MORE THAN JUST TIMBER: SILVICULTURAL OPTIONS AND ECOSYSTEM SERVICES FROM MANAGED SOUTHERN PINE STANDS

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Abstract--The dramatic decline of timber harvests on public lands in the western United States (U.S.) has helped intensify silviculture in the southern U.S. Today, intensive southern pine management usually involves establishment of plantations using site preparation, genetically improved seedlings, chemical fertilization and competition control, early stand density regulation, and increasingly shorter rotations. Little is known about the consequences of this intensification on the ecosystem services provided by pine-dominated forests. Using a synthesis of field studies, simulations, and literature reviews, we compared the impacts of different management options on key services such as diversity, forest productivity (including carbon sequestration), and erosion and other site-related qualities. This review suggests that naturally regenerated pine stands tend to be more structurally and compositionally diverse than plantations, especially as management intensity decreases. Currently, well-managed naturally regenerated pine stands yield only 50 to 90 percent of the wood fiber produced by plantations but in forms more conducive to long-term sequestration in structures. Carbon sequestration is largely a function of stand density, treatment timing, and what is counted as "stored carbon." Plantation establishment also typically involves more soil disturbance, thereby increasing the potential for short-term sedimentation, soil compaction, and drainage issues and may provide accelerated problems with invasive species. Because of the greater tangible cash value of timber yield as an ecosystem service, natural regeneration will not replace pine plantation silviculture for landowners focused largely on commodity production. However, since family forest landowners control 70 percent of southern forests, the combination of acceptable wood production and better ecosystem services from naturally regenerated pine-dominated stands should present opportunities for a subset of those interested in multiple resource values.

INTRODUCTION

Historically, naturally regenerated stands have dominated the silviculture of southern timberlands. Prior to widespread Euroamerican settlement, forests in this region naturally originated by seed or sprout. The first efforts to manage forests across the South depended almost exclusively on natural regeneration whether following uneven- or even-aged silviculture; it was not until the mid-20th century that plantations became a viable option. The growth of plantation-based pine management accelerated after 1980, with extensive (landscape-scale) forest type conversions by corporations and other larger private landowners (Wear and others 2007, Wear and Greis 2012). Even with this widespread conversion, planted pine stands are found on only 27 percent of the coastal plain forest area in the southeastern U.S. (Wear and Greis 2012).

Recent ownership trends have witnessed vertically integrated forest products companies being supplanted (in most instances) by various investment-related ownerships (Wear and Greis 2012). Over the last few decades, a dramatic decline of timber produced on public lands in the western U.S. coupled with other technological and silvicultural advances have helped intensify silviculture in the southern U.S. regardless of stand origin or ownership (Wear and Greis 2012). Today, southern pine management increasingly involves site preparation, genetically improved seedlings (in plantations), chemical fertilization and competition control, early stand density regulation, and shorter rotations intended to produce sawlog-sized stems of more or less uniform size (Allen and others 2005, Rousseau and others 2005). Given continued interest in increasing silvicultural intensity in southern pine forests (Allen and others 2005), it is incumbent on forest managers, researchers, and landowners to better understand the socioeconomic and ecological implications of this trend.

For example, little is known about the consequences of silvicultural intensification on ecosystem services provided by pine-dominated forests. There are numerous definitions of ecosystem services, but useful ones consider the direct and indirect contributions of ecosystems to human well-being and incorporate a range of functions, including

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“supporting services” (for example, nutrient cycling), “provisioning services” (for example, timber, food, energy), “regulating services” (for example, pollination, water purification), and “cultural services” (for example, aesthetics, recreational experiences) (Braat and de Groot 2012). In this paper, we consider a number of the implications of forest conversions from naturally regenerated pine, pine-hardwood, and hardwood-dominated forests to pine plantations in the southeastern U.S., with an emphasis on ecosystem services.

MATERIALS AND METHODS

Using a synthesis of field studies, simulations, and literature reviews, we compared the impacts of different management options on ecosystem services such as diversity, forest productivity, carbon sequestration, and erosion and other site-related qualities. This literature review and synthesis was not intended to be an exhaustive treatise on this topic but rather a brief summary of some key points related to silvicultural practices and ecosystem services in southern pine-dominated forests.

RESULTS AND DISCUSSION

Some impacts of the conversion of naturally regenerated pine-dominated forests into pine plantations are self-evident. For example, it is likely that for any given stand, converting from a complicated overstory found in a naturally regenerated multi-aged pine-hardwood forest to a tightly regulated monoculture of improved loblolly pine (*Pinus taeda* L.) may increase certain ecosystem services (for example, production of wood fiber) at the expense of others (for example, decreased biodiversity due to the loss of structural complexity). Other impacts may not be as apparent, at least not initially.

Diversity

Within naturally propagated populations, southern pines have considerable amounts of genetic diversity (Xu and others 2008) which allows these species to adapt to changing environmental conditions, forest health threats, and resource competitors. Supplanting this variability with genotypes selected for a limited number of traits (for example, early growth rate or fusiform rust resistance) may leave plantations vulnerable to other unanticipated influences, such as extreme droughts, ice storms, wind, pests, or other pathogens. By definition, monoculture plantations (as well as pure stands of natural original) have very low tree species richness. In practice, many monocultures, even intensively managed ones, have a number of other tree species present. Harvesting permits the reestablishment of early successional species that may be rare or absent in unmanaged stands of natural origin, thereby increasing community diversity at least temporarily (Jeffries and others 2010, Jones and others 2009). Though it is not unusual for hardwoods to be a notable fraction of the stocking in many stands, the use of broad spectrum herbicides and/or mechanical treatments in intensively managed southern pine forests can greatly reduce if not eliminate non-pine competitors, at least temporarily (Jones and others 2012).

Other aspects of biodiversity are also influenced at least in part by the management of southern pine-dominated forests. Locality-focused studies have often found limited impacts of site preparation and vegetation management treatments on wildlife in landscapes dominated by similar early successional communities (Hanberry and others 2012, 2013; Lane and others 2011). Thinning dense even-aged stands also permits the development of preferred forage species for many animals (Peitz and others 2001). However, most of these studies also recognize that certain taxa, especially wildlife associated with interior forest habitats, are rare or absent from these intensively managed landscapes; for instance, Lane and others (2011) reported a low abundance of interior bird species in pine plantation-dominated landscapes. Other long-term meta-analyses on certain functional groups have noted marked declines of populations and even widespread extirpations, such as seen in some forest birds in the southeastern U.S. between 1966 and 2006 (USDA Forest Service 2011) coincidental to the large-scale transition to plantation-dominated landscapes. The conversion of naturally regenerated forests to plantations probably also impacts other floral, fungal, and faunal communities, although it is hard to disentangle certain aspects of habitat requirements from others. As an example, studies of forest-dwelling bats in the southeastern U.S. have found young pine plantations did not have major impacts on foraging opportunities, especially those taking place above the canopy, but roost habitat for species requiring large trees or snags with loose bark or cavities were considerably lessened

(Elmore and others 2005, Menzel and others 2005).

Diversity can refer to more than just genetic, taxonomic, or stand compositional variability. Physical structure also plays a significant role in shaping the biotic communities associated with forest type, although not always in a clear pattern. Naturally regenerated pine stands can be more structurally diverse than plantations. Part of this may arise from the impacts of competition control activities, even though thinning of dense overstories can release understory plants (Jones and others 2012, Peitz and others 2001). For southern pine stands managed with uneven-aged silvicultural techniques, a broad range of size classes is typically present across the stand (Baker and others 1996, Guldin 2011, Reynolds 1959). Given the need for abundant sunlight to encourage the establishment of the relatively shade-intolerant southern pines, the practice of uneven-aged silviculture requires much of the stand to be kept at low density via numerous large gaps in the pine-dominated overstory (Baker and others 1996). The implementation of uneven-aged silviculture in the shade-intolerant southern pines therefore tends to produce a stand with considerable horizontal and vertical structure. Some of the impacts of structural simplification caused by converting more complex natural stands into plantations can be offset by the incorporation of structural complexity via reserves or corridors such as riparian management zones commonly incorporated in "certified" ownerships. Researchers have found that such habitats can help certain fauna persist in otherwise unfavorable stand conditions (Hein and others 2008, Lane and others 2011).

Forest Productivity and Carbon Sequestration

Our review suggests that carbon sequestration is largely a function of stand density, treatment timing, and the definition of stored carbon. Research has shown that intensively managed southern pine plantations produce significantly greater wood volume than most naturally regenerated, well-managed pine forests (Allen and others 2005, Stanturf and others 2003). Bragg and Guldin (2010), using a very simplified modeling approach for well-managed loblolly pine plantations and even- and uneven-aged loblolly and shortleaf pine (*P. echinata* Mill.)-dominated natural stands reported that plantations produced about twice the tree biomass and harvested volumes of uneven-aged stands and at least 10 percent more net biomass than the natural even-aged stand (fig. 1). Some of this disparity is directly attributable to the fact that uneven-aged southern pine stands tend to be understocked, a deliberate result of the treatments needed to ensure continuous regeneration of the shade-intolerant pines (Baker and others 1996, Reynolds 1959). In addition to cultural treatments such as site preparation, use of genetically improved seedlings, and early competition control, even-aged stands also tend to receive mid-rotation thinnings earlier in the rotation and may also be fertilized in addition to chemical and/or mechanical releases, thereby boosting their yields. The prospects for even further gains in plantation volume growth and wood quality are considerable (Allen and others 2005, Blazier and others 2004).

One possible but rarely considered productivity-related consequence of short rotations in low-density southern pine plantations is the high proportion of juvenile wood produced under these conditions (Clark and others 1994, Megraw 1985). Juvenile or "crown" wood has significantly lower specific gravity than mature wood, implying a substantially lower fraction of carbon. For stems of equal size, slower growing pines have a higher proportion of mature wood, and hence may actually sequester more carbon per unit of wood volume produced. Few studies have considered the large-scale impacts of this differential pattern in carbon accumulation, but it probably accounts for some of the difference in volume production between plantation and naturally-regenerated stands. Similarly, if fiber from plantations is converted to pulp, residual fuels, and paper products, the long-term sequestration benefit is less than for lumber products used in housing manufactured from logs commonly produced in naturally regenerated stands (Lippke and others 2011).

Plantations optimized for volume growth using simplified genetics, fertilization, competition control, and density management will have different impacts on overall ecosystem productivity than naturally regenerated forests (Tian and others 2012), but how these treatments will respond to climate change is still uncertain. Shorter rotations can permit

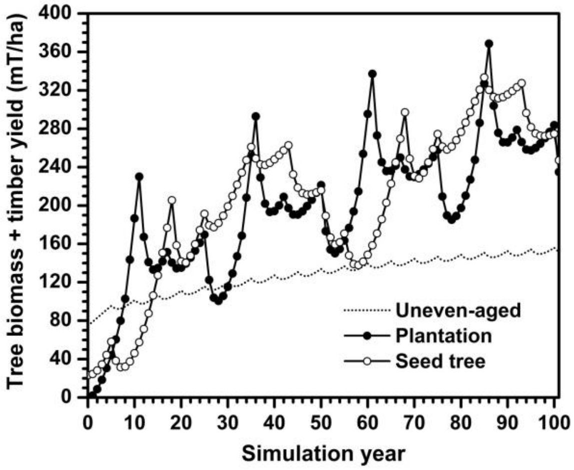

Figure 1--Projected net biomass accrual (standing live trees plus harvested yield minus decomposition or other losses) differences between various southern pine silvicultural techniques. Adapted from Bragg and Guldin (2010).

landowners to more quickly adjust their management to changing climate, but this may be less of an issue in more genetically diverse natural forests. Pine growth is typically considered to be resource-limited in the southeastern U.S., and moisture can be one of those constraining factors (Albaugh and others 2004, Allen and others 2005). Some models predict only limited climate-change-related productivity impacts due to compensating effects of longer growing seasons, CO_2 fertilization, and possible increases in overall precipitation (Sun and others 2000). However, it can be expected that greater moisture demands will be placed on the soil by faster growing trees selected for higher leaf area and net photosynthetic rate (Teskey and others 1987). Assuming it is obtainable, greater soil moisture consumption by such trees can reduce the water yield for other parts of the ecosystem and may decrease the quantity and quality available for human consumption if groundwater and overland flow are diminished (Farley and others 2005, Licata and others 2008). How moisture-limited ecosystem productivity may interact with future droughts and differences in overall stand stocking (low-density plantations versus higher-density stands) requires further study.

There are also other ecosystem services that may benefit from the continuous presence of large-diameter pines in uneven-aged stands, especially those with structural characteristics unique to large live trees. Big pines can provide opportunities for certain types of habitat usually unavailable in younger, faster growing plantations. For example, cavities in large, older, red heart [*Phellinus pini* (Thore:Fr.) Ames]-decayed pines are the nesting habitat of red-cockaded woodpeckers [*Picoides borealis* (Vieillot)]), a federally listed endangered species (Jackson and others 1979). Larger pine snags with loose attached bark are also preferred roost habitat for certain bat species (Perry and Thill 2007). Obviously, adjacent stands with large pines may be capable of providing habitat, but as the overall forest matrix changes, certain species face declines that may threaten them with extinction, as has been seen with the red-cockaded woodpecker in the changing pine forest demographics of the southeastern U.S. (Jackson and others 1979).

Erosion and Other Site Impacts

With very few exceptions, the process of logging disrupts soil surfaces. Site preparation practices across much of the southeastern U.S. often involve the use of deep ripping plows (subsoiling), disking, and/or bedding. These are often done to improve soil conditions on sites that have subsurface rooting depth limitations or those that have been rutted or compacted by past land-use practices, including timber harvest (Carter and others 2006, Fox and others 2007, Lincoln and others 2007, Miwa and others 2004). By design, these treatments penetrate the soil and disturb soil horizons, roots, existing drainage patterns, and vegetation on the surface, all of which are intended to benefit early pine growth and survival. On sites with even greater water drainage issues, ditches were sometimes dug to improve pine survival and growth. Only rarely do naturally regenerated pine-dominated stands receive such intensive site preparation treatments. In these stands, most soil impacts arise from logging, including felling and skidding which, obviously, also occur when harvesting plantations. Hence, naturally regenerated stands are less likely to experience any detrimental effects of these site preparations or, conversely, enjoy any potential benefits.

Unfortunately, while much has been reported on soil nutrient dynamics, carbon sequestration, surficial water movement, and biological diversity following intensive site preparation, the results have been inconclusive (Scott and others 2006). For example, bedding impacts the recovery of water table depth following the logging of wet sites (Xu and others 2002) but had no effect on arthropod diversity on another location (Bird and others 2000). Site disturbance is often cited as a reason why invasive species become more widespread, especially if the equipment used to conduct the treatments is contaminated with propagules (Miller and others 2010). Undoubtedly, the physical disruption of previously intact soils may also negatively impact cultural (archeological) resources and lead to localized erosion problems if not properly ameliorated. The conversion of stands of natural origin to plantations can affect a number of soil properties, including rates of forest floor accumulation, nitrogen dynamics, and moisture levels (Scott and Messina 2010), although such changes do not inherently have positive or negative consequences on ecosystem services. The large-scale transformation of landscapes into pine plantations requires further study, especially given the scope and rate of these alterations.

CONCLUSIONS

Well-tended natural-origin pine stands yield only a fraction of the wood volume produced by intensively managed plantations for a given rotation length. For this reason alone, natural regeneration will not soon replace pine plantation silviculture for landowners focused solely on commodity production. In fact, some anticipate that the development of southern pine-based bioenergy will further accelerate the rate of conversion from natural stands to plantations under the current system of pricing and incentives (Abt and others 2012). However, the combination of acceptable timber production and (in many cases) more complementary ecosystem services present opportunities for the greater than 70 percent of southern forests controlled by non-industrial landowners. For instance, hardwoods and slower-growing, larger pines sequester more carbon per unit volume of wood than fast-growing, smaller pines, so reconsidering this provisioning service in terms of total ecosystem carbon accumulated (including that stored long-term in dead wood and belowground) rather than merchantable bole volume produced may show different outcomes when comparing these silvicultural systems (Sohngen and Brown 2006). While some have inferred the retention of naturally regenerated forests on lands otherwise suited for more productive pine plantations as a measure of willingness to pay for some types of ecosystem services (Raunikar and Buongiorno 2006), this “trade-off” could also result from either a lack of knowledge or interest in silviculture rather than more altruistic motivations. However, many surveys of non-industrial private landowners in the southeastern U.S. have identified financial benefits as only one of many motivations behind land ownership and management decisions (Butler and Leatherberry 2004, Davis and Fly 2010, Kluender and Walkingstick 2000), suggesting that opportunities for ecosystem services beyond wood production exist (McIntyre and others 2010).

If other ecosystem services are considered than the production of wood volume, the values of natural- and plantation-origin pine forests may be more comparable, although not necessarily equivalent. Unfortunately, unlike the relatively straightforward determination of certain provisioning services, quantifying the influence of silvicultural regime on supporting, regulating, and cultural services is not as easy. First, we have little concrete data on the socioeconomic contributions of certain forest-based ecosystem services (such as pollination, water purification, aesthetics, recreation) or derived components such as the non-timber flora and fauna found in those forests. After all, what is the cash value of a box turtle (*Terrapene carolina*) in Arkansas (fig. 2) or a scenic view in Mississippi? Who pays for that, and how would that payment be made? Second, there is only limited documentation regarding the specific system responses of conversion from natural stands to pine plantations in terms of ecosystem services. Without further unbiased research and analysis, it is not possible to unequivocally state that one is better, worse, or even the same regarding supporting, regulating, and cultural services. Finally, evolving technological and regulatory environments will likely continue to alter the potential for ecosystem services to influence southern pine silviculture well into the future; a national or even global adoption of a compliance-based cap-and-trade system for carbon with rigorous contingencies for wood products and forest-based carbon sequestration could dramatically alter the economics of the region.

It is almost certain that further intensification of timber management is likely in southern pine-dominated landscapes. Most econometric analyses of future forest conditions in this region forecast that pine plantations will continue to displace naturally regenerated forests of all types, including pine-dominated, upland hardwood-dominated, and mixed pine-hardwood

Figure 2--The box turtle conundrum for pricing ecosystem services. Because this protected species does not currently have any value in the commercial pet trade, as a human food source, or as a sport hunting species, some would assign it a value of $0. However, many states assign a restitution value for animals that could act as the basis for valuation, and box turtles do have a potential monetary value in their role as part of the biota of an ecosystem consuming invertebrates that can be forest pests and disseminating seeds of desirable plants. Further, many (most?) people are likely willing to pay in order to ensure that this and other native taxa collectively remain. This could even be extended to the costs associated with habitat preservation and species conservation (Dalrymple and others 2012).

forests (Abt and others 2012, Sohngen and Brown 2006, Wear and Greis 2012, Zhang and Polyakov 2010). Between growing global demand for wood products, declining supplies from other regions (such as the decrease in production from beetle-killed forests in western North America), and a shrinking available forest land base in the southeastern U.S., pressures on remaining southern pine forests to continue to produce are not likely to change into the foreseeable future. Other challenges related to the impacts of silvicultural practices on ecosystem services are expected as the climate changes, new invasive species arrive and existing ones expand further, human resource demands continue to strain natural ecosystems, forestlands fragment, and land use practices change. Hopefully, some kind of ecological “tipping point” will not be reached that causes a region-wide collapse in many other tangible but underappreciated ecosystem services.

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