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Forest Ecology and Management 227 (2006) 185–192
Forest Ecology and Management
www.elsevier.com/locate/foreco

Expanding site productivity research to sustain non-timber forest functions

D. Andrew Scott [a,*], James A. Burger [b], Barbara Crane [c]

[a] USDA Forest Service, Southern Research Station, 2500 Shreveport Highway, Pineville, LA 71360, United States
[b] Virginia Polytechnic Institute and State University, Department of Forestry (0324), 228 Cheatham Hall, Blacksburg, VA 24061, United States
[c] USDA Forest Service, Southern Region, 1720 Peachtree Road NW, Atlanta, GA 30309, United States

Abstract

Southern forests produce multiple products and services including timber, wildlife habitat, species bio- and genetic diversity, water quality and control, waste remediation, recreation, and carbon sequestration. All of these benefits must be produced in a sustainable manner to meet today's societal needs without compromising future needs. A forest site is productive to the extent that it provides some level of one or more of these products and services. Historically, site productivity research emphasized biomass production and did not directly address the forest's capability for producing other products and services. However, past and on-going site productivity research has greatly increased our understanding of those soil and site properties and processes that influence forest development, and those that are influenced by management. Directing forest site productivity research toward understanding how site processes control both timber and non-timber benefits on all southern forest lands can help us develop the management strategies necessary to produce multiple products and services concomitantly with timber production.
Published by Elsevier B.V.

Keywords: Site productivity; Forest functions; Sustainability; ecosystem management; Intensive forest management

1. Introduction

Recent literature reviews and meta-analyses have concluded that little evidence exists to support the notion of widespread reductions in productivity caused by forest plantation management (Powers et al., 1990; Morris and Miller, 1994; Fox, 2000; Johnson and Curtis, 2001). The major reviews also postulate that most reductions in site productivity that do occur can be remedied through fertilization or soil physical manipulation, and that productivity can often be increased through these practices. While this news is positive for the future of timber production, especially on industrial plantation lands, it does not necessarily take into account the needs and circumstances surrounding the 71% of forest land in the southern United States that is owned by non-industrial private landowners (Connor and Hartsell, 2002).

For much of the past century, attitudes toward managing forests did not differ greatly among federal agencies, private landowners, and forest industry. According to Tarrant et al. (2002) who referenced Bengston (1994) and Steel et al. (1994), "For the past 100 years, forest management has endorsed a resource conservation philosophy that emphasizes wise human use and development of resources, dominance of economic over non-economic values, and human control over nature". In the southern United States, most forest landowners were interested in restoring timber production to previously degraded landscapes. Since the 1970s, various owners began to have quite differing views on forest management, largely because their respective goals changed. Forest industry began to manage forests more intensively in order to maximize financial returns, reduce risk, and provide more stable supplies of wood to mills. The fundamental change in public demands on forests over the past few decades (Dunlap, 1991; Bengston, 1994) altered the mandates for the national forests from timber and watershed protection (Organic Act of 1897) to multiple use management (Forest Management Act of 1960), and more recently to ecosystem management (Overbay, 1992; Thomas, 1995). Non-industrial private forest landowners, however, have diverse goals that vary from intensive timber management to natural ecosystem restoration to no-action management (Wicker, 2002).

Intensive plantation management and ecosystem management are the two most widely researched management approaches. Intensive plantation management is characterized by the a priori use of external inputs, such as genetically

* Corresponding author. Tel.: +1 318 473 7204; fax: +1 318 473 7273.
E-mail address: andyscott@fs.fed.us (D.A. Scott).

0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2006.02.017

improved trees, mechanical and chemical site preparation, chemical fertilizers, and synthetic chemical-based pest management on the most productive sites. Many of the concepts and strategies employed in intensive forestry have been adopted and adapted from agricultural cropping practices, such as soil tillage to prepare the planting site and a reliance on chemical fertilizers to maintain or improve soil fertility. The fundamental conceptual design in intensive management is the reduction of risk associated with natural forces through artificial (and predictable) external forces. This design provides for a relatively risk-free and predictable source of fiber to supply industrial mills, and it ensures the most efficient use of the landbase for the primary goal. Other lands owned by industrial forest products companies, such as watershed protection areas, sensitive wildlife habitats, and less productive sites, are managed less intensively. These areas are vital to maintaining sustainable non-timber forest functions across industry's landbase.

Ecosystem management embraces natural forces and tries to reduce external and artificial inputs to the extent possible. The goal of ecosystem management is to maintain natural, biodiverse, healthy forests that indirectly supply a variety of products and services. In the South, common objectives of ecosystem management include restoration of longleaf pine (*Pinus palustris*) and shortleaf pine (*Pinus echinata*) ecosystems to their historical range, conservation of endangered, threatened, at risk or keystone plant and animal species, maintenance and improvement of specific habitats, and watershed protection. Although ecosystem management embraces tools such as planting, prescribed burning, limited types of harvesting, and landscape management, the expected outcomes of these practices are focused on ecosystem functions and non-timber services into the future.

Neither intensive management nor ecosystem management is alone sufficient to meet the sustainability goals across the forest landbase. Intensive plantations will certainly be needed to meet our nation's future wood supply (Sedjo and Botkin, 1997), and current and past site productivity research and sustainable certification programs like the Sustainable Forestry Initiative® ensure sustainable wood supplies without compromising other values to the extent possible. However, the quest for a broader view of southern forest sustainability rests largely with NIPF landowners, since they own 71% of the timberland, compared with 19% for forest industry and 11% for public agencies (Connor and Hartsell, 2002). Currently, management of NIPF forests ranges from periodic selection harvesting and reliance on natural regeneration to low-intensity plantation management. Wicker (2002) stated that attempting to extend the intensive management style to NIPF may hinder the adoption of new information on sustainable forestry. He states:

> "Government and private programs that focus on the objectives of a single owner group will miss opportunities to encourage and support the production of diverse benefits valued by a public having diverse interests and needs. More landowners might be receptive to such encouragement if they understood forestry and forest management to be a means of securing a variety of forest resource benefits, rather than just those associated with the production of valuable commercial timber supplies".

On the other hand, implementing ecosystem management to a much larger landbase would require landscape-scale cooperation among landowners and fail to ensure economic outputs. While landowners in the South generally accept many ecosystem management principles, they do not look favorably on implementing them on their own lands (Brunson et al., 1996). Based on Wicker's conclusions, the diversity in NIPF landowners' goals and abilities precludes the use of either management approach from singly ensuring a broad view of sustainability for the southern United States forests. Ensuring that forest management actions on extensively managed lands do not reduce the capacity of these sites to produce both timber and non-timber forest functions should be an important component of future site productivity research. Other research is needed to determine the optimum management to realize these alternative functions, but site productivity research should be conducted to ensure the soil and site remain capable of supporting multiple alternative functions. Therefore, the purpose of this paper is to make an argument for research that would identify conditions and management practices that ensure that sites maintain their capacity to produce non-timber functions and services for a broad ownership.

2. Effects of forest management on soil properties and processes

Powers (2002) clearly defined the principles guiding our understanding of forest management and site productivity: "(1) Within the constraints set by climate and relief, the productive potential of a site depends on soil resources. (2) Management practices cause soil disturbances that affect soil properties and processes. In turn, these processes govern potential productivity. (3) The main soil processes controlling potential productivity involve physical, chemical, and biological interactions between soil porosity and site organic matter". Realized productivity, however, requires a much more complex understanding of species, genotype, stocking, stand history, and time. Burger (1996) cautioned that we must not confuse forest productivity with site productivity because cultural treatments that improved the former may actually degrade the latter. These principles hold for all forest processes that relate to biological functioning, and provide the best framework for evaluating forest management effects on other forest services and functions. Even forest functions that do not relate to biological productivity are still largely governed by the same principles stated by Powers (2002). For example, off-highway vehicle recreation, a major forest use in the southern United States, is not directly related to biological productivity. However, soil properties and processes are directly related to both biological productivity and in determining suitable areas and the sustainability of forest recreation. Historical and current site productivity research has provided a wealth of information regarding forest management on soil processes, which could

provide a direct link between research designed to answer questions regarding intensive timber management and the research needed to ensure other forest functions.

Grigal (2000) reviewed the concepts of axioms, corollaries, and postulates to show what we understand regarding forest management and soil productivity. The axioms, which generally relate to the direct effects of forest management on soil properties and processes, indicate that forest management can increase erosion and mass flow, cause abrupt changes in soil physical properties over much of a stand, remove nutrients, increase runoff, alter coarse woody debris (CWD), and change soil biological communities. Other axioms and corollaries are more indirect than the main axioms but nonetheless are widely accepted. For example, scientists and managers widely believe that: (1) erosion removes soil superior for plant growth, (2) compaction, puddling, and rutting reduce tree growth through altering aeration and rooting space, (3) atmospheric deposition is sufficient to replace nitrogen (N) and sulfur (S) removed during stem-only harvests, and (4) whole-tree harvesting has the greatest potential to impact productivity by altering macronutrients, such as phosphorus (P), potassium (K), and calcium (Ca), that are not replaced through deposition. He further points out several postulates that remain to be determined, such as whether nutrients removed during harvesting or soil biological changes following organic residue removals impact productivity. The key to most of these impacts is not whether they can cause change or even how they can alter productivity, but under what conditions do they alter productivity and under what conditions they can be ameliorated.

Miwa et al. (2004) summarized current knowledge regarding soil physical disturbances in the southern United States. They reviewed 17 studies from the southern United States along with several from outside the South on the impacts on soils and 6 studies from the southern United States that combined soil impacts with subsequent tree growth measurements. However, all 17 studies found that soil properties including infiltration rate, bulk density, macroporosity, soil strength, and saturated hydraulic conductivity were all negatively impacted by wet-weather harvesting. In the six studies from the South that had subsequent tree growth measurements, growth was reduced within impacted areas, although stand-level means were not always significantly reduced. Only one study (Simmons and Ezell, 1983) showed an improvement in survival and growth, and this study showed that compaction affected sandy loam and loamy sand soils differently. In contrast, Sanchez et al. (2006) and Eisenbies et al. (2004) both found in rigorously designed and monitored studies that soil physical disturbances had neutral to positive impacts on early pine productivity across multiple soil types, indicating that our understanding of the relationship between soil physical properties, soil quality, and tree growth is still in question. It is clear from past studies that soil physical disturbance can have detrimental impacts on productivity, but it is also clear that all soil physical disturbance is not detrimental to productivity. Future research is needed to help determine what soils, under what conditions, will be negatively impacted by physical disturbance, which will be positively affected, and which will not be affected. Additional research is also needed to determine which sites are most at risk of permanent damage if artificial amelioration is not an option, such as in ecosystem management or on some NIPF lands, where only natural recovery processes are available.

Miwa et al. (2004) also discussed artificial (mechanical tillage) and natural recovery processes. They separated the impacts of site preparation by physiographic region, and found that in the Atlantic Coastal Plain and the Florida Peninsula, 23 of 24 studies showed improved tree growth following bedding or disking, while the other showed no effect. In the Gulf Coastal Plain, however, only 6 of 11 studies showed a positive impact of mechanical site preparation on tree growth, while 3 showed a reduction in tree growth and 2 showed no effect. The impacts of site preparation on soil properties were found to be generally positive, with a few studies indicating that some mechanical treatments reduced soil nutrients. In general, site preparation practices are largely positive and misapplications generally occur when information available on the processes controlling soil and site productivity on given sites is inadequate.

Natural recovery processes include shrinking and swelling caused by 2:1 expanding clays, biopedoturbation by soil fauna and flora, and soil expansion and contraction caused by freezing and drying cycles (Miwa et al., 2004). Shrinking and swelling can be a major process in disturbed soils recovery, but it is minor in soils without 2:1 clay minerals, i.e., soils with siliceous mineralogy. Similarly, freezing and thawing cycles are of variable importance depending on latitude. The other major natural ameliorative process, biopedoturbation, is present on all soil types and is influenced by all management that affects woody debris and soil organic matter.

While direct evidence is lacking to make a general statement regarding nutrient removals and subsequent productivity, the conceptual understanding is relatively simple. Harvesting-induced nutrient removals in excess of inputs can cause reduced soil nutrient availability and productivity losses. This has clearly been demonstrated in long-term agricultural research studies (Vance, 2000) and is treated in depth by Kimmins (2003) and Fisher and Binkley (2000). Our problem in determining whether this factor is significant is three-fold. First, we can easily calculate nutrient removals caused by harvesting, but we cannot easily estimate natural inputs from weathering or deposition (Johnson, 1994). Secondly, short-term responses are not necessarily indicative of long-term changes, so long-term studies are required to conclusively make evaluations. Finally, the evidence we do have is from isolated studies on only a few site types that do not cover the range of sites and soils necessary to make regional conclusions, let alone universal ones.

This last problem is probably the most important. The first problem can be solved from indirect measures, such as tree growth and nutrient availability indices (Johnson, 1994). The second will be solved over time as existing studies, such as the Long-Term Soil Productivity study (Powers et al., 1996), come to fruition. But the final problem of site-specificity is the most challenging and pertinent, especially for forest functions other than timber. Burger and Scott (2002) and Scott et al. (2004)

show that soil productivity response to management is highly soil-specific across the southern region and within single site types. Fox (2000) also concluded in his review of intensive forest management that forest soil productivity can be sustained under intensive management, but it can also be degraded, and that site-specific research is the key to developing appropriate management strategies. Frameworks have been developed to address this issue in a general sense (Burger, 1997) and for the southern United States specifically (Burger and Scott, 2002), but much additional research is needed to produce management guidelines. Furthermore, the discrepancy between intensive management strategies and other strategies requires a different research strategy. Intensive management, while having the greatest potential to reduce fertility through short rotations, has the greatest opportunity to correct nutrient deficiencies. In contrast, ecosystem management or low-intensity management on NIPF lands has less potential to induce a loss of soil fertility but is also restricted from correcting problems that do occur.

Criteria and indicator-based soil quality monitoring are a logical basis for applying the wealth of knowledge regarding the impact of forest management on soil properties and processes on other forest functions. They provide a rigorous framework that focuses not on the direct results of forest management, but on the indirect soil related effects. Future research aimed at understanding how alternative forest functions and services relate to these soil-based indicators would greatly advance our understanding of all the relationship between forest functions, soil properties and processes, and forest management activities.

3. The land resource

It is well known that large forest management investments are not economically attractive on poor quality land, but research needed to guide NIPF landowners on management approaches is lacking. The NIPF landbase may be especially at risk from improper management (Scott et al., 2004). Much of the pinelands in the southern United States have been severely degraded by abusive agriculture or cutting followed by indiscriminant burning and cattle grazing. The establishment of trees on these sites has improved the soils from this state dramatically (Richter et al., 2000). Furthermore, intensive cultural practices such as fertilization and tillage can have long lasting positive impacts (Fox, 2000). However, many NIPF landowners cannot afford these practices, especially if timber is not their primary management objective. Many NIPF landowners, as well as governmental agencies, choose or are mandated to manage their lands within the limits of inherent productivity and may not be able to ameliorate the effects of past poor management practices as do industrial landowners.

This reliance on inherent productivity raises two questions regarding the applicability of existing evidence on the effects of various forest management practices on sustainability of the South as a whole. Although much of the land that forest industry and federal agencies were able to purchase from the 1930s to the 1960s was degraded lands, forest industry has sold much of the poor quality land to other entities through the years in an attempt to consolidate their land holdings on productive sites that are responsive to cultural treatments (Dr. Richard F. Fisher, personal communication). Furthermore, as planted forests are reaching their second, third, or even fourth rotation, the management intensity performed in the past has likely impacted site productivity. Past fertilization and site preparation may have increased the inherent site productivity of these lands. On the other hand, neither the USDA Forest Service nor NIPF landowners have consolidated their landbases to maximize productivity, nor have they widely employed management actions designed to improve site productivity. Therefore, we need to determine the extent to which past research is applicable to a given ownership category for both timber and non-timber functions and design future research that will address these landowners.

4. Alternative forest functions and their research status

Several international protocols have been developed to help countries assess, monitor, and plan for the sustained production of multiple forest functions for perpetuity. The most widely used is the Montreal Process, which was created to be a framework for nations to assess their overall forest sustainability. They were not created to assess site-specific management goals, objectives, or actions. They do, however, indicate the multiple functions that sustainable forests perform and that site-specific management should strive to emulate when possible. The criterion and indicators for the Montreal Process clearly show the multiple outputs that forests are expected to produce or conserve: (1) biological diversity, (2) productive capacity, (3) health and vitality, (4) soil and water resources, (5) contributions to the global carbon cycles, and (6) long-term multiple socioeconomic benefits to meet the needs of societies.

Reviewing the direct and indirect impacts of management on each of these forest functions would require several volumes. Furthermore, the role of site productivity scientists should not be to understand all the direct impacts of forest management operations on each individual forest function, but to focus on the effects of forest management operations on soil and site processes that, in turn, affect various forest functions. Forest productivity includes the interaction of species selection, cultural treatments, and site productivity (Burger, 1996). Burger (1996) further argued that, because of these interactions, soil-based indicators were most appropriate for understanding the fundamental impact of forest management on site productivity. However, Fox (2000) pointed out that foresters and land managers have been critical of soil-based approaches and recommends that a balanced approach be used to combine both crop and soil metrics to interpret sustainability.

We are faced with the same conundrum regarding alternative forest functions as we are regarding forest productivity. Alternative forest functions are also affected by many physical, biological, and cultural interactions that may or may not be directly affected as a result of forest management activities. What remains to be determined is the link between forest management, soils, and these functions, especially as it pertains to the NIPF landowners who want revenue from timber

harvesting while realizing other service goals as well. Four examples of the indirect role that forest management and soil productivity have on non-timber forest functions include: (1) maintaining a diverse and productive understory for wildlife habitat, (2) maintaining a healthy forest, (3) maintaining the production of non-timber forest products, and (4) maintaining and improving water quality and quantity.

Wildlife habitat is a particularly important non-timber resource in the southern forests to NIPF landowners, and is of major importance to state and federal agencies and to forest industries. Forest management directly impacts wildlife habitat by controlling stand age, structure, and disturbance regime. On the Mississippi Long-Term Soil Productivity sites (Tiarks et al., 1997; Scott et al., 2004), whole-tree harvesting with no soil physical impact reduced the relative abundance of dogwood (*Cornus florida*) and oaks (*Quercus* spp.) from 1126 and 889 to 0 and 59 rootstocks ha^{-1}, respectively, compared to stem-only harvesting (unpublished data). Wax myrtle (*Myrica cerifera*) commonly associated with more nutrient-poor sites and considered to be only an emergency food plant for browsers (although birds do eat the fruits) (Halls, 1977) was not found on stem-only harvested plots, but had 120 rootstocks ha^{-1} on whole-tree harvested plots (unpublished data). Conversely, Mellin (1995) found that while tree species declined from 18 on stem-only harvested plots with no compaction to 12 on plots with complete removal of surface organic matter and severe compaction, grass and herb richness increased by 11 and 7 species, respectively, on the more disturbed plots. Jeffries (2002) found little evidence in species change due to intensive forest practices over three rotations in the North Carolina Piedmont, illustrating that impacts are dependent upon site and disturbance type. In addition to the potential impacts on wildlife habitat, species shifts caused by harvesting may have more long-term, ecosystem-level effects (Perry, 1998).

Forest management also impacts wildlife habitat indirectly through altering soil conditions that, in turn, impact species assemblages and nutritional value for herbivores. For example, Hauser et al. (1993) examined the impact of three common site preparation treatments on plant diversity and pine productivity on a wet flatwoods site in the mid-Atlantic coastal plain. They found that intensive mechanical site preparation reduced plant diversity by changing site hydrology and limiting sprouting of several deciduous hardwood shrub and tree species, yet pine productivity increased. Lister (1999) found that soil disturbance caused by harvesting activities reduced non-crop woody plants by 64% compared to undisturbed areas, and this loss may have been the cause of altered surface hydrology (Xu et al., 2000). Early pine productivity was not changed by the soil physical disturbances (Xu et al., 2000). These studies indicate the potential impacts of soil physical disturbance on the alteration of the non-crop vegetation while maintaining or improving pine productivity.

The relationship between soil fertility and wildlife habitat food value was recognized over a half century ago (Albrecht, 1944), yet has received little research attention in recent years even though forest management has changed dramatically over this time period. Most recent research has focused on the food value of planted food plots to supplement natural vegetation, e.g., Johnson and Dancak (1993), which indicated that natural food value is lacking. Forest management that further reduces food value would be detrimental to wildlife habitat and needs to be identified.

Diseases, declines, and pests, such as littleleaf disease, annosus root rot, fusiform rust, and bark beetles, are clearly related to tree stress, and tree stress is clearly related to soil properties and processes. For example, southern pine beetle infestations are related to variability in surface hydrology across sites because differences in surface hydrology alter carbohydrate partitioning from growth processes to defense processes (Lorio, 1986). Specifically, many sites in southeastern Texas and central and southwestern Louisiana exhibit a pattern of small hummocks called pimple mounds, which provide contrasting drainage classes within a given site. This microrelief affects soil water, tree growth, rooting characteristics, and physiology. Trees growing in the intermound areas that have poorer drainage tend to be disproportionately stressed due to smaller root systems, and may be important focal points for infestations during endemic periods (Lorio and Hodges, 1974). Harvesting that alters surface hydrology and rooting may not affect long-term growth when measured at the stand level, but it may impact short-term and small-scale stresses that encourage beetle attacks. Soil compaction has also been associated with littleleaf disease, caused by the water mold *Phytophthora cinnamoni* (Oak and Tainter, 1988), and is suspected in loblolly pine decline associated with *Leptographium* spp. in Alabama (Hess et al., 2002). These health issues are not generally as problematic on intensively managed lands, because even though soil physical properties may be negatively altered during harvest, forest industry often ameliorates disturbed sites, maintains active growth with fertilization and weed control, and promptly thins young plantations to further reduce stress on remaining trees. Other landowners do not have the same capabilities, and must therefore carefully consider these types of health issues during management. Additional site productivity research needs to identify soils on which changes in soil properties may directly or indirectly contribute to forest health issues.

Non-timber forest products are an important commodity across the South (Chamberlain et al., 1998). Two common non-timber product enterprises in pine stands throughout the South are livestock grazing and pine straw harvesting. Because both rely on crop tree productivity and/or herbaceous vegetation, the science for maintaining productivity in these systems is well known. The primary factors in maintaining sustainability in both systems include nutrient removals and soil compaction. Pine straw harvesting has been linked to reduced pine productivity through nutrient removals, and fertilization is warranted in these systems to maintain productivity (Morris et al., 1992; Haywood et al., 1995). Active management, including fertilization, burning, and forest thinning, is needed to ensure sustainability in southeastern silvopastures (Clason, 1999), but these systems can be quite financially attractive (Clason, 1995). Furthermore, both are widely studied because of the direct economic value. In the cases of pine straw

harvesting and livestock grazing, reductions in productivity are relatively easy to identify since outputs can be observed annually, and procedures are in place to help landowners determine the correct ameliorative action, e.g., fertilization and prescribed burning, when problems do arise.

Finally, the single most important non-timber forest resource across all ownership categories throughout the South is water quality and quantity. This has been the case since the early 1900s and will continue to increase in importance with time as the South becomes more urbanized. In fact, the conservation ethic that instigated the development of the USDA Forest Service National Forest System, the Soil Conservation Service (now the Natural Resources Conservation Service), and county soil water conservation districts was a result of the need for clean and predictable water supplies.

Water resources and forest management have been studied extensively. In the early 20th century, most forestry research in the South was focused on reforesting the cutover and abandoned forest and agricultural lands with an expressed desire in improving water quality (Barnett, 2004). Research on forest management and water quality has remained intense, especially after the passage of the Federal Water Pollution Control Act of 1972 that initiated the development of Best Management Practices (BMPs). Most research has shown that, regardless of management type, forest harvesting has a limited and short-lived impact on water quality when BMPs are used properly (Aust and Blinn, 2004; Sun et al., 2004; Fulton and West, 2002; Prud'homme and Greis, 2002; Binkley and Brown, 1993). Other research has shown that other practices, such as fertilization (Binkley et al., 1999) and herbicide applications (Neary and Michael, 1996), also have minimal impacts on water quality when employed properly. The main finding from most studies on BMP effectiveness is that conservation measures work at maintaining water quality, but for them to work, they must be implemented.

Across the 13 southern states, 7 states have reported BMP implementation rates by landownership in percentage of stands properly employing state BMPs (Prud'homme and Greis, 2002). BMP implementation averaged 96% across these seven states on all public lands, 94% on forest industry lands, but only 86% on NIPF lands. Within NIPF lands, tract size was important in determining implementation rates, as well. In South Carolina, where implementation monitoring was separated into public, forest industry, large non-industrial tracts (>400 ha), and small non-industrial tracts (<400 ha), implementation rates were 100, 98, 94, and 87%, respectively. In Texas, additional information showed that compliance increased when a professional forester was involved, when the logger had attended training, when the landowner was familiar with BMPs, and when BMPs were specified in the harvest contract. Based on this information, the challenge with respect to research on water quality resources on NIPF lands does not directly relate to soil productivity research, but to socio-economic factors influencing BMP compliance on NIPF lands. Improving compliance on NIPF lands is especially important since BMPs also improve other forest functions, such as wildlife habitat.

5. Future research needs

The socioeconomic value of the southern pine forests to the United States and the world demands that site productivity research continue to ensure a sustainable supply of wood fiber. Increasing and maintaining wood fiber output from planted forests is essential for both producing needed wood products, but also reducing pressure on non-intensively managed forests (Sedjo and Botkin, 1997). Future research into intensive forestry will likely be focused on site-specific management and impacts of management on soil nutrient and water cycling through entire rotations. However, because forest sustainability involves more than just wood fiber, and the majority of southern pine forest landowners have multiple management objectives, we need to ensure that forest management practices do not reduce site capacity for these other objectives.

Forest managers have learned many lessons from agriculture, and can learn more, especially with regard to sustainable production of multiple benefits. For example, Safley (1998) indicates that traditional agriculture is approaching sustainability not by increased specialization and remediation of problems, but by anticipating and preventing problems, maintaining diverse economic enterprises, taking advantage of natural processes where possible but using external inputs in a prescriptive manner to ameliorate conditions or meet specific needs, monitoring and adapting accordingly to new conditions, and extending our findings to all forest landowners. Therefore, future site productivity research focused on non-timber forest functions should attempt to answer these questions:

(1) How do soil impacts associated with our current intensive management model relate to landowners interested in non-timber forest functions?
(2) How representative (relative to geography and ownership) are our past, current, and future study sites compared to the larger southern pine landbase within physiographic regions, considering soil type and especially past management practices?
(3) Within given soil types, what soil properties or processes are most susceptible to change by forest management and how do these properties and processes impact functions other than timber productivity?
(4) Are there situations where low-intensity, ecosystem management carries its own risks due to limits on the tools available to mitigate forest health or sustainability concerns?

6. Conclusions

Southern pine forests are among the most productive in the world for both timber and non-timber forest functions. Decades of research have helped forest industries, NIPF landowners, and government agencies understand how forest management has the capability to impact site productivity for timber production and have helped devise ways to mitigate the negative impacts and accentuate the positive. However, many landowners, both governmental and private, choose or need to manage within the constraints of inherent land productivity. Many landowners are

also interested in producing diverse, healthy forests with good wildlife habitat, clean water, and various products. Site productivity research must expand from its current emphasis on intensive timber production on high-quality sites to timber and non-timber forest functions across the entire gradient of site quality.

Site productivity research is a key component for the sustainability of all forest functions, since all terrestrial biological functions are dependent on soil. Future site productivity research in the southern pine forests should continue to ensure sustainable timber production on highly productive sites, but also alternative forest functions on low, medium, and high quality sites.

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