people value forests noninstrumentally, in ways that go beyond their contribution to self-interested goals.

Aesthetic value is a type of noninstrumental value, in which the concept of the good is beauty. Aesthetic value has historically had profound impacts on public land policy and management: "One of the main reasons that we have set aside certain natural areas as national, state, and county parks is because they are considered beautiful" (Callicott 1992: 12).

Finally, moral or spiritual value is also a type of noninstrumental value. Humans value an object morally when they regard it with love, affection, reverence, and respect (Sagoff 1991). This is what Aldo Leopold (1966: 261) had in mind when he wrote: "It is inconceivable to me that an ethical relation to land can exist without love, respect, and admiration for land, and a high regard for its value. By value, I of course mean something far broader than mere economic value . . ."

Spiritual value is a type of moral value. Environmental psychologists and philosophers have studied the spiritual value of forests and trees. One environmental psychologist has defined spiritual as "the experience of being related to or in touch with an 'other' that transcends one's individual sense of self and gives meaning to one's life at a deeper than intellectual level" (Schroeder 1992: 25).

In addition to broad conceptual categorizations of forest values such as that depicted in Figure 1, many detailed typologies have been developed based on empirical research with stakeholders that show the diversity of specific values associated with forests. Different stakeholder groups often hold unique forest values, and different types of forest ecosystems—such as old-growth or urban forests—have distinct sets of values associated with them. Examples of detailed value frameworks include typologies of old-growth values in Canada (Moyer et al. 2008), the diverse values of family forest owners in the United States (Bengston et al. 2011), national forest values of Alaska residents (Brown and Reed 2000), and national forest values in New England (Manning 2003).

Historical and Current Trends

Environmental historians and other scholars have documented the sweeping changes in forest values and our relationship with forests and other wildlands over time (Clawson 1979, Nash 2001, Perlin 1989) and especially during the last half of the 20th century (Hays 1987, 1988). Many factors combined to make the period following World War II a time of rapid and significant change in environmental and forest values:

- a massive increase in outdoor recreation in the 1950s and 1960s (Cordell 2008). Unprecedented numbers of people visited national forests, national parks, and other public lands during this time.
- an increasingly urban population (U.S. Census Bureau 2012). Urbanization has changed the amount of direct interaction that most people have with wildlands.
- sprawling development patterns, growing multiple and seasonal home ownership, and amenity migration (Hammer et al. 2009). These shifts have expanded the wildland-urban interface and brought people with diverse environmental values into rural areas. Retirement by the baby boom generation over the next 20 years and continued sprawl are expected to intensify most of these trends.
- long-term structural changes in the economy such as the decline in the relative importance of the primary sector (making direct use of natural resources), decreased employment in the primary sector, and the rise of employment in the service sector. These changes in the production of goods and in employment have contributed to a shift away from economic or utilitarian forest values and toward the ecological and noninstrumental values of forests (Xu and Bengston 1997).

The net result of these and other changes has been a steady shift in the relative importance of various held forest values over time. For example, Bengston et al. (2004) found a decrease in anthropocentric forest value orientations (clusters of interrelated values and basic beliefs about forests) over the period 1980 through 2001, and an increase in the share of biocentric values. Hays (1988) found that the American public has increasingly valued forests for their amenity and ecological values such as open space and scenic beauty, clean air and water, wildlife habitat, and biodiversity. Finally, a nationwide survey of Americans' values related to public lands was carried out in support of the USDA Forest Service's strategic planning efforts (Shields et al. 2002). The results showed that the public has a strong values orientation toward environmental protection and biocentric values, and a moderately strong conservation and preservation ethic. These shifts in forest value orientations have implications for identifying appropriate goals for public forest management and policy, developing socially acceptable means for accomplishing those goals, and dealing with inevitable conflict over forest management.

A Look 20 Years Ahead

Predicting how forest values will evolve over the next 20 or 30 years is fraught with uncertainty because so many known and unknown factors could affect the nature and direction of changes in values (Lawrence 2004). Just as many factors shaped forest values in the past, a wide range of factors could affect them in the future, including:

- broader cultural currents, such as disillusionment with consumer culture and a decline in materialist values.
- major technological innovations, such as artificial reality technology. Technological innovations could increasingly substitute for first-hand experiences with nature, thereby fueling a decline in environmental values.
- economic change, such as significant economic decline. Pressure could be exerted to accelerate the exploitation of natural resources in an attempt to increase economic growth, fostering more utilitarian environmental values and attitudes.
- social trends that promote a decline in outdoor activities and engagement, such as growing "videophilia." These trends could result in apathy toward the environment and an increasing disconnect with nature (Balmford et al. 2002, Kareiva 2008, Zaradic 2008).

- the growing use of social media. The increasing influence of social media is changing where and how people engage in outdoor recreation (Zimmerman 2018) and could significantly affect environmental values.

Therefore, rather than attempting to predict the future of forest values, this section briefly explores several plausible directions in which forest values could unfold in the coming decades. Three mini-scenarios are briefly sketched out here, representing a wide range—but by no means an exhaustive list—of plausible forest value futures. These scenarios were developed by identifying broad forest value trends (growing ecological, utilitarian, and apathetic values) and drawing from a variety of information sources to support and elaborate these trends. The mini-scenarios are labeled Eco-Utopia, Back to the Utilitarian Future, and Growing Apathy and Disengagement.

Eco-Utopia is a forest future in which the ecological and spiritual values of forests grow significantly and eventually become dominant. The sharp rise of life support and spiritual forest values was prompted in part by an acceleration in climate disruption and recognition that a disastrous climate tipping point from which we might not recover was rapidly approaching. Indicators of this tipping point included the collapse of the West Antarctic Ice Sheet, the complete summer melting of Arctic sea ice, and the abrupt increase in all the impacts of climate change, from heat waves, droughts, and wildfires to more intense storms, flooding, and the spread of tropical diseases into temperate zones. These indisputable signs of a rapidly changing climate came at the same time as growing Indigenous empowerment, especially with respect to natural resources and the environment, in many regions of the world. Solutions that embraced both ecological science and Indigenous values of the sacredness of the Earth were seen as crucial to dealing with mounting environmental crises. The integration of science and Indigenous spirituality and epistemologies changed how most people viewed the natural world and humanity's relationship to it, resulting in a massive mobilization to stabilize the global climate. The rise of ecological and Indigenous values had profound effects on forestry and natural resource management, as managers aspired to "go with the flow" of natural processes in every way. Foresters quickly came to view fire as a natural part of the landscape with important ecological functions. They learned to live with fire and help build fire-resilient communities rather than wage war against it (Olson et al. 2015).

Back to the Utilitarian Future is a scenario in which forests are highly valued and of growing importance, but for very different reasons than in an Eco-Utopian future. In this scenario, the economic/utilitarian values of forests have come to the forefront. A new "age of wood" dawned due to multiple and significant technological innovations in wood products that cumulatively created a thriving bioeconomy and dramatically increased the demand for wood and wood fiber (Bowyer et al. 2017). Examples of these innovations include wood-based nanomaterials with thousands of uses ranging from computer chips to automotive panels; tall wood buildings or "plyscrapers" made of cross-laminated timber and other "mass timber" technologies; 3D printing using cellulose from wood pulp; fabric made from wood fibers that uses 99 percent less water and 80 percent less energy than producing cotton; transparent wood substitute for glass in windows and solar cells made by chemically removing lignin from natural wood fibers; and countless other game-changing technologies (Bengston 2019). These innovations combined to create a revolution in wood products, the rise of a bioeconomy based on renewable and biodegradable wood-based materials, and a dramatic increase in the economic and utilitarian values of forests. The increased utilization of wood also increased tree planting on a massive scale, resulting in increased absorption of atmospheric carbon dioxide. Rapid development of markets for small diameter wood that formerly lacked economic value led to widespread thinning of overgrown forests to supply the markets and decreased the risk of catastrophic wildfire.

In contrast to the first two scenarios, **Growing Apathy and Disengagement** is a future in which all types of forest values decline significantly. The roots of this decline can be traced to a steady drop in outdoor activities—from gardening to hiking—as more and more people became "glued to their screens" instead of experiencing nature. Environmental and conservation issues were utterly ignored during political campaigns because they had dropped so far down on the priorities of all but a very small minority of the population. Growing apathy toward the environment produced a cascade of negative results for nature and society (Bengston et al. 2019): a significant decline in political and budgetary support for the Forest Service and other natural resource management agencies; slashed natural resource research funding; the sale of many local, state, and Federal public lands to private individuals and developers; unsustainable logging and mining on former public lands; and increased stress and anxiety among children and young adults suffering from "nature deficit disorder." As forest values waned, forest ecosystems began to slowly unravel due to abuse and neglect.

Concluding Comments

Shifting values are a strong driver of change. Some have argued that, throughout human history, the predominant values of the time have always shaped the future (Lent 2017). Our forest values shape our attitudes, beliefs, and behaviors toward forests and guide forestry policy and management. The nature and speed of shifts in forest values will have a substantial impact on the future of forests and forestry.

But fundamental uncertainties about forest values in the future suggest that there are many plausible scenarios for changing forest values and how they could affect forestry and forest management agencies in the long run. The three mini-scenarios sketched out in this paper—Eco-Utopia, Back to the Utilitarian Future, and Growing Apathy and Disengagement—point to very different but equally plausible directions in which forest values could unfold, with sharply different implications for forestry and society. Exploring a wide range of alternative futures can provide a useful basis for ongoing strategic conversations about the future of forestry and help decision makers prepare for whatever scenarios unfold.

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Indigenous Rights and Empowerment in Natural Resource Management and Decision Making as a Driver of Change in U.S. Forestry

Michael J. Dockry

Abstract: Indigenous peoples have been fighting for recognition of their rights to land and resources for generations. They have also voiced clear opposition to activities that degrade natural resources, the environment, and tribal sovereignty. Over the past several decades, Indigenous empowerment and influence over natural resource management has increased to the point where they have the potential to influence major environmental issues like climate change, fossil fuel extraction and transport, timber harvesting, and water management. This paper explores these and several other key areas where Indigenous rights are being recognized and exercised in ways that could have important implications for natural resource management. Additionally, three scenarios are presented to represent possible futures with regard to natural resource management: increased collaboration and comanagement, increased litigation, and increased violence. A fourth scenario is also presented where all three scenarios occur simultaneously in different places and times throughout the world. Indigenous empowerment has the potential to become a major driver of change for natural resource management and policy.

KEY WORDS: Indigenous peoples, Indigenous rights, Indigenous empowerment, tribal sovereignty, comanagement

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Introduction

Since colonization, Indigenous and American Indian people have been increasingly exercising their sovereign rights to manage land and resources (Fenelon and Hall 2008, Jorgensen 2007, Mander and Tauli-Corpuz 2006, Wilkinson 2005). Indigenous sovereignty comes from its original control over lands, cultures, and communities and is not something that is given to Indigenous people by settler governments (Barker 2005, Bruyneel 2007). In the United States, tribal sovereignty is inherent and predates the U.S. Constitution (Wilkins and Lomawaima 2001). While Indigenous sovereignty is complicated by the history of colonialism, simply put, Indigenous communities had their own sovereign governments before European contact and they never relinquished their rights to govern themselves and their lands. Indigenous empowerment is the increasing political, economic, social, legal, environmental, and cultural standing of Indigenous communities across the globe. Indigenous empowerment is fostered by an increased recognition of tribal sovereignty and Indigenous cultures by national governments, court systems, and broader society. The roots of Indigenous empowerment are the Indigenous people, communities, and tribes reclaiming their sovereignty and exercising self-determination for their own goals and values.

Treaties are agreements signed between sovereign governments and support the concept of tribal sovereignty. American Indian treaties often ceded tribal lands to the U.S. Government but often reserved the rights to use that land in traditional ways for things like hunting, fishing, and gathering (Wilkins and Lomawaima 2001). While Indigenous treaties do not apply to every government, Indigenous rights to cultural values, land, resources, and customary use, as well as input into development projects, were officially recognized by most of the countries in the world in the 2007 United Nations General Assembly's Declaration on the Rights of Indigenous Peoples (United Nations 2007). The United States voted "no" on the 2007 declaration but in 2010 affirmed its support (Echo-Hawk 2016). Since long before the United Nations declaration, American Indian tribes have fought for their rights to land, resources, and self-government. This paper will outline some of the current trends in Indigenous rights and demands, and how they may impact potential futures of forests and forest management.

Current Trends and Impacts

Indigenous empowerment is growing internationally around human rights, environmental protection, land tenure, and natural resource management. Several countries have recognized the "Rights of Mother Earth" and the importance of Indigenous perspectives on environmental protection. In 2010 Bolivia held an alternative climate change summit titled, "The World People's Summit on Climate Change and the Rights of Mother Earth" in response to perceived inaction on climate change at the United Nations (Postero 2013). The conference called upon the United Nations to develop, among other things, a declaration on the "Rights of Mother Earth" and to fully recognize the rights of Indigenous peoples. Indigenous Maori people in New Zealand successfully fought to have a river be recognized as having the same rights as people (Roy 2017). In a case that cited the New Zealand precedent, the Ganges River and a tributary were granted similar rights by courts in India (Safi 2017). It is unclear how these trends will continue.

Indigenous protests are also growing internationally. Indigenous groups have staged protests around environmental issues like energy extraction and timber harvesting. The

United Nations has reported that Indigenous peoples have the right to oppose energy extraction in their territories (Anaya 2015) and there are examples from throughout the world of this opposition including in South America (Vásquez 2014), Canada (Barker and Ross 2017), Africa (Watts 2016), and Russia and the Arctic, to name a few (Nuttall 2005). Sometimes, these protests turn violent and activists and states clash, as was the case in Bagua, Peru (Shepard 2009), Brazil, (Hanna et al. 2016) and other locations around the globe where Indigenous people resist losing control of their territories to mining, petroleum, and timber interests (Clark 2010, Downey et al. 2016, United Nations 2018). Indigenous protests often express opposition not just to immediate environmental degradation but also to long-term changes due to climate change and loss. Indigenous protests are often more complex than other environmental protests because they seek to strengthen cultures, strengthen Indigenous sovereignty, and ensure the rights of their future generations.

Like energy extraction, timber harvest is often a site of Indigenous activism and protest. In Canada, Anishinaabe people staged blockades to stop timber harvests they viewed as impacting their lands, cultures, and communities (Barker and Ross 2017, Willow 2012). In Bolivia, Indigenous communities waged a 600-km protest march to combat unsustainable logging and reclaim territorial control, which led to the enacting of one of the most progressive tropical forestry laws in the world (Dockry and Langston 2018). There is a growing recognition by the international community, scholars, and development practitioners that Indigenous peoples are the key to protecting tropical forests and biodiversity (Stevens 2014).

Another trend is the growing partnerships with Indigenous peoples around natural resource management. In the United States, Indigenous people are increasingly regarded by Federal and state forest managers as setting good examples of how to manage forest lands for complex ecological and social change (Dockry and Hoagland 2017, Ross et al. 2016, Sessions et al. 2017). State and Federal managers are forming partnerships with Indigenous tribes to maintain forest products industries (Corrao and Andringa 2017), improve forest resilience and fire use (Lake et al. 2017), manage for culturally important species and landscapes (Garibaldi and Turner 2004, Ross et al. 2016), and engage in collaborative research (Johnson and Larsen 2013). Additionally, traditional ecological knowledge is viewed as important to understand ecological change across North America and beyond (Berkes 2012, Kimmerer 2013, Parlee and Caine 2018, Pierotti and Wildcat 2000).

Another area of growing Indigenous empowerment is through litigation and the courts. Tribes have been exerting their treaty-protected rights, water rights, rights to natural resources, rights to be consulted on state and Federal decisions, and rights to comanage natural resources. Indigenous peoples in the United States have won major court cases that have recognized their rights to hunt, fish, and gather (among other things) in land they ceded by treaty. These cases have established Indigenous natural resource management institutions that work with Federal, state, and tribal governments to ensure treaty-protected resources are available for tribal members. There are multiple treaty groups in the Midwest, including the Great Lakes Indian Fish and Wildlife Commission (https://www.glifwc.org/), the 1854 Treaty Authority (https://www.1854treatyauthority.org/), and the Chippewa Ottawa Treaty Authority (https://www.1836cora.org/). There are also treaty authorities in the Pacific Northwest, such as the Northwest Indian Fisheries Commission (https://nwifc.org/) and the Columbia River Intertribal Fish Commission (https://www.critfc.org/). Litigation is ongoing around snowmaking on sacred peaks in Arizona (Bauer 2007), water rights (Krol 2017), comanagement agreements and public lands (Tanner 2017), and youth litigating for actions to combat climate change for future generations (https://www.earthguardians.org/).

Outside of court-mandated treaty rights protection, Federal agencies are beginning to form partnerships with Indigenous tribes to manage natural resources and landscapes that are important for tribal communities through government-to-government consultation and management of adjacent lands (see, for example, Lucero and Tamez 2017). In 2009, the U.S. President signed an executive order that compelled each Federal agency to develop a tribal consultation plan to work with Federally recognized tribes (Routel and Holth 2012). The USDA Forest Service, for example, has a coordinated tribal relations program that works at all levels of the agency to support tribal sovereignty, build partnerships for mutual benefit, ensure tribal treaty resources are available on National Forest System lands, and support government-to-government consultation (Catton 2016, USDA Forest Service 2009).

The American Indian and Indigenous protest movement in the United States has been growing stronger as tribes gain political, social, and economic power. Recent protests against the Dakota Access Pipeline gained international attention and brought together representatives from hundreds of Indigenous peoples to support the Standing Rock Sioux Tribe and the Oceti Sakowin's sovereignty, protect water resources, and take a stand against climate change (Dhillon and Estes 2016). Similar protests are beginning to form around another pipeline in Michigan (Kaufman and Allen 2018) and across the country (Nicholson 2018). At the same time, cities across the country are recognizing the power and rights of Indigenous people by, for example, changing Columbus Day to Indigenous Peoples Day. Tribes are taking their sovereignty further by working toward control of their own data (https://usIndigenousdata.arizona.edu/), resisting the genetic modification of traditional foods like wild rice (Anishinaabe [Chippewa/Ojibwe] Nations of Minnesota 2011), and strengthening their communities through youth leadership programming. Tribal colleges and universities play a significant role in fostering Indigenous empowerment and building tribal nations by preparing future leaders, managers, entrepreneurs, health care professionals, teachers, and scientists (see https://www.aihec.org/).

A Look 20 Years Ahead

Over the next 20 years, it is likely that Indigenous rights will continue to influence natural resource management and government decisions. This could play out in several different ways. One scenario for Indigenous rights would be increased collaboration and comanagement to achieve mutual goals. While Federal and state relations with American Indian tribes are not always amicable (Catton 2016), this scenario would represent an expansion of current comanagement arrangements like the Anchor Forest program in the Pacific Northwest. The Anchor Forest program develops regional multijurisdictional (tribal, Federal, state, and private) agreements to manage forests for sustainable timber and biomass production while developing the processing infrastructure and capacity of the region (Corrao and Andringa 2017). Under this possible future scenario, increased comanagement would help support landscape-level natural resource management and strengthen ecological resilience to disturbance, climate change, and invasive species. Additionally, the effects of decreasing Federal and state budgets for natural resource management would be mitigated under this scenario because management would be a truly shared and collaborative endeavor. This collaborative management would have the strength of more staff and resources for sustainable management, but it would also bring Indigenous knowledge and western science together to solve landscape-level ecological problems.

Another possible future scenario that could result from Indigenous empowerment in natural resource management is the potential for increased litigation. Indigenous people have been fighting for their rights, land, cultures, and environmental protection for centuries. In the late 20th century, tribes began to gain political and economic power while continuing to fight for their rights—particularly their reserved treaty rights. These fights ultimately led to court cases that were, for the most part, upheld by tribal reserved treaty rights in places like the Great Lakes region and the Pacific Northwest (Wilkinson 2005). Currently there are several high-profile Indigenous protests and legal cases surrounding Indigenous treaty rights, water rights, and pipelines. Under this scenario, American Indian tribes begin to escalate their litigation to include most Federal natural resource decisions on issues such as transportation, oil and gas extraction, timber harvest, grazing, river management including dams, water, air, plants, and wildlife. The litigation could expand to state-level and private party litigation. The litigation will be costly for all parties and could paralyze natural resource management, create animosity, and inhibit collaborative management.

A very negative scenario could be the increase in violence associated with Indigenous protests, responses by states, and counterprotests. If Indigenous people observe a lack of respect for their rights and values in natural resource management decisions, protests could grow across the country, leading to more confrontations between protesters and state and Federal law enforcement officers. For example, issues such as transportation, oil and gas, the protests over the Dakota Access Pipeline in North Dakota attracted Indigenous people and their allies from throughout the country and world. While the protesters employed prayer, ceremony, and nonviolent civil disobedience, the backlash against them was often violent. Violence originating from Indigenous people could also begin to occur under this scenario. Some Indigenous anarchists have argued that more aggressive and violent tactics are needed to ensure their voices are heard. These anarchists attribute the success of Mi'kmaq resistance to hydraulic fracturing (fracking) in the Canadian province of New Brunswick in 2013 to these tactics: militant action, sabotage, and roadblocks (CrimethInc.com 2017). Because Indigenous people see some of the current environmental trends—such as nonsustainable resource extraction, climate change, and pollution—as ultimate threats to their people, future generations, and lifeways, protests have the potential to continue to escalate violence from all sides. Additionally, these protests could become more widespread and eventually happen in urban areas and at multiple sites across the country and world.

Finally, there is also the possibility that the future will entail a combination of the three scenarios: collaboration and comanagement, increased litigation, and increased violence all happening at different places and times. This scenario in many ways is what is currently happening. There are excellent examples of collaborative resource management across the United States, Indigenous litigation is happening more and more frequently, and there are pockets of violence (most often violence toward Indigenous people) happening at protest sites. In this scenario, all of these things continue to increase, but they balance each other out to the point where none of the three scenarios dominates.

Implications for Forestry and the Forest Sector

Implications for forestry and the forest sector mirror the scenarios. There is a real opportunity for increased collaboration and partnership-building with Indigenous peoples. These partnerships could enhance landscape-level conservation, natural resource management, and Indigenous empowerment if partnerships develop ethically, support Indigenous sovereignty, and engage Indigenous communities as equal partners. This may require continued structuring of natural resource institutions to work effectively with tribes through resources, staff, training, and consultation processes. It is possible that potential increases in litigation could decrease management options, delay projects, and degrade the collaborative relationships. Litigation could also diminish the ability to develop solutions to things like climate change, cross-boundary management, and landscape-level conservation. However, decreasing budgets for natural resource management institutions and the complex landscape-level issues like climate change, invasive species, and water management could foster increased partnerships and comanagement. Currently, wildland fire fighting is an example of collaborative management between Federal agencies, tribes, and states. Collaborative fire management could serve as a model for other areas of natural resource conservation, such as collaborative forest restoration, habitat improvement, riparian restoration, timber harvesting, and forest products.

Conclusions

Indigenous empowerment is growing in the United States and throughout the world. Indigenous sovereignty is the foundation for Indigenous empowerment. Indigenous people are demanding recognition of their sovereignty in natural resource management; control over their people, cultures, and territories; and a voice in major environmental issues like timber harvesting, energy development, mining, and climate change. Indigenous protest, litigation, and collaborative partnerships will continue to shape their relationships with national governments and natural resource management. Indigenous peoples are and will continue to be important drivers of change in forests and forestry in the United States and globally.

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Education as a Driver of Change in U.S. Forests and the Forest Sector

Terry L. Sharik, Andrew J. Storer, Tara L. Bal, and Dalia Abbas

Abstract: The purpose of this paper is to examine education as a driver of change in U.S. forests and the forest sector over the next two decades. Likely outcomes in general education include: (1) greater emphasis on the production of information products and services associated with a knowledge-creation society; (2) more emphasis on nondiscipline-specific or generic and transferable competencies; (3) increase in the importance of information and communication technologies in the development of knowledge-creation skills and competencies; (4) greater attention paid to the environment in which students learn, with an overall emphasis on engagement, and in particular on the relationship between instruction and student outcomes; and (5) expansion of virtual, informal lifelong learning made possible by an infrastructure of digital networks complementing the instructor-mediated learning approaches. Expectations from natural resources education include: (1) better integration of the ecological, social, and economic dimensions of sustainability and their application through policy, planning, and management; (2) stronger emphasis on field-based youth education about natural resources and forest ecosystems in science, technology, engineering, and mathematics (STEM) education; (3) transition in higher education from classical teaching methods to learning-centered methods; (4) increase in distance learning to serve nontraditional students and practicing professionals on a global scale; (5) replacement of many of the specialized degrees at the bachelor's level, such as forestry and wildlife management, with a rigorous interdisciplinary degree in natural resources or ecosystem management and specialization at the master's level; (6) increased emphasis on 2-year associate's degrees with technical skills aligned with employer needs; (7) increased educational opportunities for practicing professionals designed to meet their needs at various stages in their careers; (8) a growing need for increasing scientific and natural resources literacy in the public and with decision makers; and (9) increase in gender and racial or ethnic diversity.

KEY WORDS: forestry education, knowledge-creation society, educational environment, student engagement, virtual learning, lifelong learning, STEM education, distance learning

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Introduction

Education clearly has the potential to be a driver of change in U.S. forests and the forest sector. Consideration of this potential is complicated by the fact that education in the field of forestry and natural resources more generally is also greatly influenced by the forest sector, as well as other segments of society. Thus, it is fitting that it be the last of the drivers of change in this collection as all other drivers of change involve education at some level.

Evolution of Forestry and Natural Resources Education

In some sense, we are faced with defining what "forestry education" is about, and how it differs from other education areas. If it is defined as education related to the science and management of forests or forest ecosystems as opposed to other ecosystems, then even here it has become increasingly complex over the past century. This is because education related to forests has evolved from the single discipline of "forestry" to multiple disciplines emphasizing individual "resources," principally wood, water, soil, wildlife, and recreation. This evolution has been a natural outcome of increasing knowledge (Fig. 1). More recently, due to this "siloing" of individual resources in separate disciplines and professional organizations, the broader discipline of "natural resource science" (and "management") has emerged to integrate these various disciplines. Along with the emergence of this broader discipline, there has been greater consideration of anthropocentric services provided by ecosystems from solely provisioning services (i.e., resources) to also include regulating, cultural, and supporting services (Millennium Ecosystem Assessment 2005). At the same time, the scale of the discipline has evolved from local to landscape and regional considerations (driven in part by spatial technology), and by extension

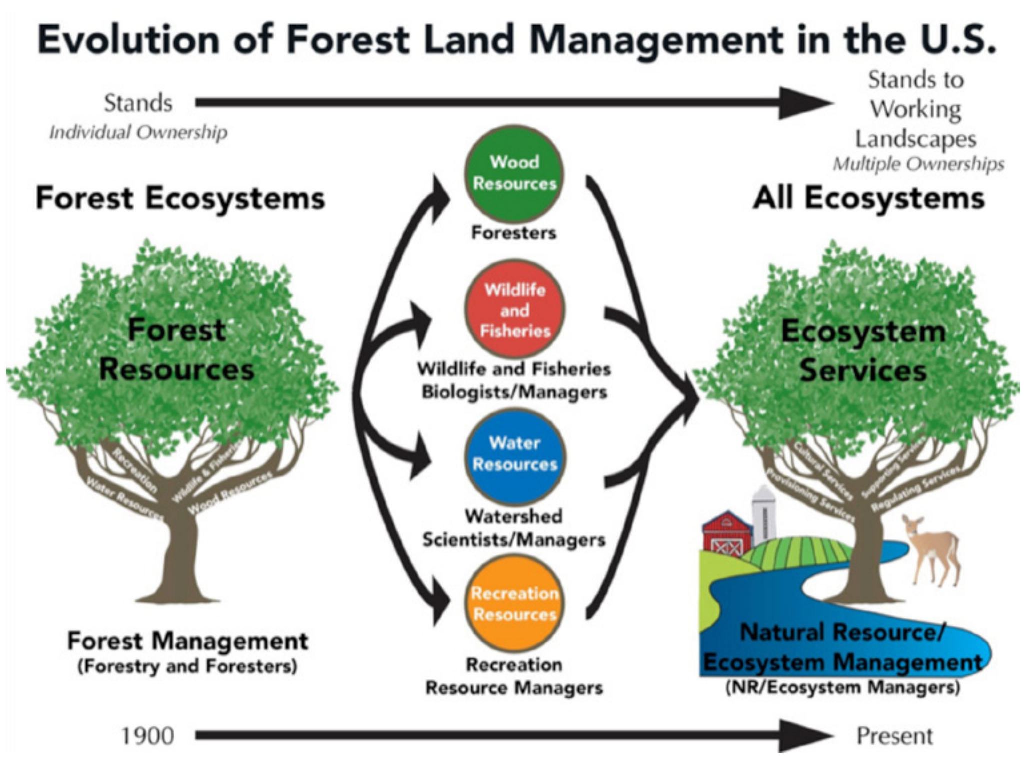

Figure 1.—The evolution of forest land management in the United States.

from individual to multiple ownerships, and from strictly forest ecosystems to multiple ecosystems, including wildland, agrarian, and urban variants of each.

As readers might imagine, this evolution brought with it substantial changes in "forestry" education. Currently fewer than one-fifth of undergraduates enrolled in what were originally "forestry schools" are forestry majors, while nearly 40 percent receive degrees in the broader disciplines of "natural resources conservation and management," and "environmental science and studies" from "natural resources" academic units (Sharik et al. 2015). One result of this increasing integration of various disciplines representing natural resource science and management is that the field has many of the same characteristics as several other emerging fields of study, such as ecosystem science, environmental science, sustainability science, and integration and implementation science (and management). Further, as systems-thinking approaches expand, an integrated landscape encompassing forests and nonforested areas becomes the unit of analysis. There is higher complexity at this unit of analysis because the landscape is made up of different hydrological, soil, wildlife, and climate properties. As a result, ecosystem science is probably the most clearly aligned with natural resource science because the former evolved from the latter. In contrast, environmental science tends to place a greater emphasis on the physical environment. Sustainability science is premised on a stronger coupling of human and natural systems and focuses on the sustainability of both in relation to each other. Integration and implementation science, which originated in the public health field, places more emphasis on the process by which complex issues such as human health and well-being are addressed, and on humans in relation to their environment (Bammer 2005).

All of the disciplinary fields just noted have something in common: They deal with complex problems or issues involving nature and humans, and thus require a great breadth of knowledge to solve or manage these problems or issues (Fig. 2). We consider natural resource science to be about the management of critical issues related to natural resources (and the environment) or, alternatively, the management of a diverse array of services provided by ecosystems. Therefore, from this perspective, effective management of natural resource issues and ecosystem services requires the integration of the biological, physical, and social sciences, or put another way, more broadly, the integration of the ecological, economic, and social dimensions of sustainability. This is what interdisciplinarity, multidisciplinarity, or transdisciplinarity is about. But it does not end there, as natural resource science is an applied field. Thus, these basic sciences must be applied in the context of policy, planning, and management. There is an aesthetic component to the management of ecosystems as well (Fig. 2), so the arts and humanities must also be considered. Given this complexity, it should not be surprising that educators are challenged to provide natural resource majors with the knowledge, skills and abilities, and behaviors necessary to manage these ecosystems for diverse publics that differ in the way they value various services provided by them.

One of the challenges we face is that the vast majority of faculty teaching in natural resource science programs consider themselves experts in the ecological realm as opposed to the socioeconomic realm. Within the ecological realm, they report that they identify with organisms rather than the atmosphere or substrates—which emphasize the physical sciences (Fig. 2). This affinity makes sense from the standpoint that natural resource scientists and managers have historically been tasked with being stewards of organisms and not ecosystems per se. The problem is that

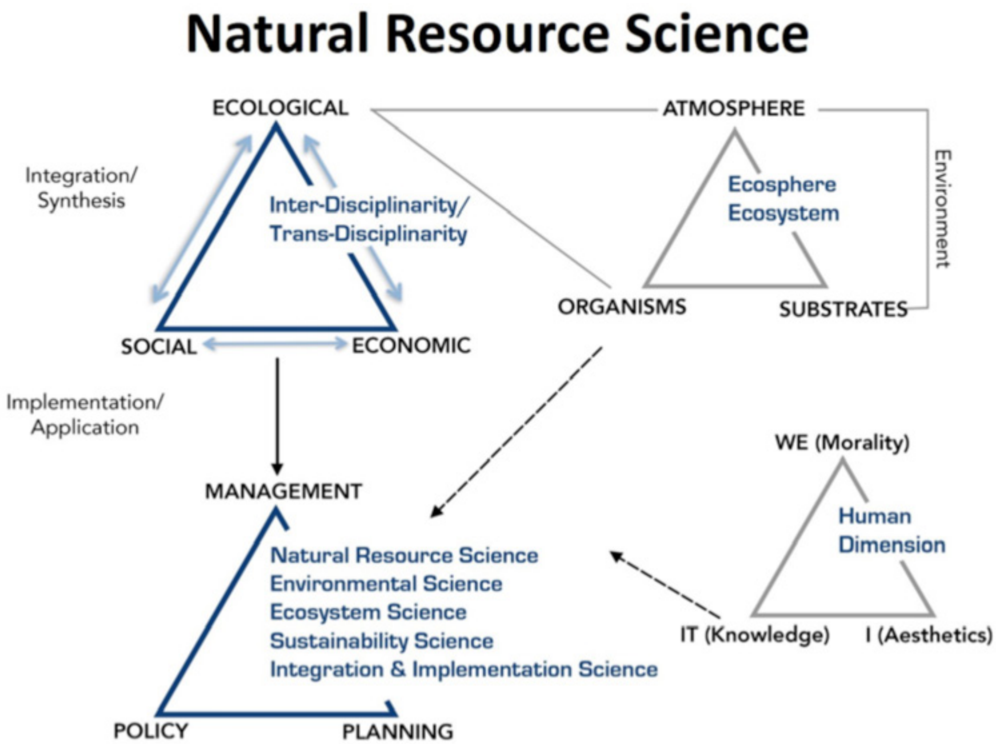

Figure 2.—Diagrammatic representation of natural resource science.

complex natural resource issues require an understanding of all the basic sciences as well as the integration of the applied disciplines of policy, planning, and management.

Current Educational Trends and Impacts

Natural resource science and related disciplines do not exist in a vacuum, but rather are influenced by a multitude of environmental and socioeconomic trends that are variously characterized as megatrends or "drivers of change." Included on the environmental side are such elements as climate change, energy development, biodiversity, and invasive species, and on the socioeconomic side, globalization, political instability, aging societies, new technologies, and increased emphasis on the bio or green economy (Association of Public and Land Grant Universities [APLU] 2014, Rekola et al. 2017). In addition to these factors, APLU also recognizes urbanization and land use, Indigenous rights, water, fire, and the evolving forest products sector as drivers of change in U.S. forests and the forest sector.

The director of the World Economic Forum, Klaus Schwab, describes the "Fourth Industrial Revolution" as perhaps the biggest driver of change in the 21st century (Schwab 2016). The megatrends associated with this revolution include physical elements, such as autonomous vehicles, 3D printing, advanced robotics (with "machine learning"), and new materials; digital factors, principally the Internet of Things, characterized by connected technologies and various platforms that connect things to people; and biological elements, mainly molecular genetics and synthetic biology. Related to these trends, the U.S. Bureau of Labor Statistics estimates that 73 percent of new jobs between 2014 and 2024 will be in computer applications, with the remainder in engineering (10 percent), mathematical science (6 percent), social science (5 percent), physical science (3 percent), and life science (3 percent). While natural resource science is commonly characterized as a life science, as noted earlier it encompasses the biological, physical, and social sciences, along with mathematics, statistics, and engineering. It thus encompasses all science, technology, engineering, and mathematics (STEM) fields and more, including the arts and humanities.

Some have argued that recent developments in information and communication technologies have resulted in a profound shift from the production of material goods to information products and services, or in other words, to a "knowledge creation society" (Pifarré 2014). A hallmark of this model is customized services that meet individual needs and preferences, and an organizational structure that places decision making closer to the customer and makes it more responsive to customer diversity and demands. Networks are used to access and share information, and they both enable and reinforce the collaborative relationships characteristic of the model. From the standpoint of education, the question becomes one of what pedagogies and competencies are associated with this model. For competencies in particular, the overall findings point to a shift from discipline-specific to nondiscipline-specific or generic and transferable competencies, as they are called (Pifarré 2014, Wagerif and Monsour 2012). Many lists of these generic competencies or skills have been compiled (and in many cases the skills have been ranked) based on research, and there is general agreement among them. For example, Pifarré (2014) cites the skills listed by Grubb (2006), which include: (1) problem solving, (2) communications, (3) teamwork, (4) information analysis, (5) critical thinking, and (6) reasoning. Such lists have been generated specifically for forestry or related natural resource disciplines by surveying the employers of graduates of these fields and the graduates themselves; results have been similar to those mentioned (Bullard et al. 2014, Pipatwattanakul 2017, Rekola et al. 2017, Sample 2015). That of Pipatwattanakul (2017) in particular seems notable and includes: (1) sense-making, (2) social intelligence, (3) novel and adaptive thinking, (4) cross-cultural competency, (5) computational thinking, (6) new media literacy, (7) transdisciplinarity, (8) design mindset, (9) cognitive load management, and (10) virtual collaboration.

Assuming there is general agreement on what these "knowledge creation" skills and competencies are, the challenge remains as to how to incorporate them into the curriculum and into student life in general. In this regard, Pifarré (2014) outlined four pedagogical guidelines for doing this with information and communication technologies: (1) implementation of challenge-based learning, (2) defining key established knowledge, (3) unpacking the cognitive processes to help students solve complex and challenging tasks, and (4) placing an emphasis on teamwork and collaborative learning strategies. With **challenge-based learning**, teachers and students work together to learn about different kinds of issues, propose solutions to real problems, and take action. Students are engaged to reflect on their learning and the impact of their actions, and to publish their solutions for a general audience. In **defining key established knowledge**, students are asked to understand and solve complex problems encountered in real-world situations. The idea is to focus on a small number of key concepts, principles, and procedures, and on how ideas are organized and connected across areas to form complex knowledge systems (Bransford et al. 2001, Donovan et al. 1999). These core concepts and principles in the discipline, along with student interests and motivations, are used to pose challenging questions. **Unpacking cognitive processes** generally refers to breaking down something into its basic components in order to define more fully or reframe understandings. The process typically requires the use of schemas or platforms to help teachers identify, categorize, and organize key processes and skills. Finally, **teamwork and collaborative learning strategies** involve task management in combination with an understanding of social relationships. Such understanding may result in examining alternative approaches to traditional hierarchical team leadership, peer assessment for group awareness, and group reflections on learning.

Jankowski (2017) argues that the environment in which learning takes place is central to student success. Key elements in the environment include student, teacher, teaching approaches, curriculum, institution, and factors beyond these contexts in which the student lives, coupled with prior experiences. While it is important that students feel integrated into the academic and social culture to learn well, they must also feel engaged. At the heart of this engagement is the relationship between instruction and student outcomes—that what teachers do and how instruction occurs matter greatly. Accordingly, Jankowski (2017) outlines five areas of intersection between instruction and student outcomes that facilitate the learning process and student success: transparency, pedagogical approaches, assessment, self-regulation, and alignment. Transparency involves students having a clear understanding of goals assessment criteria. Pedagogical approaches that have transformative potential include problem-based learning, collaborative learning, service learning, undergraduate research, experiential learning, and flipped classrooms. These approaches can also support student persistence and the completion of degrees, particularly with underserved populations (Jankowski 2017). Effective assessment includes assignments that mirror the types of tasks students will experience in the real world and where students receive opportunities to apply feedback on their assignments. Self-regulation refers to students managing their own learning, including time for reflection on their own learning styles and their course assessments (Jankowski 2017, Steiner 2016). Alignment of overall learning outcomes, content, instructional design, pedagogical approaches, assignments, and evaluative criteria supports deep learning (Bransford et al. 2001, Donovan et al. 1999, Wang et al. 2013).

Thomas and Brown (2011) envision a "new culture of learning" that is devoid of classrooms and teachers per se, one in which the emerging digital network infrastructure provides us with seemingly unlimited access to information while at the same time connecting us to one another. They place a strong emphasis on learning collectives, made up of people "who generally share values and beliefs about the world and their place in it, who value participation over belonging, and who engage in a set of shared practices." This new culture of learning requires environments that are bounded and yet at the same time allow freedom to "play" and cultivate the imagination, where play is defined as "the tension between the rules of the game and the freedom to act within those rules." Learning occurs through engagement "within the world" rather than learning "about the world" and embraces the unknown and queries it. According to the authors, other positive qualities of this new culture include its capacity to encourage innovation; thrive on change; align people with their interests and passions; and move individuals from "learning **from** each other" to "learning **with** each other," from "learning to belong" to "belonging to learn," and from "fixing a problem" to "growing a solution." The authors cite Wikipedia as one of the best examples of this new culture of learning. They envision this new culture as not replacing our current methods of learning in traditional educational venues, but rather augmenting them in all stages of life, and thus being "arc of life" learning. This informal mode of learning will most likely only augment formal education instead of replacing it because it is not typically refereed by experts or sanctioned by accrediting bodies. Refereeing or accreditation might compromise the quality of the learning experience or lead to "confirmation bias," in which information is used to confirm a currently held idea or opinion while ignoring information that is contrary to this idea or opinion (APLU 2014), among other shortcomings.

Thomas and Brown (2011) argue that an important part of the new learning culture is a shift to "tacit" learning, where knowledge is "assumed, unsaid, and understood as a product of experience and interaction" and uses all the senses. This model contrasts with the more traditional "explicit" knowledge, which is "easily identified, articulated, transferred, and testable" and uses relatively few of our senses as it is not experiential. The authors see tacit learning as much more aligned with a rapidly changing and expanding base of knowledge in the digital world that we are now experiencing. Inquiry (i.e., asking questions to generate progressively more complicated and difficult questions) is viewed as one of the more effective means for tacit learning as it is said to stimulate the imagination and arouse passion, create a strong motivation to learn, and provide a set of constraints that create deep meaning. Questions are viewed as more important than answers per se, and wrong answers are generally seen as resulting in a greater degree of learning than right answers. Indwelling, or "familiarity with ideas, practices, and processes that are so engrained they become second nature," is viewed as another important dimension of tacit learning. "Dispositions" are closely aligned with indwelling and indicate how learners will make connections at the tacit level. Those who share a common disposition exhibit five key character traits. Specifically, they (1) keep an eye on the bottom line of improvement, (2) understand the power of diversity in talents and abilities, (3) thrive on change, (4) see learning as fun (and in some sense, playful), and (5) live on the edge with respect to radical alternatives and innovative strategies for completing tasks.

It has long been known that learning occurs more deeply when done in context (Donovan et al. 1999). In this regard, Thomas and Brown (2011) emphasize the importance of reframing knowledge as a "where" question in contrast to the traditional "what" question. Students are highlighting the importance of context in a digital world where information has mushroomed, and thus how to find information on a given topic and evaluate it is increasingly valued. Likewise, hands-on activities are seen as creating context by "building" within a particular environment. With this building or "making" one is also learning how to craft context such that it carries more of the message, and as such, helps in dealing with information overload. Thomas and Brown (2011) also suggest that new media tools allow one to restructure context in a way that allows content to remain stable, but to change its meaning.

In thinking about what a new educational environment in the 21st century might look like, Thomas and Brown (2011) turn to massively multiplayer online games (MMOs) as the best living examples for several reasons. Massively multiplayer online games involve a constantly changing environment where (1) "participants are building, creating, and participating in a massive network of dozens of databases, hundreds of wikis and websites, and thousands of message forums, literally creating a large-scale knowledge economy"; (2) "participants are constantly measuring and evaluating their own performances, even if that requires them to build new tools to do it"; (3) "user interface dashboards are individually and personally constructed by users to help them make sense of the world and their own performance in it"; (4) "evaluation is based on after-action reviews not to determine rewards but to continually enhance performance"; and (5) "learning happens on a continuous basis because the participants are internally motivated to find, share, and filter new information on a near-constant basis"

(Thomas and Brown 2011). Further, we might add that the financial cost of this education to the participant is negligible.

Relationships to Natural Resources Education

Given this backdrop of literature on education, we now want to turn our attention to natural resources education, and forestry as a subset of natural resources education. While the focus of this paper is on students in higher education to prepare them for the workforce that manages forest ecosystems, many of the same principles and approaches apply to the entire pipeline from kindergarten through 12th grade (K–12), through higher education, to practicing professionals and the public. The most definitive treatment of this topic is probably the "Science, Education and Outreach Roadmap for Natural Resources," prepared by the APLU's Board on Natural Resources and Board on Oceans, Atmosphere, and Climate (APLU 2014). The framing for this publication is based on six "grand challenges" in the preservation, conservation, and use of natural resources in the United States: sustainability, water, climate change, agriculture, energy, and education. Education is listed as the last grand challenge, as it is in this compilation, because it has applications in all the other challenges. The general approach was to: (1) frame the issues associated with each grand challenge; (2) perform a gap analysis of where we are at the present in terms of capacity and science gaps, and specific education and outreach needs; (3) identify research needs and priorities to meet the challenge; and (4) specify expected outcomes under both the status quo and with the roadmap's recommendations. Accordingly, the grand challenge of natural resources education is to foster learning approaches that prepare people in the 21st century for effectively managing forest (and other) ecosystems and the services they provide, or otherwise supporting the management of these ecosystems as informed citizens or civic leaders. To this end, six major goals are put forth: (1) include natural resources in youth education by incorporating natural resources into STEM curricula and activities, (2) strengthen natural resources curricula in higher education, (3) improve the scientific literacy of the Nation's citizens, (4) communicate scientific information to the public in efficient and effective ways, (5) promote sustainability in natural resources, and (6) promote diversity in the natural resource professions (APLU 2014). It is apparent from this list that the intent is to treat the entire educational pipeline from youth to practicing professionals and the general citizenry, not unlike the "arc of learning" concept of Thomas and Brown (2011). Given this backdrop, we will provide highlights for each goal, weaving in some of our own observations and those of others.

Goal 1: Incorporating Natural Resources into Youth Education

The backdrop for the goal of including natural resources in youth education by incorporating them into STEM curricula and activities is that youth are clearly the front end of the pipeline for natural resource careers (and informed citizenry); relatively few of them choose these careers, and those who do are disproportionately male and non-Hispanic Caucasians (Sharik et al. 2015). One of the reasons postulated for these low numbers is that we live in a highly urbanized society (and disproportionately so for people of color) and thus youth are not often exposed to nature. Richard Louv (2005) coined the term "nature deficit disorder" early in the new millennium to describe this situation. He and other researchers noted that even young people in rural communities were spending less time outdoors for a variety of reasons. The internet and related technologies gave youth access to games and other indoor activities, and parents began to feel that it was not safe for their children to be left alone outside. We know from national surveys that the main reason high school students decide to matriculate in forestry and related natural resource degree programs is a love of nature or the outdoors (Rouleau et al. 2017, Sharik and Frisk 2011). We also know from the work of Kellert (1996) and others that interest in and attraction to nature are developed at a very early age; both the cognitive domain and the affective and emotional domain of learning are involved, while shaping attitudes and values about nature, the outdoors, and natural resources. Related to this is the finding that the development of cognitive skills is enhanced when youth are exposed to nature, especially in an unstructured way (as play), because all of their senses are being stimulated (Kellert 1996, 2005). This may help explain why experience and stimulation of all the senses and "play" are increasingly recognized as important to learning in the college years and beyond, as expressed by the general education literature cited earlier in this paper (Jankowski 2017, Pifarré 2014, Thomas and Brown 2011).

A second problem seems to be that natural resources curricula are not adequately included in K–12 curricula, especially as a part of STEM education. Many nonprofit organizations offer outdoor experiential education related to nature and natural resources, perhaps at least in part to fill the void in the K–12 curricula. The reasons for this general lack of inclusion of natural resources in K–12 curricula are complex and start with what some consider to be inadequate preservice teacher training at the university level, which in turn may rest partly on a misunderstanding of natural resources education (APLU 2014). It is possible that this misunderstanding arises to some extent from the negative image that natural resources management, and forestry in particular, may have in the eyes of the public: It may be viewed as contrary to the sustainability of ecosystems (Sharik et al. 2015). A related problem is that the K–12 curricula that are developed do not recognize cultural differences. Education in natural resources is inherently complex because there is often a large consideration of human dimensions issues that involve social scientists in addition to traditional STEM scientists. More generally, it seems that adult learning and attitudes about science in general may affect the way youth perceive natural resources education (APLU 2014).

Goal 2: Strengthening Natural Resources Curricula in Higher Education

The ideas put forth by the APLU (2014) authors are in line with the literature that we have reviewed previously in this paper and elsewhere (Bullard 2015). In this regard, they argue that training of natural resources professionals must: (1) be multidisciplinary and rigorous; (2) emphasize critical thinking, problem solving, and communication skills; and (3) facilitate the development of a career for adaptation to changing management conditions. Bullard (2015) expands this training of forestry students to include the communication of relevance and building relationships with people in various segments of society. Regarding the second point in particular, the problem is seen as natural resource educators still using traditional teaching methods instead of the learning-centered methods summarized by APLU (2014) and in this paper. Educators do not use these learning-centered methods in part because they do not have incentives to do so through the reward system. The APLU authors imply that this lack of an incentive system in turn is influenced by an overemphasis on research relative to teaching and learning, However, some have argued that research and the new learning approaches (e.g., active learning, problem solving, critical thinking) reinforce each other as they are both about discovery and innovation (Donovan et al. 1999). In this regard, O'Hara and Salwasser (2015) have argued that undergraduate education is enhanced when offered in research universities (where graduate education is also emphasized).

Another dimension of higher education in natural resources that is receiving much attention is that of distance learning, which the APLU (2014) study recognizes as creating some real challenges. In this regard, Standiford (2015) outlines the advantages and disadvantages of this approach to learning. In terms of advantages, the author points to greater opportunities for those who are practicing professionals and in diverse locations, and the fact that a distance learning curriculum can be assembled from top-flight courses offered by faculty from around the world with no constraints on the diversity of courses offered. We would add that such distance approaches aid in the globalization of the curriculum in participating institutions and increased exchanges of faculty and students (Kanowski 2015).

On the downside, there is concern that assembling courses from various institutions globally will weaken financial support for natural resources programs at individual institutions (APLU 2014). More importantly, it is argued that the teaching of field skills is compromised with distance learning and that the advantages of teamwork and collaborative learning that typically take place in a field setting are difficult to replicate in a distance learning environment. For these reasons, curricula that integrate distance learning with experiential field learning—the so-called "hybrid" courses and curricula—to produce "blended learning" are gaining traction (Standiford 2015). The Higher Learning Commission (2018) now recognizes differences between the level of interaction that students have with faculty. Distance education and online learning systems vary from correspondence courses with little to no student-faculty interaction, to include more interactive, online learning (https://www.hlcommission.org/Accreditation/distance-delivery.html).

There is also the matter of what learning should take place and at what level in higher education. The APLU (2014) report argues that natural resource managers should have a bachelor's degree for the development of technical skills and a master's degree for professional and leadership skills. An alternative model consists of a rigorous science-based, interdisciplinary degree in natural resources or ecosystem management at the bachelor's level, followed by specialization at the graduate level. Such an undergraduate degree would not be all that different from those in specialized fields such as forestry except that it would include knowledge, skills and abilities, and behaviors that apply to all resource areas (such as wood, wildlife, water, and recreation); have balance among the biological, physical, and social sciences; and have balance in the treatment of various ecosystem services. Graduate-level specialization has two elements associated with it, i.e., (1) subject area of focus (e.g., water, recreation, wildlife, wood, or ecosystem services more broadly) and (2) a management focus or science focus. Those pursuing a management focus or track would likely obtain a nonthesis or research professional degree, whereas those desiring a career in research would pursue the science focus with a thesis or research degree in the form of a Master of Science degree, with the latter perhaps leading to a Ph.D. degree. Innes (2015) points out the professional (nonthesis) master's degree can take several forms, depending on whether the objective is to serve students who have no undergraduate background in natural resources and desire to pursue a career in this area, and those who already have an undergraduate degree in natural resources and desire more specialized knowledge. Unlike many professions, including law, medicine, and education, in which the vast majority of doctoral graduates receive professional degrees, most if not all of those in the natural resources profession receive research degrees (National Science Foundation, n.d.). The model of interdisciplinarity at the undergraduate level and specialization at the graduate level is supported by the ever-increasing proportion of students pursuing interdisciplinary degrees at the undergraduate level (Sharik 2015). We might also argue that the APLU (2014) emphasis on obtaining technical skills at the undergraduate level can be covered in part by the offering of 2-year degrees, mostly in community colleges.

Most graduates will require continuing education upon entering the workforce in natural resources, and this education can take many forms—most of which have been discussed in this paper. Which forms are used and what practicing professionals seek from them can differ between early and mid- to late-career professionals (Guldin 2018).

Goal 3: Improving U.S. Scientific Literacy

APLU (2014) borrows from the National Academy of Sciences in defining scientific literacy as "the knowledge and understanding of scientific concepts and processes for personal decisionmaking, participation in civic affairs, and economic activities" (National Academy of Sciences 1996), and it argues that a scientifically literate person "has the capacity to understand experiments and reasoning as well as basic facts, to comprehend articles about science, and to engage in discussion about the validity of conclusions."

The argument is that if more citizens were scientifically literate, decision making in the natural resources would be less controversial, less contested in the legal system, and more defensible to a broader spectrum of society. It is further argued that the responsibility for improving scientific literacy in our citizens resides with our educational institutions, coupled with informal sources such as the media (APLU 2014). However, the problem seems to be that educators may not be using the scientific method in their approaches to learning, which underscores statements about research and the new learning approaches reinforcing each other as they are both about discovery and innovation. Additional problems may include insufficient instruments to measure scientific literacy and an insufficient number of science journalists (APLU 2014).

Goal 4: Communicating Scientific Information to the Public Efficiently and Effectively

The APLU (2014) report argues that we need a better understanding of how individuals make decisions about natural resources if we are to increase the effectiveness of communicating science to the public. However, there are several factors that deter effective communication, including (1) politicization of science and the mixing of science with politics, which often confuses the public; (2) confirmation bias; (3) the erosion of scientific journalism in recent decades; and (4) the democratization of information through new media platforms, often causing fragmentation and resulting in confirmation bias (APLU 2014). Overcoming these barriers will not be easy, especially given the new social media platforms. One suggestion is integrating teams of scientists and experts in the technological aspects of these new platforms with communications experts. It is also suggested that the reward system in universities and scientific and professional organizations change to more highly value communicating scientific information to the public. Moreover, comprehensive plans for communicating results of research in the natural resources could improve the understanding of research results.

Goal 5: Promoting Sustainability of Natural Resources

In promoting the sustainability of natural resources, the emphasis seems to be on educating future leaders, managers, and decision makers on natural resource stewardship in collaboration with experts from multiple disciplines and by integrating science with management (APLU 2014). This approach harkens back to our opening paragraphs, where we noted how the rise in the integration of various disciplines representing natural resource science and management renders it similar to several other emerging fields of study, including sustainability science, the latter perhaps placing a greater emphasis on the sustainability of both human and natural systems.

Goal 6: Promoting Diversity in the Natural Resources Profession

Our discussion about goal 1, which addresses youth education, is connected to promoting diversity in the profession. Among the 15 major disciplines recognized by the Federal government, natural resources (along with agriculture) is second only to engineering in having the lowest percentage of women with bachelor's degrees in the workforce; it is at the very bottom with respect to underrepresented minorities or people of color (Sharik et al. 2015). Thus, it should not be surprising that the proportion of both groups enrolled in institutions of higher learning is likewise low (but increasing). Within the general field of natural resources, forestry has the lowest proportion of women and is in the lower third with respect to minorities. The reasons for this low gender and racial and ethnic diversity in natural resources are many and complex and thus will not be treated in any detail here (but see Rouleau et al. 2017, Sharik and Frisk 2011, and Sharik et al. 2015). The challenge is how to increase these percentages so that the natural resources profession will: (1) reflect diversity in the population as a whole, (2) benefit from the innovation and problem-solving skills that this diversity brings, and (3) be able to work effectively with the public and with decision makers. In this regard, numerous strategies have been offered for making gains in domestic diversity, but there has been no rigorous assessment of the relative merits of each (Sharik 2015).

Another avenue for increasing diversity in natural resources academic programs and in turn the profession is to make education a transnational endeavor. A more multinational educational experience is greatly facilitated by technologies that support distance learning, enhanced by policies that support exchanging and recruiting faculty and students on a global scale (see Kanowski 2015).

Looking to the Future: the Next 20 Years

Based on our review of the literature, coupled with our personal experiences, we put forth outcomes in education over the next 20 years that are likely to occur. In these futures, education acts as a major agent of change in U.S. forests and the forest sector.

General Trends in Education

- There will be a greater emphasis on the production of information products and services associated with a knowledge-creation society.
- There will be increased emphasis on nondiscipline-specific or generic and transferable competencies in the learning environment.
- Information and communication technologies will become increasingly important in the development of knowledge-creation skills and competencies. Examples of these skills and competencies are implementation of challenge-based learning, defining key established knowledge, unpacking the cognitive processes for solving complex and challenging tasks, and placing an increased emphasis on teamwork and collective learning strategies.
- Greater attention will be paid to the environment in which students learn, with an overall emphasis on engagement, and in particular on the relationship between instruction and student outcomes. This

relationship will be enhanced by students having a clear understanding of where they are going and criteria by which they will be assessed throughout the curriculum, by the transformative pedagogical approaches discussed earlier, by students managing their own learning, and by alignment of various elements of the learning environment or experience.

- Complementing the new instructor-mediated learning approaches in higher education will be virtual, informal lifelong learning made possible from a digital-networked infrastructure, where learning collectives are made up of people who have common interests and share common values, and who mentor each other in various phases of the learning process depending on their expertise and experience. All this will take place at a fraction of the cost of formal learning.

Trends in Forestry and Natural Resources Education

- There will be a better integration of the ecological, social, and economic dimensions of sustainability and their application through policy, planning, and management.
- Forest products and resource extraction will remain important components of natural resources education but will include a greater emphasis on renewable resources provided by ecosystems instead of nonrenewable resources.
- Field-based youth education about natural resources and forest ecosystems will be more strongly emphasized in STEM.
- Higher education in natural resources will transition from classical teaching methods to learning-centered methods because of the demand from students, with these learning-centered methods placing a heavy emphasis on field experience and problem solving and thereby converging with research approaches.
- Distance learning will also increase to serve nontraditional students and practicing professionals on a global scale. Online learning is blended with field-based learning provided by consortia of institutions.
- Many of the specialized degrees at the bachelor's level, such as forestry or wildlife management, will largely be replaced by a rigorous science-based interdisciplinary degree in natural resource or ecosystem management, with specialization at the master's level along the lines of various resources (e.g., wood, water, wildlife, recreation) or between management and research, or a combination thereof. Professional management degrees at the master's level will serve students both with and without undergraduate degrees in natural resources using separate tracks. Professional degrees will also be offered at the doctoral level.
- Two-year associate's degrees in a particular resource area will meet the needs of those who want to devote only 2 years to higher education and remain as technicians throughout their careers, while also meeting the needs of employers desiring these technical skills. Practicing natural resources professionals will require certification and continuing education. What forms this education takes and how it is used will differ among professionals at various stages in their careers.
- The need for increasing scientific and natural resources literacy in the public and with decision makers will grow given the current political climate, and this need will be met by increasing the number of science writers and developing a deeper understanding of media platforms, especially with respect to confirmation bias. Moreover, natural resource academicians, working with information technology and communications experts, will increasingly use these media platforms for communicating scientific and natural resources information to the public, in part

because their institutions and funding agencies will increasingly value doing so.

- Domestic gender and racial and ethnic diversity in the natural resource profession will increase as a result of a deeper understanding of the factors inhibiting this diversity and the application of various strategies to overcome these barriers. For example, different cultural perspectives will be incorporated into curricula and more generally into institutions of higher learning. This increased gender and ethnic diversity will be complemented by internationalization of curricula and the student population, which in turn will be reflected in the professional workforce.

Conclusions

The implications of the transition from teaching-based education to learning-based education are a greater understanding of natural resource science and management by the public, industry, policymakers, and civic leaders. Greater understanding is expected to result in better informed and potentially less contentious decision making regarding the sustainability of forest ecosystems and the services that they provide. Current educational trends suggest that the issues facing the evolving fine line between forestry and natural resource sciences are being discussed on a global scale (Rekola et al. 2017). Because true sustainability is not bound to one country or community, but rather to a system that integrates the environment in which we live, our resources, and its people, it is increasingly difficult to separate forestry and natural resources education more generally in the United States from the rest of the world surrounding us. Observing the interface between local and global educational offerings at all stages, while accounting for our unique geographical, cultural, and ecosystem conditions, is a promising approach for the future.

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Drivers of change are overarching forces that have changed conditions in the past, are influencing the present, and are anticipated to influence the future. For this report, we define drivers of change as influential direct or indirect forces expected to shape the future of U.S. forests and the forest sector over the next 20 years. This report explores eight drivers of change expected to influence forests and forestry in the United States over the next two decades: climate change, economic drivers of change, the forest products sector, technological change, demographic change, society's changing forest values, the exercise of Indigenous rights, and forestry education. Each paper is written by experts on the particular driver or by professional futurists. The set of drivers examined here is not intended to be comprehensive. These papers provide information about important drivers of change for use by policymakers and decision makers and contribute to the USDA Forest Service's comprehensive forest futures research portfolio.

KEY WORDS: strategic foresight, futures, climate change, forest products, forestry education, Indigenous empowerment

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